Inquiry on Federal Water Policy
Research Paper #21

THE ECONOMICS OF MUNICIPAL WATER SUPPLY: APPLYING THE USER-PAY PRINCIPLE

by

Steve H. Hanke and M. Fortin

Steve Hanke is Professor of Applied Economics,
Johns Hopkins University, Baltimore, Maryland.
M. Fortin is Senior Economist,
Ecologistics Limited, Waterloo, Ontario.

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THE INQUIRY ON FEDERAL WATER POLICY

The Inquiry on Federal Water Policy was appointed by the federal Minister of the Environment in January of 1984 under the authority of the Canada Water Act. The members were Peter H. Pearse, chairman; Françoise Bertrand, member; and James W. MacLaren, member. The Inquiry was required by its terms of reference to review matters of water policy and management within federal jurisdiction and to make recommendations.

This document is one of a series of research papers commissioned by the Inquiry to advance its investigation. The views and conclusions expressed in the research papers are those of the authors. Copies of research papers and information on the series may be obtained by writing to the Enquiry Centre, Environment Canada, Ottawa, Ontario K1A 0H3.

Frank Quinn
Director of Research

Abstract

This report consists of two papers on the user-pay principle which requires that users pay the full economic costs of the goods and services that they consume. Equity, efficiency and conservation would be promoted by the application of this principle to municipal water use.

The first paper reviews municipal water rates and rate-setting practices in Canada. Since this sector is almost entirely public in ownership, the extent to which user-pay principles prevail will be a matter of government policy and institutional practice. The second paper reviews economic concepts and tools and applies them to urban water supply problems in other countries.

Résumé

Ce rapport est formé de deux exposés sur le principe selon lequel l'utilisateur doit payer le plein montant des coûts encourus pour lui fournir les biens et services qu'il consomme. L'équité, l'efficacité et la conservation seraient encouragées par l'application de ce principe à l'utilisation municipale de l'eau.

Le premier exposé passe en revue les tarifs appliqués aux eaux municipales et les façons dont ces tarifs sont établis au Canada. Comme ce secteur est presque entièrement du domaine public, l'étendue d'application du principe de "l'utilisateur payeur" sera une question de politique gouvernementale et de pratique institutionnelle. Le deuxième exposé passe en revue des concepts et outils économiques et les appliquent à des problèmes reliés aux systèmes urbains d'approvisionnement en eau d'autres pays.

THE USER-PAY PRINCIPLE AND THE CANADIAN MUNICIPAL WATER INDUSTRY

by

M. Fortin
Senior Economist
Ecologistics Limited

Waterloo, Ontario
Canada

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Finally many individuals working in the water resources field across Canada were kind enough to spend time discussing regional conditions and problems with me. They are listed in an Appendix. Obviously, none of the above named individuals are responsible for the materials or interpretation provided in this report.

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1.0 INTRODUCTION

1.1 Overview

This report reviews municipal water rates and rate setting practices in Canada from the perspective of user-pay concepts. Implicit in these concepts are that charges are levied on customers who benefit from a service and that these charges are used to defray the cost of service.

Since the municipal water industry in Canada resides almost entirely in the public sector, the extent to which user-pay principals prevail will be a matter of government policy and traditional institutional practice. Any impediments against or opportunities for the application of user-pay principals will, therefore, emanate from policy and tradition. These policies and traditions will embody the political and institutional motivations that have given form to the existing industry and that in large part determine the extent to which user-pay principals will be promoted in the future.

1.2 User-Pay Concepts

In a comprehensive description of user charges for public services in Canada, R.M. Bird adopts a broad view of charge, namely "all taxes, prices and charges which may in one way or another be interpreted as being levied in connection with a particular public expenditure" (1976, pg. 3). He includes among user charges:

i) _prices_ for publicly supplied goods and services the consumption of which confers a private benefit on the consumer which predominates over any external effects of consumption (e.g. utility rates, rent for public housing);

ii) _compulsory fees_ levied for services undertaken in the public interest though still conferring a special advantage on the recipient (wedding licence fee, ground water well licence fee);

iii) _special assessments_ to defray the capital costs of improvements to property undertaken by the government. These are in principal proportional to the benefit accruing to each property owner (benefit assessment in Ontario municipal drainage, improvement taxes for sidewalks and sewers);

iv) _benefit taxes_ levied on individuals who benefit from a service. Tax payments are not necessarily proportional to individual benefits (gasoline tax).

This framework is useful in that it categorizes user charge instruments that can tie the provision of a service to its overall financing. We will, however, deal primarily with only one of these instruments - prices. These are of special interest since in addition to generating revenues to finance services they also allow consumers to decide on the level of their total payments by varying the level of consumption and thus the benefit enjoyed. They, therefore, serve not only to finance a service but also to help determine the level of service that is needed by acting to manage demand levels.

1.3 Organization of the Report

The report commences with a overview of the industry, describing overall size and the industry's consumers and producers. This is followed by a brief discussion and comparison of water revenues and costs. Rate setting practices at the retail level are then reviewed in some detail. A discussion of rate setting regulations and rate studies provides some insight into prevailing practices.

2.0 OVERVIEW OF THE MUNICIPAL WATER INDUSTRY IN CANADA

2.1 Industry Size

In a 1981 survey of 3,212 municipalities containing 86% of Canada's population, communities having water distribution networks and water treatment facilities numbered 2,474 and 1,755 respectively (National Inventory of Municipal Waterworks and Waste Water Systems in Canada, 1981). Distribution systems serviced 96% of the surveyed population, and 82% received treated water. Corresponding figures for the 1976 National Inventory survey were 94% and 89% with the same proportion of total population being surveyed (Tate and Lacelle, 1978).

Provincial municipal water production figures from the 1976 survey are given in Table 1. To put these values into perspective it is worth noting the level of intake for other sectors in the economy. These have been tabulated for the Inquiry by Muller (1985). Total estimated water intake in 1981 is 37,300 x $10^8 m^3$. Municipalities accounted for 8% of this. Other major users included agriculture, paper and allied products manufacturers, primary metal industries, chemical products manufacturers and electric power producers. Together with municipalities, these sectors accounted for 92% of total identified water intake.

TABLE 1

1976 MUNICIPAL WATER SUPPLY STATISTICS

Source: Tate and Lacelle, 1978

Province	Serviced Population (1000's) Distribution System	Treatment System	Total Pumpage ($10^6 m^3 a^{-1}$)	Per Capita Pumpage ($l\ day^{-1}$)
Newfoundland	334	336	80	678
Prince Edward Island	36	24	10	528
Nova Scotia	433	438	110	705
New Brunswick	340	286	180	1,433
Quebec	5,799	5,265	1,490	710
Ontario	6,532	6,425	1,560	669
Manitoba	783	783	120	432
Saskatchewan	566	556	90	414
Alberta	1,311	1,314	310	651
British Columbia	1,979	1,896	500	701
Territories	33	32	10	892
Canada	18,139	17,355	4,460	673

2.2 Consumers

2.2.1 User Classes

Municipal water supply systems typically service the following user groups: domestic, commercial, institutional and industrial. In addition, total municipal pumpage includes a percentage of lost water which may escape through system leaks and main breaks, or be used to wash treatment filters, and a percentage of unaccounted water which is attributed to unmetered consumption. Municipalities can deduce the breakdown between these categories of use from records of metered gross pumpage and metered sales to their various customers. Provincial statistics on consumption by user class are available from both the 1976 and 1981 National Inventories. The 1976 figures, reported by Tate and Lacelle (1978), are somewhat more complete and are provided in Table 2. Summary 1981 figures are provided for comparison.

Tate and Lacelle caution that the 1976 figures for losses may be low, and provide 1972 survey evidence that industrial figures may also be low by a considerable margin. Industrial consumption data for 1972 amounts to 34% of total 1976 municipal pumpage in contrast to the 19% figure reported for 1976.

High per capita industrial use generally coincides with those provinces that with high levels of overall industrial activity or industries concentrated in sectors that use a lot of water. The high variability in domestic per capita use may reflect a number of influences. For example, Tate and Lacelle mention the practice of leaving water running in the Territories to prevent freeze up of pipes.

TABLE 2

MUNICIPAL WATER SUPPLY BY USER CLASS

Source: 1976 - Tate and Lacelle, 1978
1981 - National Inventory, 1981

Province	Percentage Allocation of Pumpage (%)					Per Capita Use (1 day^{-1})	
	Domestic	Commercial/Institutional	Industrial	Losses	Unaccounted	Domestic	Industrial[a]
1976							
Newfoundland	71	9	20	0	1	482	135
Prince Edward Island	47	38	10	5	0	246	52
Nova Scotia	31	15	39	15	0	214	269
New Brunswick	56	17	25	3	0	296	355
Quebec	49	13	18	7	13	391	143
Ontario	38	19	23	10	10	278	167
Manitoba	47	21	12	18	1	205	52
Saskatchewan	38	22	16	16	8	168	71
Alberta	39	33	22	1	4	268	151
British Columbia	44	16	15	1	24	405	138
Territories	52	27	2	1	18	569	22
Canada	44	17	20	8	11	332	151
1981							
Canada	51	11 4	19	15		n.a.	n.a.

[a] Estimated in a similar manner to domestic per capita consumption with a portion of unaccounted consumption allocated to this use category.

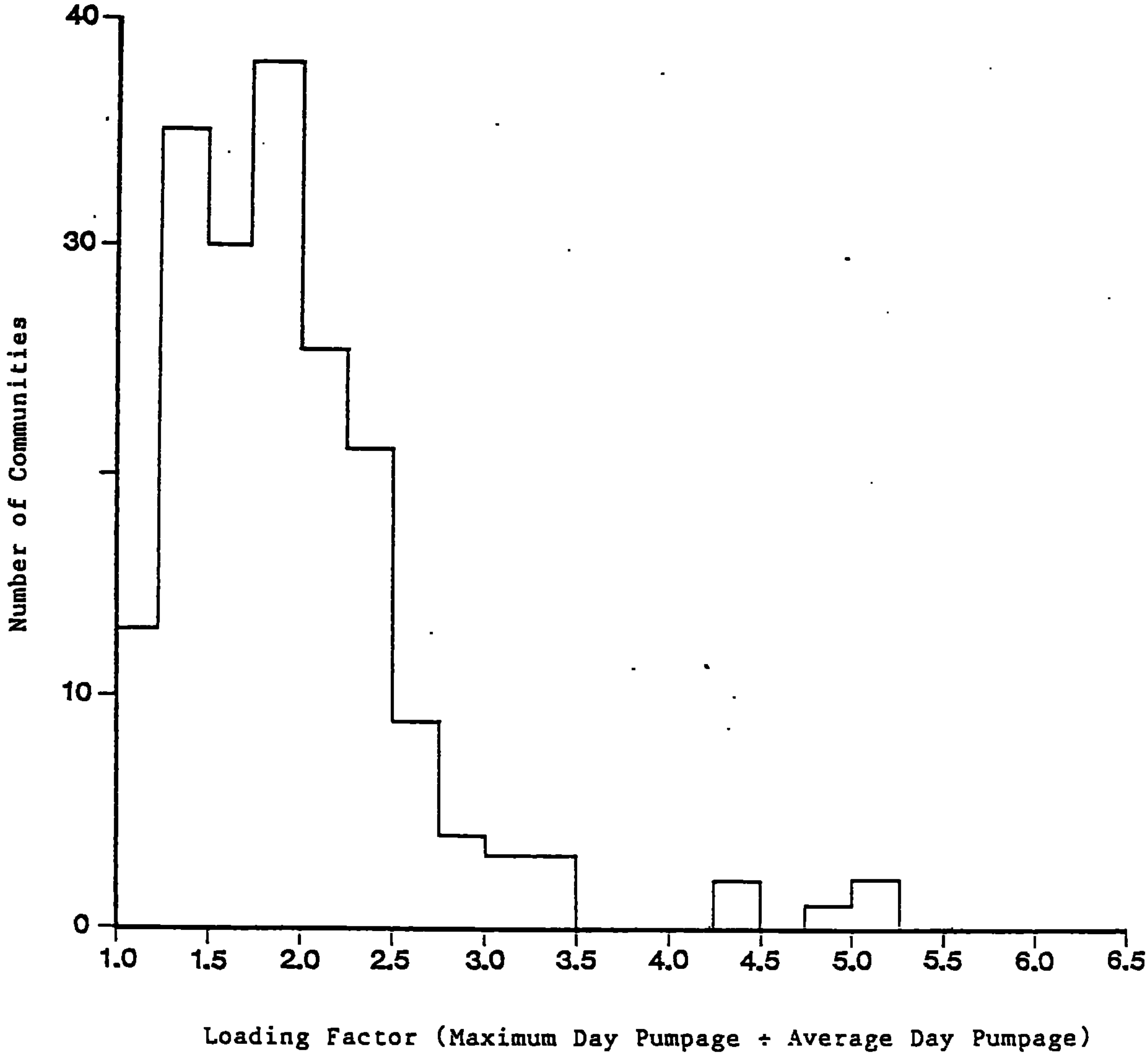
2.2.2 Seasonality of Consumption

Seasonal variability of consumption is a critical design consideration for municipal water supply systems. Loading factors, estimated as the ratio of maximum mean daily (maximum day) consumption to annual mean daily (average day) consumption, are used to describe seasonal variability. While loading factors can be highly variable (see Figure 1), loading factors for larger municipalities typically range between 1.5 and 2.0. Fortin reported a mean loading factor of 1.71 for 31 larger Ontario Municipalities (1984). Gysi reported a five-year mean value of 1.9 for Calgary (1983).

Maximum day demands coincide with summer dry weather conditions when high consumption rates for residential lawn watering occur. Though industrial and other classes of consumption are also subject to variation, high demand periods for these classes don't tend to be synchronized with dry weather as is residential consumption. Tate (1983) describes the seasonal distribution of Canadian industrial demand by sector for 1976. The transportation equipment manufacturing industry exhibits the greatest variability, with month-to-month demand varying by over 100%. Other sectors show a month-to-month variation of less than 50% and, overall, the variability does not exceed 20%.

FIGURE 1: DISTRIBUTION OF LOADING FACTORS FOR 188 ONTARIO MUNICIPALITIES

Source: Based on 1976 National Inventory Survey Data



2.2.3 Response of Consumption to Price

Sensitivity of consumer demand to the water price is essential if the merits of user-pay pricing in demand management are to be realized. Prerequisites for this sensitivity to exist are that consumers be aware of the price they face for water and that they take it into account when making decisions that will effect their level of consumption.

The awareness of price may assume varying degrees of sophistication. At one extreme, the consumer may not even realize the amount of his/her water bill if for instance two or more utilities are charged on the same bill (e.g. hydro and water). The customer's perception may extend only so far as the amount of the bill or it may also include an awareness of consumption levels and by implication the average cost of water. In the limit, the customer will understand the rate structure for water and will thus also know what his/her marginal price for water is. (At a given consumption level, marginal price is the price of an additional unit of consumption.)

The sensitivity of demand to price is an empirical question which has motivated extensive statistical analysis. A concern with the perception of price by consumers is central to such studies, and involves the distinctions made between average and marginal prices by consumers.

Another concern in demand studies is the need to distinguish among different types of demand. Each user group will display a distinct demand relationship associated with its own water requirements, whether for industrial cooling, domestic cleaning, recreation or other uses. Moreover, for any user group, the nature of demand and, therefore, of price responsiveness may vary with type of use. Residential consumption in thus broken down into domestic use and lawn sprinkling or alternatively into winter and summer use. An analysis of demand that is to provide some insight into the nature of demand and to produce a useful forecasting tool should differentiate among user groups and types of use. Moreover, the analysis should account for regional variations in demand caused, for example, by climate and consumer preferences.

Only a small number of Canadian studies of water demand have been published; these are summarized in Table 3. W.A. Sims (1979) presents a carefully argued and constructed study and employs what seems to be the best data set, but deals with such a narrow sector of demand - brewer's demand for water to dilute extra strength waste effluent - that his results are of limited value in general demand planning.

Kitchen (1975) failed to identify the expected inverse relationship between price and residential consumption. Macerollo and Ingram suggest that his data and method may not clearly distinguish between demand/price relationships and supply/cost relationships. They use statistical procedures to overcome this, but do so with data that is too highly aggregated to be of interest. The same is also true of the Sewell and Roueche study (1974) which uses aggregate community demand.

TABLE 3

CANADIAN WATER DEMAND STUDIES

AUTHOR	PERIOD	CONSUMER GROUP	APPROACH	ESTIMATED PRICE ELASTICITY OF DEMAND
A.P. Grima, 1972	1967	Residential consumers in Southern Ontario communities	Summer, winter and annual demand estimated using cross-sectional data describing individual consumers	winter -.75 summer -1.07 annual -.93
H.M. Kitchen, 1975	1971	Residential consumers (study area not specified)	Average annual demand per household estimated using cross-sectional data	- negative coeffecient on price not obtained
W.A. Sims, 1979	?	Industrial users (Brewers) across Canada	Cross-sectional/time-series data used to estimate demand for water to dilute waste effluent	-.945
C. Macerollo and M. Ingram, 1981	?	Aggregate demand in Ontario communities	Cross-sectional data used to estimate aggregate demand	-.311
D. Sigurdson, 1982	?	Residential consumers in Saskatchewan and Manitoba	Cross-sectional household data used to estimate annual demand	-.815
W.R.D. Sewell and L. Roueche, 1974	1954-1970	Aggregate Community, Victoria, British Columbia	Annual and seasonal demand estimated using aggregate time series data	off peak -.449 to -.744 peak -.067 to -.168 annual -.318 to -.568

An interesting feature of the Sewell-Roueche study is the finding that, in Victoria, summer demand appears to be less sensitive to price than winter demand, contrary to expectations. They attribute this to the distinct character of Victoria consumers. If true, this affirms the need to analyse demand characteristics at a regional scale and perhaps even at the community level when trying to incorporate demand management into water supply planning studies.

Finally both Sigurdson and Grima were able to use household level data, albeit cross-sectional data. (Combined cross-sectional and time-series data is required to differentiate between short and long-term responses of demand to price.) Their estimates of price elasticity are high relative to estimates from comparable U.S. studies. While these two studies are promising first steps, more thorough, long-term studies of municipal demand are required if reliable estimates of demand-price relationships are to be generated for purposes of water demand planning.

2.3 Producers

2.3.1 Production Facilities and the Source of Supply

Water production facilities encompass a variety of types of water supply sources, headworks or intake structures, various degrees of treatment works, transmission and distribution systems and storage facilities.

Groundwater is generally the lowest cost source of supply due to minimal treatment requirements. It provided 8% of surveyed municipal consumption in 1976 (Tate and Lacelle, 1978). Only Prince Edward Island facilities rely entirely on groundwater. Groundwater supplies are common in the Territories where 46% of surveyed supply is from wells. Saskatchewan is the only prairie province showing a marked reliance on ground water, 22%. Here, well water often requires extensive treatment due to its hardness. In other provinces, groundwater sources make up from 2% to 15% of total municipal supply.

Surface water is the major source of supply in Canada especially for large municipalities. Surface water treatment practices are regionally differentiated. Simple disinfection is common throughout British Columbia, the Territories, Northern Ontario, parts of Quebec, New Brunswick, Prince Edward Island and Newfoundland. In Nova Scotia, southern Ontario and the Prairies, full treatment involving at least coagulation, filtration and disinfection is the norm.

Full treatment has a major influence on cost. Its introduction may hail the advent of increasing costs when communities outgrow local groundwater sources and are forced to use surface water. Just such an evolution is described by Grima for London, Ontario (1984).

2.3.2 Seasonality of Supply

The supply of water, like the demand for water, is highly seasonal, typically, it peaks during the spring freshet and declines throughout the summer due to low precipitation and high evapotranspiration rates.

Fortunate communities enjoy a source of supply which naturally fulfills a seasonal storage function, accumulating water during periods of abundance, such as the spring freshet, and providing these with perrenial dependability during periods of water shortage in the summer. Lakes and ground water aquifers can act in this manner. Where such endowments are lacking, municipalities may be faced with a source of supply such as a river in which water fluctuates counter cyclically with demand. Many Prairie communities face this dilemma as do certain communities in Southern Ontario.

Solutions can involve investment in source capacity (new wells, pipelines) or source storage (reservoirs, aquifer recharge) and/or efforts at seasonal demand management. Kitchener, Ontario is currently contemplating all three courses of action to overcome its seasonal supply problem.

2.3.3 Institutional Organization of Producers

The key to an understanding of the organizational structure of the waterworks industry is an understanding of public utilities. The term, in its generic sense, is given various interpretations:

"...Anything supplied for public consumption or a service rendered for public benefit or convenience which is reasonably necessary for the maintenance of the best standard of living under modern conditions of society." (Rogers, 2nd ed.)

"...certain kinds of business...'affected with a public interest,'" (Farris and Sampson, 1973, pg. 18)

"...a public utility is any business which an appropriate legislative body declares to be a public utility!" (Farris and Sampson, 1973, pg. 29)

From an economic point of view, characteristics associated with public utilities are (Farris and Sampson, pg. 19-20):

- high social or overhead capital,
- a decreasing cost industry with a tendency towards natural monopoly,
- a somewhat inelastic demand, and
- high fixed costs.

While not exclusive to utilities, these properties do characterize most utilities and have given rise to the public ownership patterns associated with utilities. One finds a number of forms of ownership and organization for water works. They are distinguished on the basis of jurisdictional responsibility, ownership and financial management (see Table 4). At one end of the scale, there are publicly owned regional waterworks servicing several municipalities. They may exist as independent corporations as in

TABLE 4

THE ORGANIZATION OF WATERWORKS IN CANADA

TYPE	OWNERSHIP	FEATURES
Regional-Water Works	Public - usually province or Regional Government	- supply water to a number of member municipalities - may deal directly with retail customer or may sell wholesale water to municipal authorities - usually manage source of supply, treatment and transmission mains
Provincial Waterworks	Public - Province	- operated by the province and owned by the province or a municipality - may be set up to service a special users such as large manufacturers in remote areas
Municipal Utility Commission	Public - municipality	- run by a board of commissioners appointed by council - generally self-liquidating (i.e. self financing out of revenues)
Municipal Utility	Public - municipality	- run as a separate entity distinct from the works department - under direct control of council - generally self-liquidating - water revenues are not combined with general revenues
Municipal Department	Public - municipality	- run as a dependent or departmental unit of city hall - under the direct control of council - may or may not be self-liquidating - water revenues treated as part of general revenues

(continued on next page)

TABLE 4 (cont'd)

THE ORGANIZATION OF WATERWORKS IN CANADA

TYPE	OWNERSHIP	FEATURES
Franchise	Private/Public	- work of a utility is contracted to a private enterprise, - franchise stipulates the type of business that can be engaged in and the associated benefits and obligations
Investor Utility	Private	- utility operated as a private business for profit, - may or may not be regulated by legislative body
Subdivision Waterworks	Private	- utility service provided to home owners by a developer or lands not serviced by municipal works, - found in small subdivisions in unincorporated areas, - not usually run for profit, - often evolve to public ownership
Cooperative	Private	- utility owned jointly by its customers, - located in unincorporated areas

British Columbia, or as departments or utilities answering to regional governments. Waterworks servicing individual municipalities are owned either by municipalities, provinces or the private sector in Canada. Private and certain types of public sector waterworks maintain separate financial accounts and are self-financing in that most or all water supply costs are met out of water revenues. This is not necessarily the case for municipal or regional waterworks departments or provincial water works. For these, water revenues are combined with general revenues and the need to be self-financing will depend on policies applied to the waterworks operations.

The majority of waterworks in Canada are owned by municipalities (see Table 5). Based on a phone survey of provincial agencies conducted for this study (see Appendix for list of respondents) it became apparent that most of these are organized as municipal departments. Municipal commissions are common only in Ontario and New Brunswick.

The utility structure is generally used only for larger municipalities while a departmental structure is favoured by smaller communities. Quebec and Newfoundland have no utilities while both Prince Edward Island and Alberta have only one or two. There is, however, considerable variation among provinces in the nature of these organizational forms. Several provincial officials indicated, for instance, that waterworks departments function much like utilities would.

TABLE 5

WATER TREATMENT PLANT OWNERSHIP

PROVINCE	MUNICIPAL OWNERSHIP	PROVINCIAL OWNERSHIP	PRIVATE SECTOR	TOTAL
Alberta	204	2	--	206
British Columbia	127	--	1	128
Manitoba	84	50	4	138
New Brunswick	65	--	--	65
Newfoundland	182	1	7	190
Northwest Territories	5	44	1	50
Nova Scotia	65	3	2	70
Ontario	339	96	--	435
Prince Edward Island	5	--	--	5
Quebec	1 282	17	185	1 484
Saskatchewan	145	--	--	145
Yukon	7	--	--	7
Canada	2 510	213	200	2 923

Source: National Inventory of Municipal Waterworks and Wastewater Systems in Canada, 1981.

The "subdivision" waterworks is a rather nebulous creature. While residing in the private sector, their services are offered to prospective homeowners to induce purchase. They tend not to be run for profit. In Alberta, all subdivisions waterworks were sold to municipalities while in New Brunswick, no new ones are allowed.

British Columbia has a unique arrangement to accommodate the need for waterworks in unincorporated areas. An incorporated body called an Improvement District can be set up. It has taxation powers specific to its role in providing water.

Both Saskatchewan and Manitoba have some co-operative waterworks. British Columbia was the only province to report an investor utility (located in White Rock).

Provincial ownership is relatively common. Provincial governments in Ontario and Manitoba own and operate a number of plants for municipalities. Waterworks servicing primarily industry and run by the province are found in Nova Scotia, Prince Edward Island and Newfoundland.

Regional waterworks may be established by legislation as separate incorporated bodies. Alternatively they may exist as part of Regional governments. They can assume the forms of utility, commission or department. In New Brunswick, regional waterworks are set up as utility commissions, while in Ontario they are all departments of regional governments.

3.0 WATER COSTS AND REVENUES

3.1 Accounting Practices

In all provinces, municipal governments are required to keep comprehensive and detailed financial records. For this reason, water costs and revenues were generally reported to be clearly and separately accounted for. Difficulties arose only for small communities - less than say 500 - for which water costs could not be clearly separated from other works department costs due to the utilization of common resources for several functions.

The only capital costs appearing on most accounts are debt servicing costs. Depreciation accounting is only required by Nova Scotia and Prince Edward Island. From an economic point of view, cost accounting without appropriate depreciation charges is incomplete. To the extent that rate setting exercises are governed by water accounts excluding depreciation, rates will not reflect full economic costs.

3.2 Revenue Sources

Municipal revenue sources include property taxes, transfers from federal and provincial governments and user charges. Water revenues come from both local taxes and user charges. The use of property taxes to recover capital costs for water is common in Quebec where capital costs can not legally be allocated to commodity charges. In Quebec and other provinces property taxes to recover capital costs may take the form of special assessments which are used to defray the costs of investments that benefit individual properties. Facilities such as sidewalks, water and sewerage services and roads may be financed in this manner.

Both commodity and demand charges are commonly used for water throughout the country (see Section 4.0 below). Commodity charges are levied against consumption and hence vary in proportion to consumption. Marginal prices for water are determined by the commodity charge. Demand charges are assigned to an individual for the privilege of connection to the distribution system and are generally proportional to the standby level of service provided to the customer.

Bird (1971) reports national figures for total municipal revenues from the sum of all special assessments and sales revenues. Together these amounted to only 7.8% of total municipal revenues, whereas transfers amounted to 47% of the total, and property taxes to 36%. In 1981, comparable figures are (Local Government Finance, Catalogue 68-204, Statistics Canada):

10% sales and special assessments,

47% transfers,

30% property taxes.

Sales revenues and special assessments have risen somewhat in prominence while revenue shares from property taxes fell from 1971 to 1981. This would suggest an increased overall dependence on user charges in 1981.

A recent survey of Canadian Municipalities (Technical Committee on Canada's Urban Infrastructure, 1984) suggest that user charges provide a much greater share of water revenues. Proportionate shares for funding of the operation, replacement and rehabilitation of water supply systems reported by survey respondents are provided in Table 6.

TABLE 6

SOURCE OF WATER REVENUES

Source: Technical Committee on Canada's Urban Infrastructure, 1984

	Water Distribution	Water Treatment
General Tax	4.7%	4.5%
User Fees	85.5%	82.7%
Debt	8.5%	11.8%
Provincial Transfers	1.1%	0.9%
Federal Transfers	0.1%	0.0%
Other	0.2%	0.2%

Data in Table 6 are population weighted averages. Since large cities (>100,000 people) in the survey sample contain 79% of the total population of sampled cities, these results are chiefly representative of larger centres.

The low federal and provincial contributions cited in Table 6 may be representative on average for large Canadian municipalities. They deal, however, with annual revenues and not capital funds. For these, there are a number of subsidy programs at the provincial and Federal level (Table 7). These programs have a variety of eligibility criteria which tend to favour small communities. Often there is an explicit population based formula to determine grant levels. Other common formulas based on community income or per capita capital costs also favour small communities. This orientation to smaller communities likely reflect a concern that municipal services be provided in an equitable manner.

The total level of capital funding provided by grant programs will depend both on the level of coverage and on the size of grant program budgets. Transfers of funds for water from provincial coffers are shown in Table 8 along with the level of overall annual investments in water systems (gross fixed capital formation). These two sets of statistics are not entirely comparable since investment figures include irrigation as well as municipal systems, while the grant figures do not include federal transfers. They are nevertheless indicative of the past level of subsidies for capital expenditures on water systems. On average over the 1975 to 1981 period, provincial government transfers have amounted to 35% of total water system investments, ranging from 23% to 52%.

TABLE 7

CONDITIONAL GRANT PROGRAMS FOR WATERWORKS

PROVINCE	COST COVERED	LEVEL OF ASSISTANCE	COMMENT	SPONSOR
Newfoundland	Capital Cost	variable, based on need	community must contribute 20% of its revenue to debt charges to qualify	Province in Newfoundland, Federal-Provincial in Labrador
Prince Edward Island	Capital Cost	65-75%	based on tax-load	Province
Nova Scotia	Capital Cost	50%	(new program from 1985-1987)	Province
New Brunswick	no conditional grants for water	- - -	a portion of water costs are eligible for unconditional grants	Province
Quebec	costs for new systems	variable based on cost, population, land area	only for towns <5000	Province
Ontario	Capital Costs	15 - 85%	level of grant based on population	Province
Manitoba	Capital Costs	1. up to 50% 2. 50%	1. program for towns <5000, based on formula 2. program for towns <300, offset provincial grants	1. Province 2. P.F.R.A.*
Saskatchewan	Capital Costs	1. 50% 2. 50% 3. variable	1. program for 42 rural service centres 2. program for small towns 3. ad hoc grants to large towns	1. Federal-provincial 2. P.F.R.A. 3. varies
Alberta	Capital	50-75%	amount based on per capita costs, Edmonton and Calgary not eligible	Province
British Columbia	Capital	25%	- - -	Province

* Prairie Farm Rehabilitation Administration, Agriculture Canada.

TABLE 8

CAPITAL EXPENDITURES AND PROVINCIAL GRANTS FOR WATER SYSTEMS

Year	1981	1980	1979	1978	1977	1976	1975
(i) Gross Fixed Capital Formation for Water Systems in Canada[a] (10$[b])							
All Canada	634.7	593.9	541.0	495.1	383.8	321.1	252.3
(ii) Provincial Government Transfer Payments for Water Systems[b] (10$[b])							
All Canada	321.9	306.8	202.0	143.9	102.2	75.3	69.1
Newfoundland	24.1	16.7	17.7	15.7	11.9	9.6	7.4
Prince Edward Island	2.0	.07	1.2	1.1	1.1	1.1	.8
Nova Scotia	—	—	2.1	1.7	2.9	1.6	2.4
New Brunswick	13.7	13.3	12.0	11.8	3.3	2.5	—
Quebec	96.8	80.8	60.2	43.8	35.0	28.0	36.0
Ontario	114.0	66.2	40.8	30.6	25.7	17.0	12.8
Manitoba	.02	.02	.02	.09	—	—	—
Saskatchewan	3.3	1.9	2.5	2.0	2.1	.9	—
Alberta	4.4	88.0	31.8	6.3	4.8	3.4	2.3
British Columbia	63.6	39.9	33.8	30.8	15.5	11.2	7.4
Territories	—	—	—	—	—	—	—

Note: a) Statistics Canada. Fixed Capital Flows and Stocks, Historical 1936-1983, Catalogue 13-568.

b) Statistics Canada. Provincial Government Finance-Revenue and Expenditure (various years), Catalogue 68-207 annual.

3.3 Comparison of Water Costs and Revenues

A summary comparison of municipal water costs and sales revenues is provided in Table 9. These data must be interpreted with some caution since special assessments for water are not included except in Quebec data. This may explain why the ratio of revenue to costs for Quebec is so high relative to others. With the exception of Quebec, revenues fall short of costs by a significant margin.

A direct comparison of revenues and costs tells only part of the story especially if costs do not include depreciation as was noted above. Under these circumstances, even full revenue coverage of reported costs would fall short of real resource costs which must include capital depreciation.

Over the long-run, the ability to finance infrastructure replacement is a key indicator of the balance between costs and revenues. Where there is a short fall of funds this can impinge on system maintenance costs which are more discretionary than other operating costs.

The Technical Committee on Urban Infrastructure (1984) surveyed Canadian municipalities concerning the condition of their infrastructure, the costs of infrastructure repair, and impediments to solving infrastructure problems. In their report, they suggested that an annual per capita cost of $25 is required to properly maintain water systems, and compared this figure to actual maintenance expenditures of between $6 and $9 per capita. Despite this disparity only 10% of respondents reported that

TABLE 9

MUNICIPAL GOVERNMENT WATER RELATED COSTS AND SALES REVENUE

Source: Statistics Canada, Local Government Finance, Catalogue 68-204

PROVINCE		1981	1980	1979	1978	1977	1976	1975	AVERAGE
Newfoundland	Sales Rev. (10^6\$)	8.7	8.1	7.4	4.8	4.6	4.8	3.3	
	Costs (10^6\$)	27.9	28.8	25.7	16.9	9.9	9.4	9.6	
	Rev./Costs	.31	.28	.29	.28	.46	.51	.34	.35
Prince Edward Island	Sales Rev. (10^6\$)	1.4	1.6	1.4	1.4	1.3	.8	.8	
	Costs (10^6\$)	1.1	1.9	2.1	2.0	1.8	1.8	2.5	
	Rev./Costs	1.27	.84	.67	.70	.72	.44	.32	.71
Nova Scotia	Sales Rev. (10^6\$)	17.9	16.8	13.4	12.7	10.7	8.4	8.0	
	Costs (10^6\$)	20.9	27.8	25.8	15.3	17.8	12.9	13.7	
	Rev./Costs	.86	.60	.52	.83	.60	.65	.58	.66
New Brunswick	Sales Rev. (10^6\$)	13.8	12.0	11.4	10.4	9.7	8.5	7.4	
	Costs (10^6\$)	21.4	17.0	21.0	18.5	16.2	21.6	24.3	
	Rev./Costs	.64	.70	.54	.56	.60	.39	.30	.54
Quebec	Sales Rev. (10^6\$)	267.5	247.2	200.3	222.6	208.9	202.5	168.7	
	Costs (10^6\$)	289.8	292.2	192.7	336.6	210.2	169.7	132.6	
	Rev./Costs	.92	.84	1.04	.66	.99	1.19	1.27	.99
Ontario	Sales Rev. (10^6\$)	299.1	260.3	233.9	204.4	183.7	166.9	145.4	
	Costs (10^6\$)	313.4	273.4	265.7	255.4	249.5	210.3	177.1	
	Rev./Costs	.95	.95	.88	.80	.74	.80	.82	.85
Manitoba	Sales Rev. (10^6\$)	32.0	28.4	25.4	24.2	22.1	19.9	14.1	
	Costs (10^6\$)	35.4	39.9	31.9	32.2	29.7	24.7	18.3	
	Rev./Costs	.90	.71	.80	.75	.74	.81	.77	.78
Saskatchewan	Sales Rev. (10^6\$)	37.0	30.2	25.2	21.7	19.5	17.5	15.1	
	Costs (10^6\$)	41.6	35.1	41.4	29.2	23.3	27.7	20.8	
	Rev./Costs	.89	.86	.61	.74	.84	.63	.73	.76
Alberta	Sales Rev. (10^6\$)	127.0	110.2	83.2	65.4	56.4	45.5	37.1	
	Costs (10^6\$)	264.8	213.4	161.2	122.4	98.9	79.2	90.2	
	Rev./Costs	.48	.52	.51	.53	.57	.57	.41	.51
British Columbia	Sales Rev. (10^6\$)	63.2	57.6	53.1	58.5	50.5	46.6	39.9	
	Costs (10^6\$)	136.3	122.8	101.4	84.4	80.8	71.6	46.5	
	Rev./Costs	.46	.47	.52	.69	.63	.65	.86	.61
Territories	Sales Rev. (10^6\$)	4.8	3.7	3.2	2.5	2.4	1.9	1.8	
	Costs (10^6\$)	6.9	7.9	6.7	7.3	8.1	5.5	2.7	
	Rev./Costs	.70	.47	.48	.34	.30	.35	.67	.47
All Canada	Sales Rev. (10^6\$)	872.4	776.1	657.9	628.7	569.9	523.3	315.1	
	Costs (10^6\$)	1,159.6	1,060.3	875.5	921.3	746.1	634.6	538.4	
	Rev./Costs	.75	.73	.75	.68	.76	.82	.59	.73

their water system infrastructure was not acceptable or needed much repair, while over 40% reported an improvement in the condition of their water system infrastructure over the past 15 years. Total estimated costs for required repairs to water systems amounted to $1,117 million or $135 per capita for sampled municipalities. Funding shortage was by far the most commonly identified impediment to undertaking these repairs.

The Technical Committee on Urban Infrastructure concludes that total required repair expenditures for water and other infrastructure ($598 per capita) imply the need for a significant increase of expenditures over 1983 capital and operating budgets for public works ($236 per capita). They arrive at this conclusion without considering the scheduling of repair costs, and they seem to overlook the possibility that existing capital budgets ($99 per capita in 1983) may include a significant repair and replacement component. Certainly the required water system repair expenditures of $135 per capita, when spread over, say, five years, is comparable to 1981 investment levels of about $30 per capita on water systems deduced from Table 8 data (assuming a 20 million service population). This calculation ignores the actual distribution of repair cost requirements which would likely reveal certain municipalities with disproportionately large investment requirements.

4.0 WATER RATE SETTING PRACTICES

4.1 Background

Our interest in rate structures stems from two concepts introduced in Section 1.0; that of user pricing involving a customer charge per unit of consumption and the more general concept of user charges involving various forms of customer charges related to the provision of a service. The critical economic distinction between these concepts is the linkage established by user pricing between consumption and payment level. Only with such a linkage can there be any consumer motivation to regulate consumption in order to regulate payments. Non-price user charges provide this sort of linkage only at the outset of a customer contract when a potential customer can opt to avoid the charge entirely by not entering into a service contract. (At times such an option is not available to urban customers, for user charges may be levied even without a service hookup.)

From an economic point of view, rate structures are of interest precisely because they tie consumption levels to payment and, therefore, potentially to the cost of consumption. Where a price is imposed, the customer is "informed", by the water bill, of the cost of water supply in a direct manner, and can choose to respond accordingly. Customer response will be determined by the perceived price of each additional unit of consumption. Where the customer is accurately informed about the rate structure, then the perceived price of water will correspond to the actual price, which measures the impact on disposable income of additional consumption. This measure of price is called the "marginal" price.

4.2 Types of Rate Structures

The level of payment for water will depend on the level and structure of water rates. A diversity of rate structure types are used. These are differentiated primarily on the basis of their use of pricing and non-price charges and the degree to which they differentiate among user groups.

From the customer's perspective, the simplest rate structure is the flat rate. A flat rate structure includes only a fixed levy imposed in each billing period. For this charge, the customer is given unregulated access to water. Consumption itself is unpriced or free and marginal price equals zero.

Flat rate charges are determined in a variety of ways related to the cost of providing service and to some measure of expected consumption level as well. Consumption itself is not metered at the customer level. Typically, charges will vary among classes of users based on the results of a cost allocation exercise.

Flat rate charges are levied through a water bill. The cost of water supply may also be recovered through special assessments or general property taxes (provided the water works authority has taxation powers). Flat rate charges and taxes are economically equivalent to the extent that they imply a zero marginal price.

User pricing, in its simplest form, involves a level rate per unit consumption with no other associated water charges. More commonly, however, pricing is combined with certain fixed charges and the unit rates themselves vary with the level of consumption or among user groups.

Traditionally the most common form of the user price is the declining block rate structure. Consumption in each billing period is divided into successive blocks, with consumption in each block charged a lower price than in the previous block. The blocks often correspond to average consumption levels of user classes, with one or two initial small blocks capturing residential and light commercial consumption, and subsequent blocks capturing commercial, industrial and heavy industrial users.

While the block structure itself is used to differentiate among user classes, this may also be done in a more explicit fashion for instance by setting distinct residential and nonresidential rates, including possibly parallel sets of block rates.

Customers may also be differentiated on the basis of location or jurisdiction. Higher rates may be imposed on more distant customers. This will generally occur only if jurisdictional boundaries are crossed since equity concerns within a municipality usually dictate against such discrimination.

A declining block rate provides the customer with a continual disincentive to further consumption, albeit a diminishing one, since the marginal price of water is always positive. Conservation-oriented rate structures attempt to bolster this disincentive by increasing the marginal price of water. Moving from a declining block structure to a level rate can be considered a conservation measure provided marginal prices increase. More aggressive conservation structures target the price increase at specific categories of use. An increasing block rate structure hits the large industrial user hardest. Alternatively, high seasonal rates may be imposed in the summer to impact peak seasonal use. These may take the form of a seasonal surcharge on all consumption or an excess-use surcharge on consumption exceeding a bench mark value associated with base or winter consumption levels.

When a user price is applied, the marginal price for water will depend on price levels, consumption rates and rate structures provided that no minimum billing provision is made. Under such a provision, the customer is charged a minimum amount each billing period and allowed a certain amount of free consumption corresponding to this minimum bill. This water is free in the sense that its marginal price is zero as long as consumption falls within the minimum allotment. Minimum billing is a frequently used method of recovering fixed water supply costs. An alternative method which avoids a zero marginal price is the service charge, a fixed charge on each bill that is not linked to any consumption.

Fixed costs recovered through service charges or minimum bills may include meter reading and office overhead costs as well as the cost of servicing individual clients with mains and meters. These charges frequently vary with the size of service.

4.3 Canadian Municipal Water Rates

Water rates prevailing in Canada in 1983 were analysed using files assembled by the Inland Waters Directorate, Environment Canada. File materials included municipal water rate bylaws as well as statistics on system pumpage and serviced population.

Water rate bylaws were reviewed to determine retail level rate structures and the level of retail water prices for water in each municipality in the sample. Marginal prices were determined for a consumption level characteristic of single family households, assumed to be 0.9 m^3/day or 6000 gallons/month.

After excluding municipalities for which information was incomplete a total sample of 368 municipalities remained. Summary statistics were obtained for each province, the combined territories and all of Canada. In addition, municipalities were grouped by size and analyzed. Results of the analysis are reported in Tables 10 to 13 and on Figures 2 to 4.

The composition of the sample is shown in Table 10. Both Prince Edward Island and the Territories are poorly represented, while Newfoundland, Manitoba and Saskatchewan also have small samples. While other provinces have larger samples, they aren't necessarily well distributed over the size classes of communities. This seems to reflect the actual distribution of communities in each of the size classes at the higher end. At the small-community end of the range, numbers are somewhat erratic, being relatively large for New Brunswick and Nova Scotia but low for Quebec and Ontario for instance. This may indicate a tendency to service homes in small rural communities in much of Ontario and Quebec with individual wells rather than community systems.

The data in Table 11, suggests that the most common rate structure combines a flat rate and a commodity charge. The flat rate typically is levied on small consumers - such as domestic and small commercial accounts - while the commodity charge is reserved for larger industrial consumers. This is a particularly common configuration in Quebec. Communities using this combination have water rate bylaws which either stipulate which consumers or types of consumers are to be metered or alternatively empower the water works manager to stipulate who shall be metered.

Selective metering of customers is most likely based on the costs and returns of installing meters and may also indicate ongoing programs to move to full metering.

TABLE 10

SIZE DISTRIBUTION OF SAMPLED COMMUNITIES - 1983

PROVINCE	REPORTED SERVICE POPULATIONS				
	≤1000	1001-5000	5001-30,000	30,001-100,000	100,001+
Newfoundland	0	1	6	0	0
Prince Edward Island	0	0	2	0	-
Nova Scotia	7	2	8	1	1
New Brunswick	29	22	9	2	-
Quebec	0	6	43	13	2
Ontario	11	18	46	16	11
Manitoba	1	0	5	1	0
Saskatchewan	0	1	5	1	2
Alberta	17	3	10	4	2
British Columbia	13	7	28	10	0
Territories	0	0	2	0	0
All Canada	79	60	164	48	18

NOTE: 1981 Census population was used where service population was not provided.

TABLE 11

DISTRIBUTION OF MUNICIPAL RATE STRUCTURES - 1983

Data Group	Sample Size	Using Flat Rate Only	Using Commodity Charges: Total	With A Flat Rate	With No Flat Rate	No Minimum Bill: Level Rate	No Minimum Bill: Block Rate	Minimum Bill: Level Rate	Minimum Bill: Block Rate
By Province									
Newfoundland	7	3	4	4	0	1	1	2	0
Prince Edward Island	2	0	2	2	0	0	1	1	0
Nova Scotia	19	2	17	4	13	0	0	5	12
New Brunswick	62	45	17	13	4	1	4	7	5
Quebec	64	14	50	44	6	14	13	14	9
Ontario	102	9	93	59	35	9	15	16	53
Manitoba	7	1	6	1	5	0	1	0	5
Saskatchewan	9	0	9	0	9	2	1	2	4
Alberta	36	17	19	5	15	4	8	2	5
British Columbia	58	19	39	29	10	3	12	1	22
Territories	2	0	2	2	0	0	2	0	0
By Size of Population									
≤ 1000	78	64	14	7	7	0	4	1	9
1001-5000	60	24	36	20	16	5	10	6	15
5001-30,000	164	20	144	99	45	18	31	29	65
30,001-100,000	48	1	47	29	18	7	11	10	19
100,000+	18	1	17	6	11	4	2	4	7
All Canada	368	110	258	161	97	34	58	50	115

Only 26% of the sampled communities have abandoned flat rate billing altogether. The proportion having done so varies from 9% for towns with 1000 or fewer residents to 61% for the largest towns (>100,000). These statistics suggest that metering tends to be adopted as a municipality grows perhaps because it becomes more important to monitor and manage demand. Saskatchewan stands out as the only province where flat rates were not found at all.

Commodity charge rate structures are enumerated by type in Table 11. A block rate structure is by far the most common type, accounting for 67% of these rate structures overall. Level rate structures were relatively frequent in only Newfoundland, New Brunswick, Quebec and Saskatchewan, while they were not found at all in Manitoba.

Minimum billing with a free allotment of water is superimposed on the commodity charge structure in 64% of the sample communities. This in effect introduces an initial block of consumption with a zero marginal price. If this minimum billing block is sufficiently large to encompass domestic consumption then the domestic consumer is faced with a situation that is analogous to the flat rate with a zero marginal price. Minimum billing predominates in every province except Alberta. It is also more prevalent in smaller than larger communities.

Price levels, summarized in Tables 12 and 13, and in Figures 2 to 4, are highly variable due in part to the complexity of rate structures. An attempt is made to present a simple summary analysis here by looking at level rate price levels, the first and last block price levels of block rates, and finally marginal prices. Prices include sewer surcharges applied to water rates, and also account for prompt-payment discounts.

For the analysis of level-rate prices, the sample includes communities with either simple level rates or two step block rates for which the first block corresponds to a minimum bill. Both of these rate structures have only one nonzero price for water. The analysis of block rates focuses only on nonzero prices. Therefore, the first block price is the first nonzero price and may occur in the second block if the first block corresponds to a minimum bill.

The average price for level rates is generally located between the average price levels for the first and last blocks (see Table 12), and it is always much closer to the average first-block price than the last. A comparison of Figures 2 and 3 shows this as well. This may reveal the dynamics of adopting a level rate. Declining block rates are a traditional water pricing strategy in Canada. Level rates, if introduced, often supersede block rates and are set simply be moving block prices towards the first block price. This process was recently witnessed in both Guelph and Cambridge.

TABLE 12

RETAIL WATER PRICES (cents/1000 gal) - 1983

Data Group	Level Rate Prices				Block Rates - First Price				Block Rates - Last Price			
	n	mean	max.	min.	n	mean	max.	min.	n	mean	max.	min.
By Province												
Newfoundland	2	65	100	30	2	34	40	28	2	17	20	14
Prince Edward Island	1	111	-	-	1	68	-	-	1	51	-	-
Nova Scotia	0	-	-	-	17	114	295	43	17	58	127	17
New Brunswick	5	156	260	60	12	211	400	33	12	94	168	42
Quebec	27	91	235	26	23	88	300	24	23	46	115	14
Ontario	24	147	568	40	69	169	391	75	69	108	266	20
Manitoba	1	335	-	-	5	275	453	100	5	176	394	70
Saskatchewan	3	314	385	175	6	293	420	168	6	255	353	165
Alberta	12	217	438	73	7	243	450	106	7	190	450	48
British Columbia	15	92	312	9	23	92	193	30	23	56	128	13
Territories	2	451	687	215	-	-	-	-	-	-	-	-
By Size of Population												
≤1000	4	216	335	110	10	248	450	65	10	173	450	52
1001-5000	15	178	438	32	21	183	335	81	21	101	216	17
5001-30,000	49	144	687	24	94	142	453	24	94	88	394	13
30,001-100,000	18	87	175	9	29	124	354	30	29	76	221	14
100,000+	6	170	385	40	11	175	379	37	11	132	245	46
All Canada	92	143	687	9	165	153	453	24	165	95	450	13

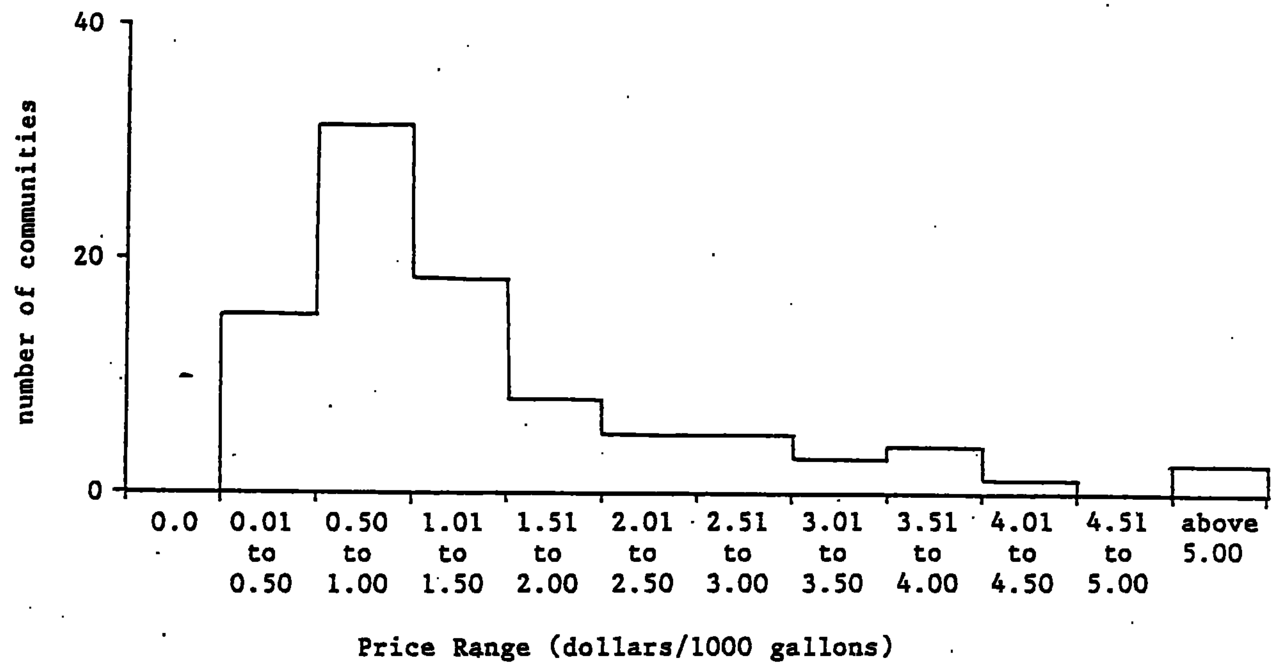
TABLE 13

DOMESTIC MARGINAL PRICES (cents/1000 gal.) - 1983

Data Group	Marginal Price at 6000 gal/mo. n	mean	max.	min.
By Province				
Newfoundland	7	0	0	0
Prince Edward Island	2	0	0	0
Nova Scotia	19	80	295	9
New Brunswick	62	39	400	0
Quebec	64	8	180	0
Ontario	102	120	568	0
Manitoba	7	244	453	0
Saskatchewan	9	296	420	168
Alberta	36	113	450	0
British Columbia	58	18	170	0
Territories	2	344	682	0
By Size of Population				
≤1000	78	38	450	0
1001-5000	60	83	438	0
5001-30,000	164	79	687	0
30,001-100,000	48	65	354	0
100,000+	18	150	385	0
All Canada	368	73	687	0

NOTE: Marginal domestic price data covers all communities. This includes communities with a flat rate for domestic users or a minimum bill consumption allotment exceeding 6000 gal/mo. for these the marginal price is zero.

FIGURE 2 DISTRIBUTION OF LEVEL RATE WATER PRICES – Canada, 1983.



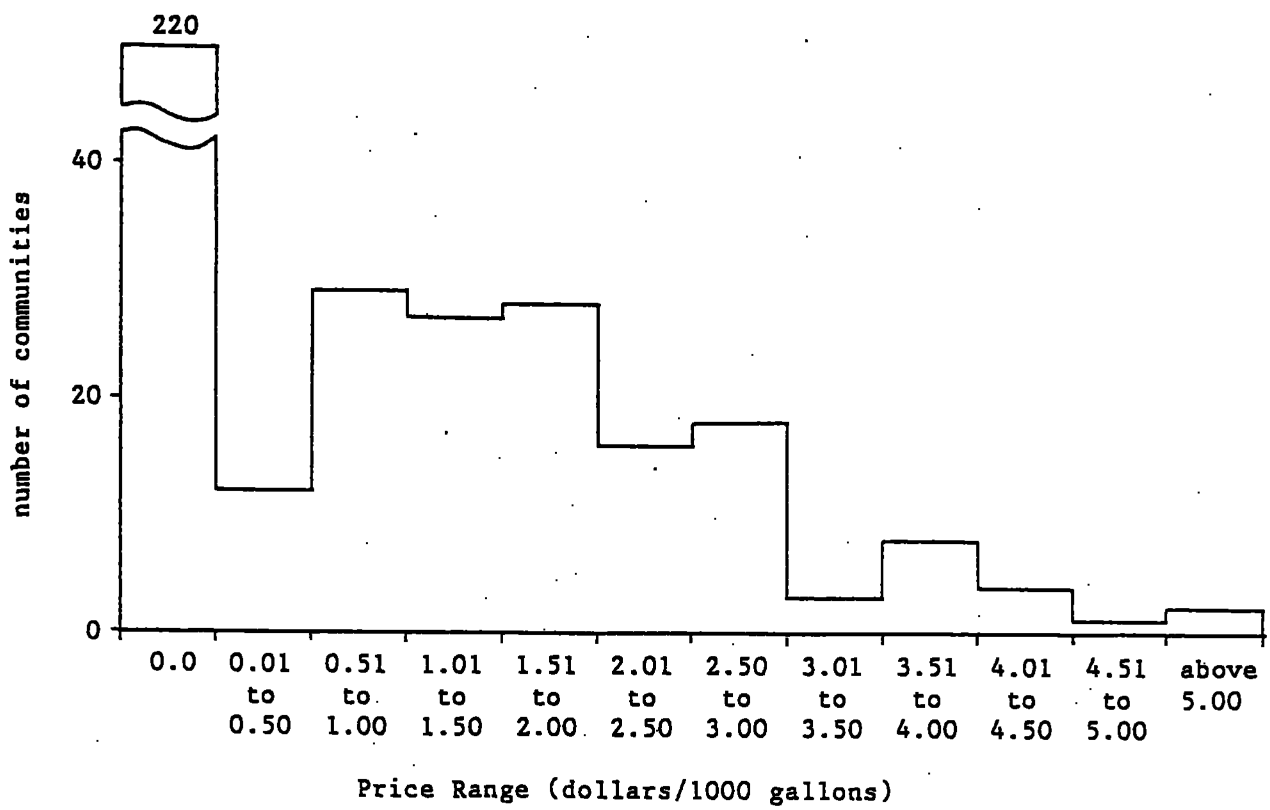
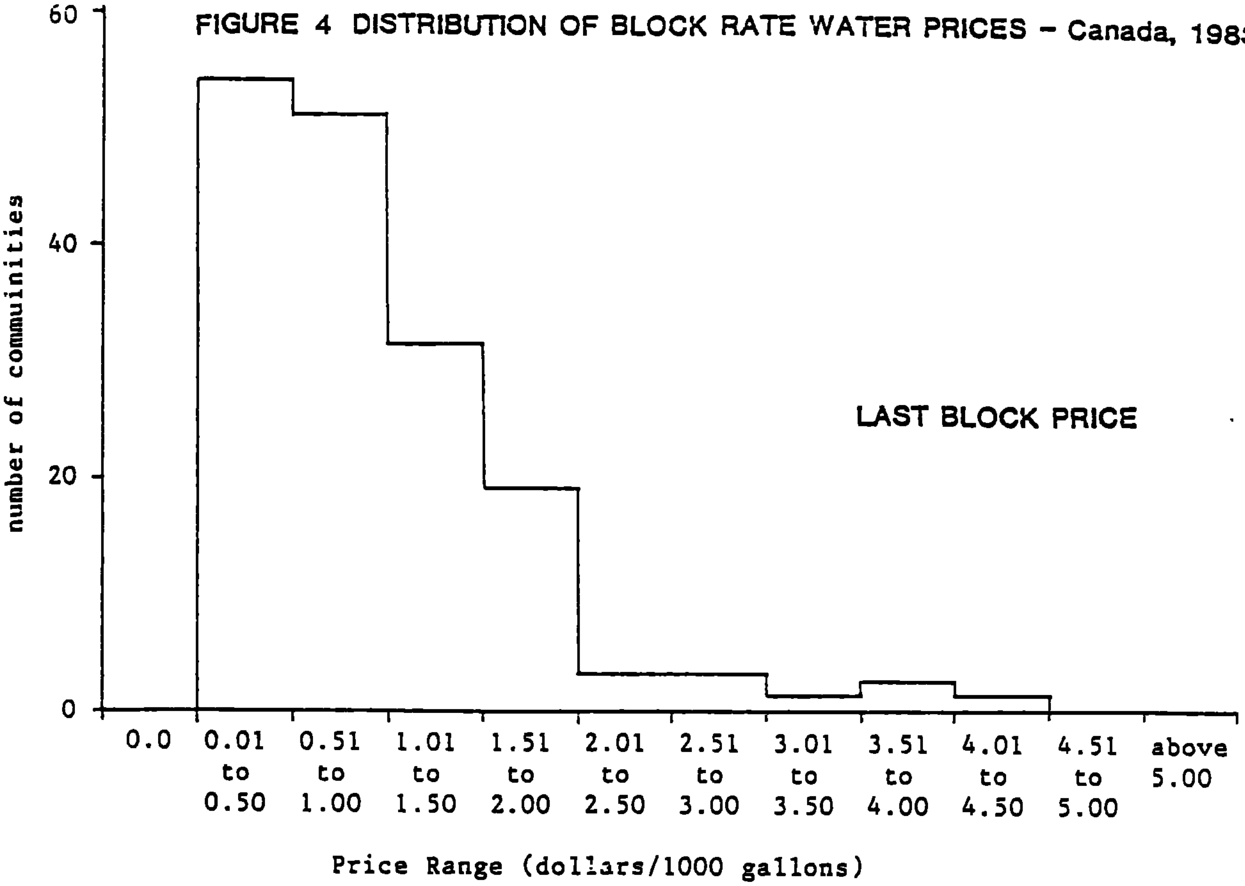


FIGURE 3 DISTRIBUTION OF DOMESTIC MARGINAL PRICES FOR WATER AT A 6000 GALLON / MONTH CONSUMPTION LEVEL – Canada, 1983.

FIGURE 4 DISTRIBUTION OF BLOCK RATE WATER PRICES - Canada, 1983.



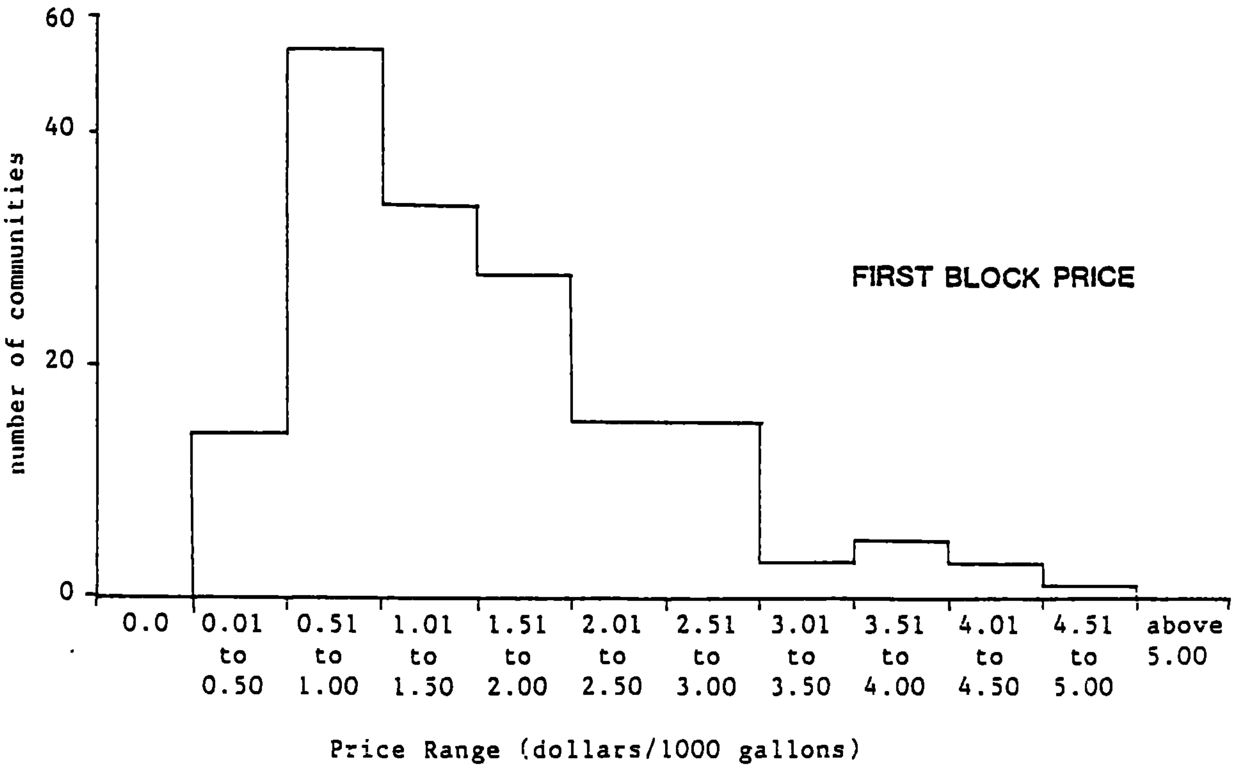


FIGURE 5 DISTRIBUTION OF BLOCK RATE WATER PRICES - Canada, 1983.

The cheapest water on average is found in British Columbia and to the east of Manitoba. in the prairies, prices are two to three times the levels in these other areas. The most expensive water, both on average ($4.51/1000 gallons) and across individual observations ($6.87/1000 gallons), is found in the Territories. The lowest overall rates occur in Newfoundland.

These provincial variations in price probably reflect variations in average costs among provinces (see Sections 4.4 and 4.5 below regarding rates setting and average costs). For instance a number of cost advantages prevail in Newfoundland, the province with the lowest prices. These advantages include abundant supplies, frequent occurrence of gravity-fed systems and generally good quality (Haynes, 1984). Conversely, the prairies have significant quality problems in many areas while in the Territories, climatic conditions can result in high supply costs - these are both high price areas. Of course the influence of costs will be tempered by available grants which reduce capital costs and offset revenue requirements.

Considering community size, there is a distinct pattern common to level and block rates. Prices fall with increasing community size up to the "30,000 to 100,000" size class and then increase. This is evident in the average prices and the extreme values (maximum and minimum). A general pattern of economies and diseconomies to scale in water supply may underlie this behaviour.

Declining block rate prices are almost universal where block rates are used. Only two exceptions were found, an increasing rate schedule in Saskatchewan, for which price rose from $1.68 to $3.53/1000 gallons, and a U shaped schedule in Alberta, with the first and last block rates both set at $4.50/1000 gallons.

Price levels tell only part of the story for block rates. The number and size of blocks are also critical components of this type of rate structure. The number of blocks varies up to nine but consistently averages about 3 to 4 (Table 14). Over the long-run, there may be a trend towards fewer blocks. Fortin (1984) noted that 15 out of 36 large Ontario communities reduced the number of blocks or did away with blocks altogether in their rate schedules between 1970 and 1983.

The size of the blocks is highly variable. The size of the average first block varies by three orders of magnitude across provinces. Variation in the maximum first and last block size is even greater. A pattern is nevertheless discernible, especially in the data presented by community size. Larger block sizes are found in large communities. Among the provinces, larger blocks are found in the more populous provinces (with the exception of Newfoundland). A plausible explanation is that larger blocks are designed to accommodate the larger industrial consumers found in these areas.

TABLE 14 - PART A
DESCRIPTION OF BLOCK RATE STRUCTURES - 1983

Data Group	Sample Size	No. of Blocks mean	max.	min.	Upper Limit of the First Block[a] mean (1000 gal/mo)	max.	min.	Lower Limit of the Last Block[b] mean (1000 gal/mo)	max.	min.
By Province										
Newfoundland	2	2.0	2	2	502	1,000	1	502	1,000	3
Prince Edward Island	1	3.0	-	-	22	--	-	440	--	-
Nova Scotia	17	2.4	4	1	255	1,667	7	314	1,667	7
New Brunswick	12	3.4	8	2	24	73	2	657	5,000	17
Quebec	23	3.8	8	2	1055	10,000	4	7382	100,000	25
Ontario	69	2.9	6	1	187	9,250	1	575	11,000	5
Manitoba	5	3.2	4	3	12	17	8	360	1,333	42
Saskatchewan	6	4.0	6	3	12	28	2	160	622	22
Alberta	7	4.7	9	2	21	50	3	1133	3,100	3
British Columbia	23	4.2	9	2	332	6,600	2	3117	52,800	10
Territories	-	--	-	-	--	--	-	--	--	-

(See notes on the following page.)

TABLE 14 - PART B

DESCRIPTION OF BLOCK RATE STRUCTURES - 1983

Data Group	Sample Size	No. of Blocks mean	max.	min.	Upper Limit of the First Block[a] (1000 gal/mo) mean	max.	min.	Lower Limit of the Last Block[b] (1000 gal/mo) mean	max.	min.
By Size of Population										
≤1000	10	2.7	5	2	51	333	7	132	500	7
1001-5000	21	2.9	5	2	17	90	2	108	450	11
5001-30,000	94	3.4	9	1	263	10,000	1	1218	52,800	3
30,001-100,000	29	3.6	9	2	477	8,333	4	5584	100,000	25
100,001+	11	2.9	5	2	1030	9,250	3	2412	11,000	5
All Canada	165	3.3	9	1	307	10,000	1	1858	100,000	3

NOTE: a) First block is defined as the first segment of consumption for which a nonzero price is charged. Thus a community with a three block structure for which the first block corresponds to a minimum bill would be described as having two blocks.

b) "Last block" identifies the remainder or excess consumption block corresponding to the last and usually lowest unit price. Where there are only two blocks, the upper limit of the first block equals the lower limit of the last block.

A striking economic interpretation of water rate structures is provided in Table 13 and Figure 4. Here, marginal prices for domestic consumers are analysed. We have seen above that both flat rates and minimum bills imply a zero marginal price for water. It is obvious from Table 13 and Figure 4 above that a zero marginal price is very common. It is not enough, therefore, to consider only the presence of commodity charges as proof of user-pay pricing. One must ensure that the commodity charge rate structure effectively levies a nonzero price for water on the consumer before deducing that a commodity charge is synonymous with user-pay pricing.

Another important economic dimension of water rates is the price discrimination that is inherent in rate structures. Minimum bills, block rates and a mix of flat rates and commodity charges all mean that marginal prices will likely vary across classes of customers. Block rates are in fact designed to achieve this end, the justification being that declining block rate prices are consistent with declining average costs of servicing larger clients.

Other forms of discrimination, both across customer classes and across seasons, were encountered. A relatively common practice is to levy higher rates on rural customers served by a municipal system. Differential rates are at times levied on industry, or alternatively industrial consumers may be exempt from sewer surcharges. Discrimination among domestic consumers is practiced in at least one Ontario municipality where summer residents are charged higher rates than permanent residents.

No examples of seasonal surcharges were uncovered, but there are several prairie communities that provide a summer discount by charging lower rates during the summer peak demand period. This would encourage the use of water for lawn watering and presumably would increase capacity requirements.

4.4 Canadian Municipal Water Rate Regulation

To understand rate setting practices in Canada, one must appreciate the institutional restrictions imposed on municipal water works authorities. Waterworks managed by provincial agencies are usually constrained to set rates so as to recover costs. Costs may or may not include capital costs, however. Moreover, in certain provinces, rates are administered according to policies that show little relationship to cost.

Municipal water works are governed by provincial government policies concerning both general municipal activities and specific waterworks activities. A common restriction faced by municipalities across Canada is the need to seek approval from provincial agencies such as Municipal Boards for debenturing debt. The mandate of municipal boards in this regard is to insure the continued solvency of municipalities. Municipalities must therefore demonstrate that overall revenues are sufficient to service debt.

Beyond the implicit constraint on rates imposed through debenturing policy, a number of provinces also impose direct controls on municipal water rates as outlined below:

Newfoundland	- municipalities must charge a minimum flat rate of at least $8/month for water and $4/month for sewerage.
Prince Edward Island	- preferred rate setting procedures are advocated but are not mandatory.
Nova Scotia	- the Public Utility Board requires annual reporting and regulates rate levels and structures.
	- rate setting manuals are employed.
	- metering is encouraged.
New Brunswick	- all rates are reviewed annually.
	- balanced budgets are required on a one or three year cycle (allowing a small maintenance cost reserve), and rates are adjusted to satisfy this requirement.
	- discriminatory rates are not allowed.
Quebec	- capital costs must be recovered through special assessments and operating costs through a water charge.
	- rates of private systems must be approved and disputes over intermunicipal wholesale rates are reviewed.
	- municipal retail water rates are not regulated.
Ontario	- the Ontario Municipal Board can review rates if it receives complaints.
	- no other regulation exists.

Manitoba	-	rate setting guidelines are published and the type of rate structure may be regulated.
	-	rates are regulated by the Public Utilities Board to insure solvency (all municipalities except Winnipeg).
	-	deficits and withdrawals from reserves must be approved.
Saskatchewan	-	Local Government Board reviews rates to insure debt servicing capacity.
	-	no other regulations.
Alberta	-	Public Utilities Board can review disputed intermunicipal wholesale rates.
British Columbia	-	no direct regulation of municipal rates.
	-	encourage setting of domestic rates below commercial rates.
	-	the Controller of Water Rights is empowered to review and regulate rates for non-municipal utilities or municipalities selling wholesale water beyond its border.

Recovery of costs is a common theme in provincial regulations. A cost recovery policy may also be imposed at the municipal level by councils. For instance, utilities typically operate under self-liquidating rules which require that investments be paid for out of water revenues.

The need for cost recovery imposes a financial lower constraint on water rates. Of particular economic interest is the additional upper constraint on water rates that may be imposed. This upper constraint relates to a prohibition on profit taking and is quite explicit, for instance, in New Brunswick where a balanced budget is required. The accumulation of reserves may be allowed in order to finance investments, but the general policy seems to prohibit a return to capital being earned by public sector waterworks authorities.

In the private sector, profitability is the main motivation for efficiency and serves as a primary indicator of the need for new investments. By prohibiting a return to capital for public sector waterworks, provincial and municipal governments prevent the exorbitant profit taking that is possible in natural monopolies such as waterworks. At the same time, however, they exclude the possibility of using market-like mechanisms to manage the supply costs of municipal water. In effect profit, when coupled with the competition that prevails under franchising arrangements, can act as a cost management tool just as price can act as a demand management tool.

4.5 Water Rate Studies

Water rate studies are undertaken at the municipal level to design appropriate rate schedules. The philosophy of these rate setting exercises reflects, on one hand, the engineering profession's responsibility to service the public in a manner that will safeguard health and safety, and on the other hand, the requirement of public utilities to set rates so as to recover costs in an equitable manner. The engineering outlook translates into an assumption that demand levels are fixed and largely independent of water rates - water rates serving only a financial function as opposed to a demand management function. Public utility constraints on pricing behaviour emphasize the financial role of rates and have led to a variety of rate setting practices which focus on allocating costs to customer classes in order to determine rates in each class which measure the average costs of providing service.

A variety of methods are used to determine flat rate charges. Domestic charge levels may be determined as a function of the number of fixtures in a residence, the number of rooms or the number of dwelling units (in multiple unit structures). Such schemes attempt to maintain a realistic relationship between water rates and the expected cost burden imposed by individual customers. They are limited by the failure to actually measure water consumption.

Rate setting exercises using commodity charges can go much further in allocating costs to specific user groups in accordance with the average cost burden. The base-extra capacity method is a case in point. Steps in this method are as follows (Banker and Costanza, 1983):

i) allocate costs of service between base or average-day demand and extra-capacity demand (maximum and peak day use);

ii) distribute cost components (base and extra capacity) to various customer classes in proportion to their average day and extra-capacity service requirements;

iii) estimate unit costs of services commensurate with total costs allocated to each user class and the level of consumption of each class.

Economists promote an alternative rate setting philosophy based on efficiency. The concept of efficiency requires that resources should only be allocated to those uses which generate benefits that are at least as great as the associated resource costs. For water works systems, this translates into a requirement that the price of water - an implicit measure of benefit received by the customer - be equal to the unit cost of providing additional water in the system. This unit cost for an incremental supply is called the marginal cost. An analogous rule in the private sector would be that investments in a new productive facility can only be justified if the expected product price is sufficient to cover the cost of production for the new facility.

The interdependence of demand and price are explicitly acknowledged by economists who argue for marginal cost pricing. They view pricing as a means of simultaneously managing both supply and demand.

A number of economists have investigated the empirical relationships between marginal costs and average-cost water rates. A recent Canadian study (Grima, 1984) used a statistical approach to deduce marginal costs from reported cost data for 43 Ontario Municipalities. Variable costs, average costs and estimated marginal costs are compared to the price of water in these municipalities. Grima concludes that "the pricing of urban water services in Ontario up to a decade ago was somewhat haphazard or at least not cost related". This conclusion, however, seems stronger than warranted by the analysis. No attention has been given to the manner in which costs were allocated within each municipalities rate schedule. Nor does it seem that the elements of cost were examined in detail to derive a more precise estimate of marginal cost. The statistical procedures that Grima uses to estimate marginal cost are approximate at best.

Water works managers are accustomed to a much more detailed analysis of system costs as they relate to water rates than is provided by Grima. Loudon reports on a more detailed rate setting exercise for the Region of Durham using marginal cost concepts (1985). In this exercise, a water rate far in excess of prevailing rates was proposed but was turned down as being impractical. Within the terms of reference of a municipal organization, this notion of practicality highlights the very compelling nature of prevailing rate setting philosophies based as they are on cost recovery and meeting demand. These are compatible with political concerns at the municipal level while the economists notion of efficiency must appear in contrast to be rather intangible and meaningless.

While user-pay pricing is gaining greater currency in the water industry, marginal-cost pricing, as one version of user-pay pricing, is gaining ground only very slowly if at all. Its adoption will occur only if economists desist from facile criticisms of the industry and attempt a more pragmatic and consultative analysis of municipal water resource allocation problems.

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APPENDIX

The following individuals were interviewed to obtain regional information used in this report:

Newfoundland:	K. Dominie, Environment A. Brown, Municipal Affairs
Nova Scotia:	A. Crouse, Environment E. Rowe, Board of Public Utilities E. Cramm, Municipal Affairs
New Brunswick:	N. Denning, Environment R. Stuart, Municipal Affairs
Quebec:	R. Cournoyer, Affaires Municipaux J. Vachon, l'Environment J. Boucher, l'Environment
Ontario:	K. Roberts, Environment C. Wilson, Environment P. Burns, Municipal Affairs B. Alty, Municipal Board B. Wagner, Municipal Board
Manitoba:	K. Kjartenson, Environment L. Whitney, Natural Resources D. DeGraffe, Public Utilities Board L. Bisson, Municipal Affairs T. Francis, Manitoba Water Services Board D. Shwaluk, Manitoba Water Services Board
Saskatchewan:	R. McDonald, M.R. 2 Consulting Engineers R. Pentland, Saskatchewan Water Corporation
Alberta:	J. Milos, Environment D. Shillibear, Utilities and Telecommunications
British Columbia:	A. Millward, Greater Vancouver Water District B. Kruger, Greater Vancouver Water District A. A. Hayman, Environment J. Farrow, Environment J. Callan, Municipal Affairs J. Wigmore, Environment

THE USER-PAY PRINCIPLE

AND

MARKET SOCIALISM

by

Steve H. Hanke
Professor of Applied Economics
The Johns Hopkins University
Baltimore, Maryland 21218

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Chapter 1

WATER SUPPLY AND ECONOMICS

Traditional Water Supply Planning

Two elements are central to traditional water supply planning: a water requirements forecast and a cost minimizing strategy to supply the requirements. Three steps are necessary to produce a water requirements forecast. First, a population forecast is made. This is usually accomplished by extrapolating past trends. Second, a forecast of per capita water use is prepared. Again, the technique used is commonly an extrapolation of past trends. A water requirements forecast is then produced by multiplying the population figures times the per capita use figures.

After a water requirements forecast is produced, the problem shifts to an evaluation of the alternative means of meeting the requirements. This problem is one of selecting a cost minimizing supply strategy.

Traditional water supply planning, therefore, accepts water requirements as a given,and then cost minimizing systems are designed to meet the fixed or given requirements. At no point in the traditional process are benefits balanced with costs. Rather, the benefits associated with meeting water requirements are implicitly assumed to always exceed costs. The only real analytical problem is to minimize the costs of meeting a fixed objective, namely the water use requirements.

Until the 1960's, the traditional method of water supply planning appeared to serve water systems well. Supplies were usually adequate, and total revenues were sufficient to meet the real costs of supply.

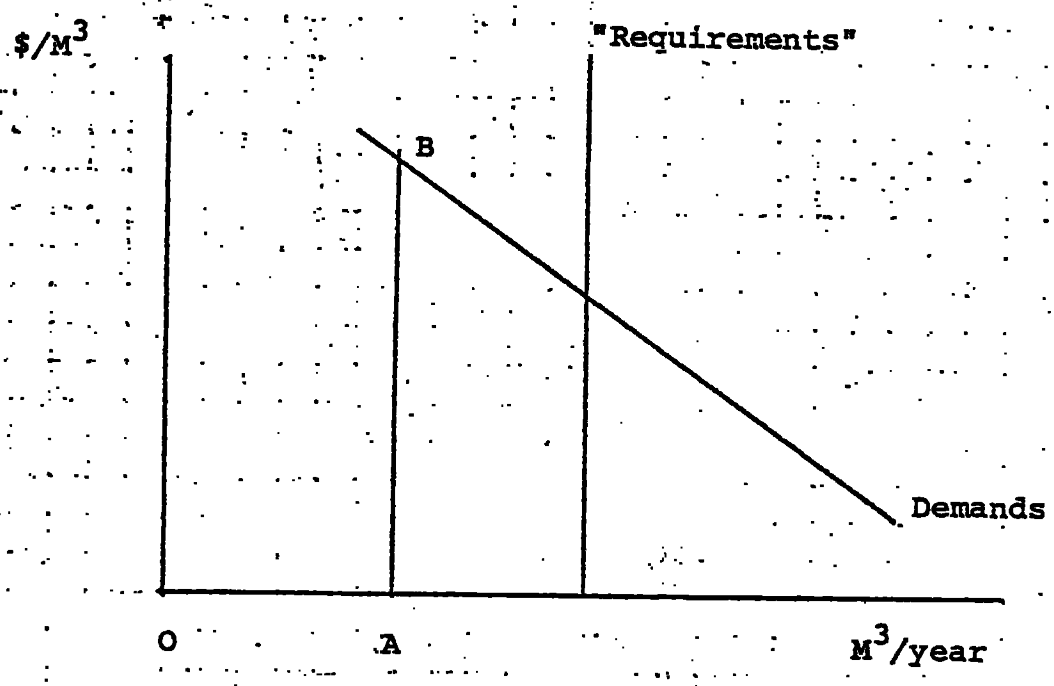
The sixties, however, brought with them inflation. Inflation increased the costs of making investments in both new and replacement facilities. These cost increases contributed to serious problems for water supply systems. Water supply revenue sources are regulated directly or indirectly by political or quasi-political bodies. Hence, revenues are not determined by the free play of supply and demand in unregulated markets. This arrangement for setting allowed revenues and the fact that regulatory bodies have either been unwilling or incapable of responding to cost increases has resulted in insufficient water system revenues. Herein lies the core of the problem faced by water system planners.

Without sufficient revenues, water systems have begun to deteriorate and new capacity has become increasingly difficult to finance (Carron and MacAvoy, 1981). Faced with a financial crisis, some water supply planners have begun to question traditional planning methods. Rather than assuming that requirements are fixed and must be met, planners are beginning to ask: what are the benefits and costs associated with alternative water conservation policies? (Binnie International (Australia) Pty. Ltd. et al., 1977; Hanke, September, 1978; Hanke, 1980(a); Hanke, 1980(b); Hanke, February 1981; Hanke, April 1981; Hanke, 1982; and Gilliland and Hanke, 1982.)

The Economic Approach to Water Supply Planning

The economic approach requires that the benefits and costs of alternative policies be estimated. Some water supply planners have begun to adopt the economic approach to water supply planning. The objective of this approach is to avoid waste in the allocation of resources. The economic approach involves forecasting demands, not requirements (see Figure 1.1). These demands have an economic meaning: for each level of water use, the demand

Figure 1.1 "Requirements" and Demands



represents the incremental or marginal valuation that consumers place on that unit of water use. For example, the value or benefit of the A$\underline{th}$ unit of water consumed in Figure 1.1 is equal to AB. The demand function, is therefore, a marginal or incremental benefit function. A supply function (Figure 1.2), which represents the least-costly combination of resources required to produce alternative quantities of water, is the second element in the economic approach. To produce the A$\underline{th}$ unit of water in Figure 1.2, the cost is AB, which represents the incremental or marginal cost of the A$\underline{th}$ unit. Therefore, the supply function is a marginal cost function. To avoid waste and allocate resources efficiently, plans must be made so that demands and supplies are equal. In Figure 1.2, this balance of marginal benefits and costs occurs at the consumption-production level OA.

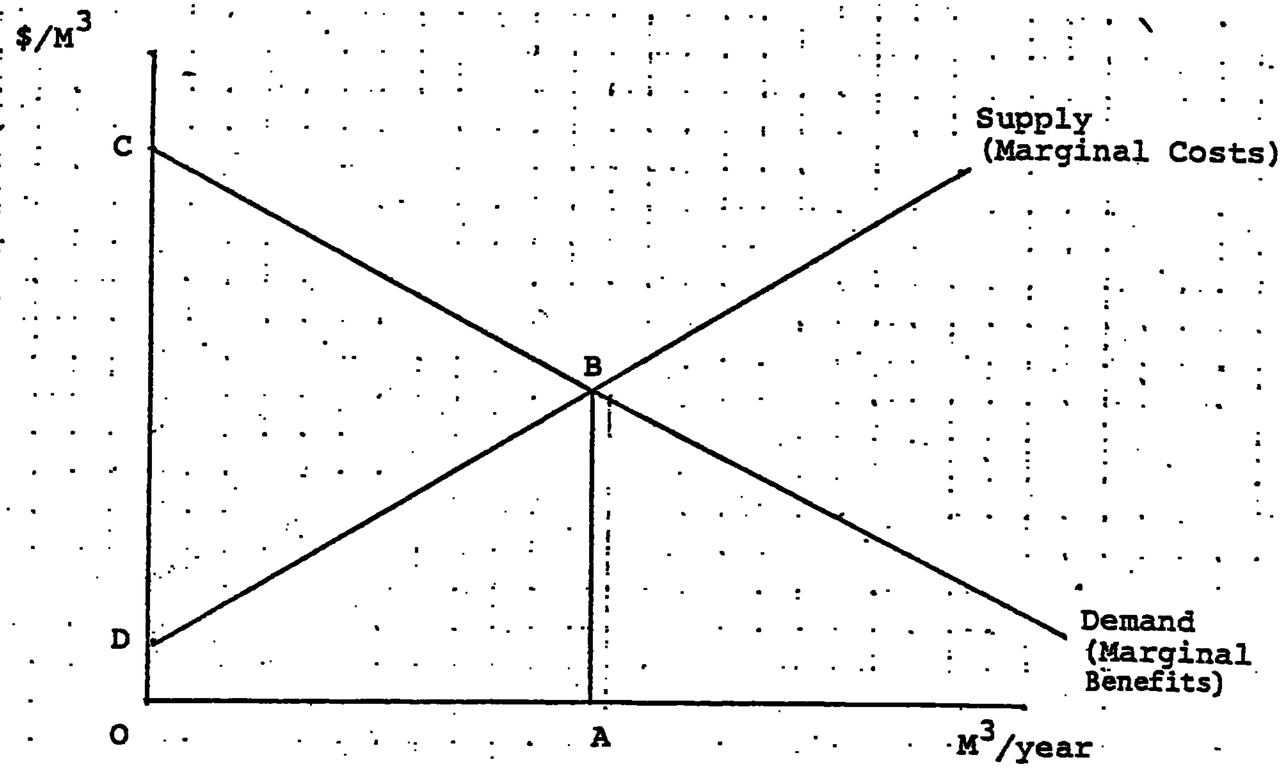
The economic balance of demands and supplies avoids waste and is efficient because:

(1) Production is increased by using low-valued resources first. Production is increased by moving along the supply function from left to right (from D to B in Figure 1.2).

(2) Production is allocated to high-valued uses first. Production is allocated by moving along the demand function from left to right (from C to B in Figure 1.2).

(3) Production and consumption (supply and demand) are balanced at an efficient level. Production and consumption are expanded as long as their marginal costs are less than their marginal benefits, and production and consumption are balanced at the point where their marginal benefits equal their marginal costs. In our example (Figure 1.2), demand and supply are efficiently

Figure 1.2 Demand and Supply Integration



balanced at an output level of OA. We do not expand production and consumption beyond this level, since any increment would generate marginal costs that exceed marginal benefits, and this would result in economic waste. Alternatively, if we fail to expand output to OA, economic waste occurs, since the marginal costs of expansion up to OA are less than the marginal benefits.

The Plan for this Paper

The purpose of this paper is to apply economic analysis to the problem of urban water supply planning. Since the economic approach represents a departure from the traditional approach, emphasis is placed on the development of general economic principles and the practical application of these principles to the specific problems that frequently confront those who are responsible for urban water supply planning and management.

The plan for the paper is to first present the basic concepts and tools for analysis. This is accomplished in Chapters two through five and Appendix 1. The concepts and tools are applied to urban water supply problems in Chapters six and seven. In the eighth and final chapter, we discuss the policy implications and insights which can be derived from using economic analysis to integrate urban water supply and demand.

Chapter 2

A BENEFIT-COST MODEL

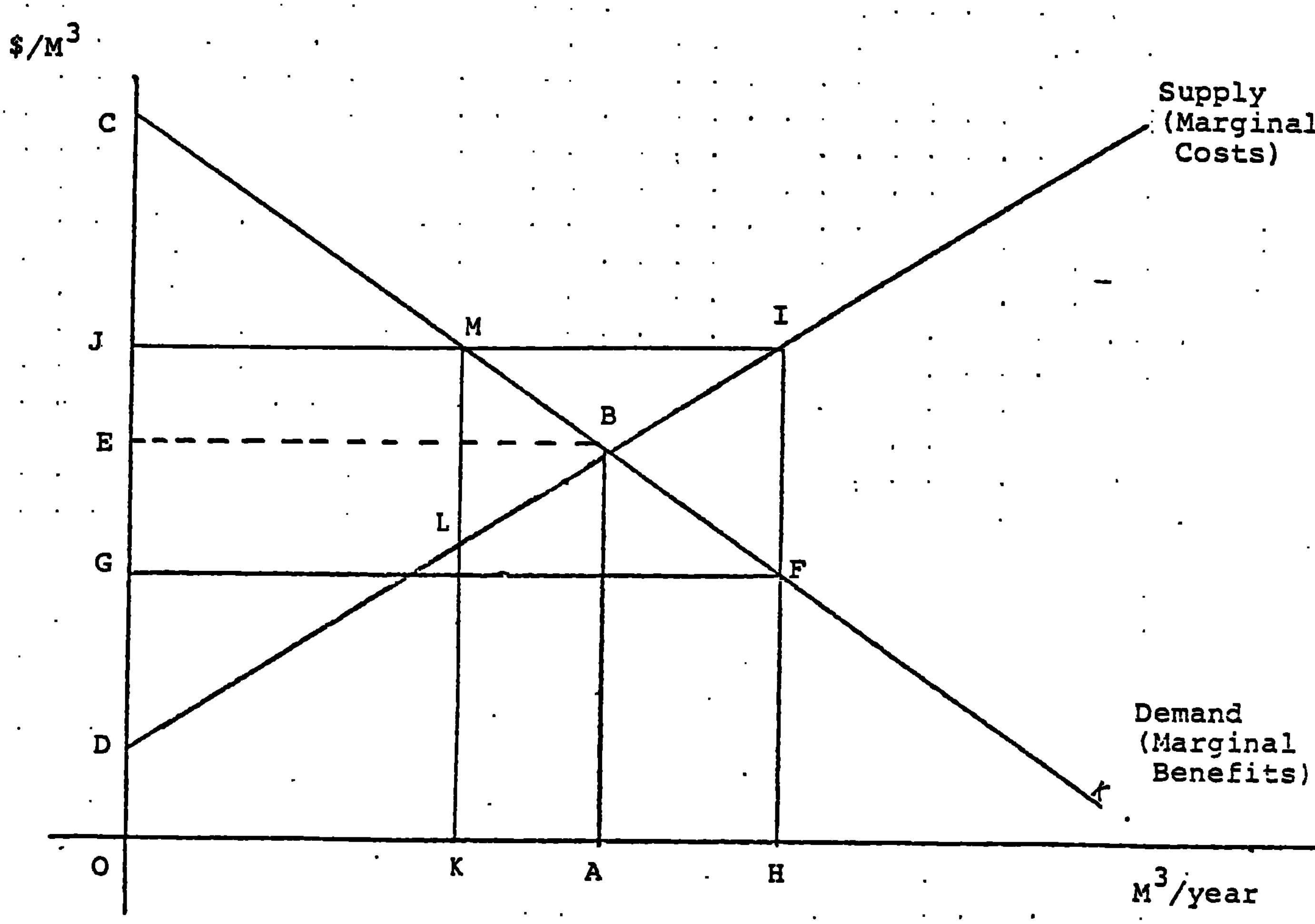
On the Economic Objective and Criterion for Choice

In order to make statements about the desirability of an action or policy, we must state our objective and determine a criterion for choice. Since we limit the scope of our analysis to economics and the attainment of efficiency in the allocation of resources, our objective is to maximize the net benefits from the use of resources. We wish, therefore, to maximize the net benefits (the difference between the total benefits and total costs) of using resources. This is accomplished by pursuing an action or policy as long as its marginal or incremental benefits exceed its marginal or incremental costs. If this criterion for choice is employed, resources will be used efficiently and waste will be avoided.

We illustrate the principles and define the terms, which we use throughout this appendix, by the use of Figure 2.1. Our objective is to maximize the difference between total benefits and total costs. Since the marginal benefit function is the first derivative of the total benefit function, we determine the total benefits of consumption by integrating the marginal benefit function over the relevant range of water use (for numerical examples, see: Powers, 1978). If water is rationed to the highest valued users first, starting at point C on the demand function first and then moving to the right toward point B as consumption is increased, then the total benefits from consuming OA units will be equal to the area OCBA.

Since the marginal cost function is the first derivative of the total cost function, we determine the total costs of production by integrating the marginal cost function over the relevant range of water production.

Figure 2.1 Benefits and Costs



If water is produced from the least costly sources first, then the total costs of producing OA units will equal ODBA.

In our example and with our criterion for choice, we can observe that net benefits are at a maximum when OA units are efficiently consumed and produced. At this level of water use, demands and supplies are balanced and net benefits are equal to the area CBD, which is the difference between total benefits (OCBA) and total costs (ODBA). An efficient plan should be targeted to produce OA units efficiently and to ration them efficiently to consumers.

The method that will achieve an efficient outcome and avoid waste is to produce an efficient level of output, OA (see Figure 2.1), and ration it by setting price equal to OE, the marginal cost of OA units. By applying this method, the efficient output will be produced; it will be rationed to the highest valued uses; and as a result, the net benefits will be at a maximum, area DCB.

If the price is set above OE, the efficient level, economic waste will occur and the efficient plan will not be achieved. For example, a price of OJ will result in consumption of OK and net benefits equal to the area DCML. To eliminate the waste associated with this suboptimal result, we must lower the price to OE and increase output to OA. This will increase efficiency, since the marginal benefits of consumption exceed the marginal costs of production in the range of output and consumption KA. The increase in net benefits will equal the area LMB.

If the price is set below OE, the efficient level, economic waste will occur and the efficient plan will not be achieved. There are several possibilities that could exist. One possibility involves the necessity of nonprice rationing. We use a simple example to illustrate the nature of the waste associated with this possibility. If the output is OA, the efficient level, and the price is set at OG, then the quantity of water demanded would exceed the system's output by AH units. To ration the capacity OA and retain the price of OG, we must employ some form of nonprice rationing. If we could devise a "perfect" nonprice rationing mechanism -- one which would eliminate the uses represented by the segment of the demand function BF -- and if this could be implemented with no administrative costs, then we could obtain the efficient output, ration consumption to the highest valued uses, and obtain the maximum net benefits. However, such a system of nonprice rationing cannot be devised. Although a nonprice rationing system can constrain consumption to OA units, it cannot guarantee that only the highest valued uses, represented by the segment CB on the demand function, will be served (Hanke, 1980(b)). In fact, some of the lower valued uses, which are represented by the segment of the BF of the demand function, will be substituted for some of the higher valued uses, which are represented by segment CB on the demand function. As a result, the total gross benefits of OA units of consumption with nonprice rationing -- which would equal the area OCBA, if consumption was allocated to the highest valued uses first -- will be less than the area OCBA. Hence, with nonprice rationing, the net benefits of OA units of consumption will be less than the area DCB, which represents the maximum net benefits of OA output and consumption. In addition to these reduced benefits, nonprice rationing will impose another cost, the administrative cost of the nonprice rationing system.

Another possibility that can occur when the price is set below OE is the following: nonprice rationing is not imposed; then excess demands exist (if the price is OG and output is OA, excess demands equal AH); the quality of service deteriorates; and political pressure to expand capacity results. In this example, the total demands of OH can be met by expanding output with an increment in capacity of AH. This expansion will be wasteful because the marginal costs exceed the marginal benefits in the range of output and consumption AH. The waste of expanding output and consumption from OA to OH is determined by subtracting the gross costs of that increment, which equal the area ABIH, from the gross benefits, which equal the area ABFH. The result is a net loss or waste of the increment in capacity equal to the area BIF.

A Benefit-Cost Model for Water Conservation

Since water supply systems' revenue sources are regulated and have been limited in many cases to levels that are below the real costs of maintaining existing systems, some water supply planners have abandoned the traditional approach to planning. Instead, they have begun to focus on water conservation programs and methods of managing water demands. In addition, some water supply planners have begun to use the economic approach as a means of evaluating alternative water conservation policies. In short, tight budget constraints have introduced a new discipline into water supply planning. The economic approach has offered a new means of avoiding economic waste and accommodating fiscal discipline.

The economic approach differs from the traditional approach, which assumes that meeting water use requirements is desirable *per se*. Rather, the economic approach has as its objective the avoidance of economic waste and the maximization of net benefits. Given this objective, meeting fixed water use requirements or alternatively conserving water may or may not be desirable. The desirability of either of these policies will depend on the benefits and costs associated with each. Since the determination of benefits and costs is central to the economic approach to planning and since water conservation is the dominant policy presently under consideration, we focus directly on the measurement of the benefits and costs of water conservation. However, we should note that the economic tools that are developed are necessary and can be used to evaluate the benefits and costs of system expansion.

To evaluate the desirability of conservation policies, we need a benefit-cost model for water conservation. Based on the economic concepts presented, we first define a change in total benefits. The change is the savings in resources which is expected to result from the introduction of a water conservation policy. The incremental benefits (ΔB) are calculated by taking the product of the reduction in water use resulting from the policy (Q) and the marginal cost of water (MC):

$$\Delta B = Q \cdot MC. \tag{2.1}$$

Second, we define the change in costs (ΔC). The change is the sum of: (1) the resource costs to the water utility or authority of adopting the policy (U) (These could include such items as water meters, conservation devices, leakage detection programs, educational programs and enforcement programs.), (2) the resource costs to the consumers (E) (These could include such items as the purchase and installation of conservation devices, the value of time and effort used to repair leaks.), and (3) the value of "useful" consumption foregone (F) (This figure is equal to benefits lost because consumption is less after the policy is introduced.). Hence, the incremental costs are represented by:

$$\Delta C = U + E + F. \quad (2.2)$$

With these definitions, and our objective of maximizing net benefits from any conservation policy, we can state that any conservation policy is desirable only if the change in benefits exceed or are equal to the change in costs:

$$Q \cdot MC \geq U + E + F. \quad (2.3)$$

Thus, equation (2.3) becomes our criterion for choice or our benefit-cost model, for determining whether a conservation policy is desirable.

Chapter 3

DEMAND ANALYSIS

To implement our benefit-cost model (Equation 2.3), we must analyze the demand for water. Two types of demand information are required. First, we must identify the determinants of water use that can be modified or controlled by water authorities. Each of these determinants is a potential water conservation policy, and is, therefore, a candidate for benefit-cost analysis. Once we identify each determinant, we must be able to predict the impact of each on water use. That is, we must be able to predict water use without the conservation policy and water use with the policy. The difference between these two values is the change in water use which results from the use of the conservation policy. It is equal to Q in our benefit-cost model.

Second, we must be able to identify the demand function for water. This is necessary, so that we can estimate the value of "useful" consumption foregone when a water conservation policy is introduced. Once we have estimated the reduction in water use that will accompany a conservation policy, we must estimate the value of water that will no longer be consumed. This value is represented by F in our benefit-cost model.

On the Determinants of Water Use

Price - the price charged per m^3 of water is one of the determinants of water use. Price is controlled directly by water authorities and/or regulatory bodies. Since water use is negatively correlated with price, price is considered to be an important conservation measure. To measure the impact of price changes on water use (Q in Equation 2.3), we need to estimate price elasticities of demand for various types of urban water use; where the price elasticity is a dimensionless number that expresses the responsiveness of water use to changes in price. For relatively large changes in price, the price elasticity is given by the following formula:

$$e = \frac{P + \Delta P}{Q} \cdot \frac{\Delta Q}{\Delta P}, \tag{3.1}$$

where e = the price elasticity of demand, P = original price of water, Q = the original quantity of water use, ΔP = the change in price, and ΔQ = the change in water use. In cases where ΔP and ΔQ become small, then the elasticity formula given by Equation 3.1 becomes:

$$e = \frac{dQ}{dP} \cdot \frac{P}{Q}. \tag{3.1'}$$

In all cases, the price elasticity coefficient will have a negative sign, indicating a negative relationship between water use and price. Also, when the absolute value of the elasticity coefficient is greater than 1.0, water use is relatively responsive to a change in price; whereas, water use is relatively unresponsive, when the absolute value of the coefficient is less than 1.0.

There have been many studies in which price elasticities have been estimated for urban water use (Hanke, September 1978). Most of them have been conducted in the United States. Since they vary widely in quality, we should use caution when using the results.

The most reliable estimates of price elasticities are derived from studies that have the following characteristics (for more details, see: Hanke and Mehrez, December 1979 and Hanke and deMaré, August 1982):

(1) metered water use data is used to construct the demand models;

(2) data are disaggregated by user class, and these user classes are defined, so that they contain customers who are similar and thought to have similar responses to price changes;

(3) water use and price data are collected at one location for a relatively long time-series, with a relatively large number of real price changes.

One study that has these characteristics was conducted in Malmö, Sweden (Hanke and deMaré, August 1982). Table 3.1 provides a summary of the data that were collected. Several points are particularly noteworthy. The time-series data used were for 14 semi-annual time periods, starting with the last quarter of 1971 and ending with the third quarter of 1978. The cross-section data that were used were from a stratified sample of 69, single-family houses in Malmö. (The 69 houses were separated into two groups. One group was constructed in the period 1936-1946 and the other 1968-1969.) The water use data were obtained from semi-annual, metered water use records. The income data were from income tax records. The number of adults and children occupying each house and rainfall per semi-annual period were all from records maintained by the city of Malmö. The price of water was the real marginal price per m^3. Its value remained constant for each house in each billing period, regardless of the quantity of water that each house used. During the period under study the nominal price per m^3 was changed five times and the real price changed in 12 of the 14 semi-annual periods.

Using a pooled, time-series, cross-section approach, the demand for residential water demand in Malmö was estimated. The model used was a

Table 3.1. Characteristics of the Malmö data.

Variable	Mean	Standard Deviation	Type of Data
Quantity	75.2106	36.2893	TS-CS
Income	49497.0000	21781.0000	TS-CS
Adults	2.0500	0.7460	TS-CS
Children	0.9260	1.0418	TS-CS
Rainfall	39.1324	7.7768	TS
Age of Houses	0.5401	0.4986	CS
Price of water	1.7241	0.3190	TS

Notes:

It is important to note that the data contain no proxies. The data represent real values for the variables.studied.

Quantity = quantity of metered water per house, per semi-annual period, in m^3.

Income = real gross income per house in Swedish Crowns (actual values reported per annum and interpolated values used for mid-year periods).

Adults = number of adults per house, per semi-annual period.

Children = number of children per house, per semi-annual period.

Rainfall = rainfall per semi-annual period/6, in mm.

Age of Houses = a dummy variable with a value of 1 for those houses built between 1968 and 1969 and a value of 0 for those houses built between 1936 and 1946.

Price of Water= real price in Swedish Crowns per m^3 of water, per semi-annual period (includes all water and sewer commodity charges that are a function of water use).

TS = time-series data (14 semi-annual periods, starting with the last quarter of 1971 through the first quarter of 1972 and ending with the second and third quarters of 1978.

CS = cross-section data (69 houses which have remained with the same. head-of-household during the seven-year study period.

Prices and incomes were deflated to real values by using the Swedish consumer price index.

Source: (Hanke and de Maré, August 1982) static, equilibrium model that assumes a linear relationship among the variables. The results of applying ordinary least squares regression analysis to the data are contained in Table 3.2.

The equation and estimates of parameters are statistically significant. Furthermore, the signs of the independent variables are as we expected.

With the results obtained, elasticities can be derived. It is the information on price elasticities that is required to estimate the impact of price changes on water use. This elasticity information is summarized in Table 3.3.

Recall that to evaluate the benefits and costs of a price increase, we must estimate Q in Equation 2.3, where Q represents the change in water use that will result from a price increase. This is accomplished by using price elasticities. For example, if the original price for water in Malmö was 2.0 Swedish Crowns per m^3, water use was 100,000 m^3 and we consider a 50 percent price increase, then consumption would decrease (if all other determinants of water demand remain constant) by 7.5 percent or 7,500 m^3. Hence, the value of Q in Equation 2.3 would equal 7,500 m^3. To make this calculation, all we must do is multiply the elasticity (-.15) times the percentage price increase (.50) and then multiply the result (-.075) times the original water use (100,000 m^3).

<u>Water Use Restrictions</u> - Water use restrictions are regulations which require water users to use their existing stock of water-using equipment in an involuntary way, so that water use is reduced. Although these restrictions are widely used, primarily during droughts and short-term emergencies, there is only one study which measures the impact that restrictions have on water use and determines restriction elasticities (Hanke and Mehrez, 1979).

Table 3.2. Demand Equations for Malmö.

Linear Model

$$Q = 64.7 + \underset{(3.26)}{0.00017}\ \text{Income} + \underset{(2.98)}{4.76}\ \text{Adults} + \underset{(3.09)}{3.92}\ \text{Children} - \underset{(2.12)}{0.406}\ \text{Rainfall} + \underset{(11.54)}{29.03}\ \text{Age of Houses} - \underset{(1.99)}{6.42}\ \text{Price of Water}$$

$R^2 = 0.259$

Notes:

1. The numbers in parentheses are t statistics.

2. For the degrees of freedom in our equations, the critical value for the t statistics, at the 5 percent level of significance, is 1.98.

3. Tests for milticollinearity, serial correlation (the Durbin-Watson test) and heteroskedasticity (the Goldfeld-Quant test) have been made to insure that the methodology (OLS analysis) is consistent with the assumptions required to obtain unbiased estimates of the parameters and t statistics. The equations presented passed these tests. Hence, the price elasticities derived are efficient elasticities.

4. It is important to realize that our pooled data are dominated by cross-section data. Hence, the value of the R^2, which would be low for a pure time-series study, is satisfactory for our pooled analysis because of the large variation across individual units of cross-section observation which is inherently present in the data. For purposes of estimating elasticities in this context, the t statistics are most important and these are significant at the 5 percent level for each coefficient in our model.

Source: (Hanke and de Maré, August 1982)

Table 3.3. Elasticities for Malmö.

Variable	Elasticity
Income	+0.11
Adults	+0.13
Children	+0.05
Rainfall	-0.21
Price of Water	-0.15

Notes:

The general concept of elasticity as follows:

elasticity = $\frac{dD}{dI}\frac{I}{D}$, when D = the dependent variable and I = the independent variable. A linear demand function has a different elasticity at each point. It is suggested that the mean values of D and I be used to determine a single elasticity for linear equations. For example, the price elasticity for the demand model is computed as follows:

$$-6.42 \left(\frac{1.724}{75.2}\right) = -0.15.$$

Source: (Hanke and de Maré, August, 1982)

To conduct this study, multiple regression analysis was used to analyze time-series data for a 30-year period (1946-1975) for Perth, Western Australia. During this period, water use restrictions were employed in the summer months (December, January and February) in 13 of the 30 years studied. These restrictions were directed at reducing sprinkling use for residential water use. The restrictions consisted of bans on the use of outside sprinklers. The use of hand-held garden hoses was allowed.

The equation of best fit for the month of December was found to be:

$$(3.2)\quad \log_e Q = -4.35 + 2.509 \log_e T_{max} - 0.025 \log_e \text{Rain} - 0.214 \log_e \text{Res},$$

where Q = mean daily water use per account in imperial gallons, T_{max} = mean maximum daily temperature in °F for each month, Rain = total rain in millimeters for each month, and Res = a dummy variable which receives the value of 2, if restrictions were used, and the value of 1, if restrictions were not used.

In much the same way as price elasticities allowed us to predict the impact of price increases on water use, restriction elasticities allow us to predict the impact of water use restrictions on water use. The restriction elasticity in equation 3.2 is given by the coefficient of $\log_e$ Res and is equal to -0.214. (Note that the restriction elasticity for January is -0.222 and February is -0.162.)

Using Equation 3.2, and setting T_{max} = 86.4°F, Rain = 2 mm, and Res = 2 with restrictions and 1 without restrictions, we compute estimates of water use for December of 917 imperial gallons per account per day with restrictions. For each day in December and for the average water customer, water use is reduced by 127 imperial gallons or 14 percent due to imposition of water use restreictions. Therefore, if we want to operationalize our benefit-cost model for water use restrictions on the average customer in Perth, Western Australia for the month of December, we must substitute the value of 3937 imperial gallons for Q in Equation 2.3. (To obtain this value (3937), we subtract 790 from 917 and multiply by 31.)

Even though only one study has produced restriction elasticity estimates, we should note that these elasticities are consistent with engineers' rules-of-thumb which are used in North America to predict the impact of restrictions (Grima, 1972). For example, engineers often assume that water use will be about 85 percent normal, when water use restrictions of the type evaluated in Perth are imposed (for similar results, see Table 3.4).

As is the case with price elasticities, we must conclude that the limited information that we have on restriction elasticities, must be applied with caution. Although our restriction elasticities conceptually measure the proper quantities which are relevant for a benefit-cost study, they represent a limited data base: they are for residential water use, at one location and for one type of water use restriction. To be able to make generalizations that are based on sound analysis, we must conduct more studies with time-series data, at different locations and with various types of restrictions for different classes of water users.

Water Meters - Water meters provide another method for conserving water. Consumers who purchase metered water must pay a price per m^3, while unmetered customers do not. Hence, metered customers have a greater incentive to control their use, than do unmetered customers.

Table 3.4 The Impact of Water Use Restrictions (Perth, Western Australia)

Month	Water Use Ratio*	Water Use with Restrictions (as a % of use without restrictions)
December	$\frac{2^{-0.214}}{1^{-0.214}}$	86.2
January	$\frac{2^{-0.222}}{1^{-0.222}}$	85.7
February	$\frac{2^{-0.162}}{1^{-0.162}}$	89.4

*Note that the exponents in each ratio are the restriction elasticity coefficients

The impact of water metering on water use can be seen by reviewing the data in Table 3.5. These data, which were collected on a cross-sectional basis from 18 locations in the United States indicate that residential users who were metered used less water than those who were unmetered. In metered areas, average sprinkling use was about 45 percent that of unmetered areas. Household use for domestic purposes was not significantly different between the metered and unmetered areas.

Another carefully controlled cross-sectional study in Israel, however, indicates that household use can be reduced by the installation of meters (Kamen and Dar, 1973). The Kamen and Dar study included a sample from apartments in which sprinkling use did not occur. Their sample included 1157 apartment units (households), located within apartment buildings, which were metered with 1157 separate water meters. In addition, 469 apartment units located within apartment buildings, which were not individually metered, were included. In the second group, each whole building which contained apartment units was metered. A review of Table 3.6 indicates that domestic use in the apartment units that were individually metered was about 75 percent of those that were unmetered. Moreover, the use in each of the metered apartments was more closely grouped around the mean use per apartment for the metered than for the unmetered apartment units.

One study has evaluated the impact of metering at one location, Boulder, Colorado, U.S.A. over time (Hanke, 1970a). Time-series data for domestic and sprinkling use, from 1955-1968, and for 3086 customers were used. Residential customers were unmetered from 1955-1961 and metered from 1962-1968. This study found that domestic and sprinkling water use were 65 and 51 percent, respectively, of what they had been prior

Table 3.5 Water Use in Metered and Unmetered Areas

	Metered Areas (10)	Unmetered Areas (8)
	(gal/day per dwelling unit)*	
Annual Average		
Leakage and waste	25	36
Household	247	236
Sprinkling	186	420
Total	458	692
Maximum Day	979	2354
Peak Hour	2481	5170

*Data were collected for eighteen locations in the U.S.A. from October 1963 - September 1965, and at 15 minute intervals.

Source: (Howe and Linaweaver, 1967)

Table 3.6. Annual Per Capita Water Use by Town and Type of Metering.

Town	Apartment Unit Unmetered	Apartment Unit Metered
	(m^3 apartment unit)	
Jerusalem	56.0	48.0
	S.D. = 35.5	S.D. = 38.4
	S.E. = 4.37	S.E. = 3.21
Tel Aviv	86.4	65.3
	S.D. = 58.2	S.D. = 38.5
	S.E. = 3.75	S.E. = 2.31
Dan Region	87.3	57.3
	S.D. = 241.0	S.D. = 36.4
	S.E. = 20.1	S.E. = 1.96

Notes:

1. S.D. = standard deviation
2. S.E. = standard error

Source: (Kamen and Dar, 1973)

to metering. Moreover, the impact on water use of installing meters in 1962 was slightly greater in 1968 than in 1962. That is, the long-term impact was slightly greater than the short-term impact. Table 3.7 presents the data required to determine the impact of metering on water use (the value of Q in Equation 2.3).

Leakage Detection and Control - Another determinant of water demand (water production), which can be controlled by water utilities, is the water production lost through system leakage. Leakage demands do not come from the final users, since no one uses water lost by leakage. Rather, they are demands which are a function of the physical characteristics of the systems and the way in which systems are operated. To determine the impact of leakage detection and control programs on water production, we must establish a relationship between inputs for leakage detection and control and the output, which is reduced system leakage. With such a relationship or production function for leakage detection and control, we can determine the amount of water saved by applying various levels of detection and control effort.

Figure 3.1 represents a production function for leak detection and control for the city of Perth, Western Australia. The values for annual water saved can be used to determine Q in our benefit-cost model. For example, the impact of increasing leak detection and control workers from A to B (Figure 3.1) is equal to CD, which is equal to Q in our benefit-cost model.

On the Demand Function for Water

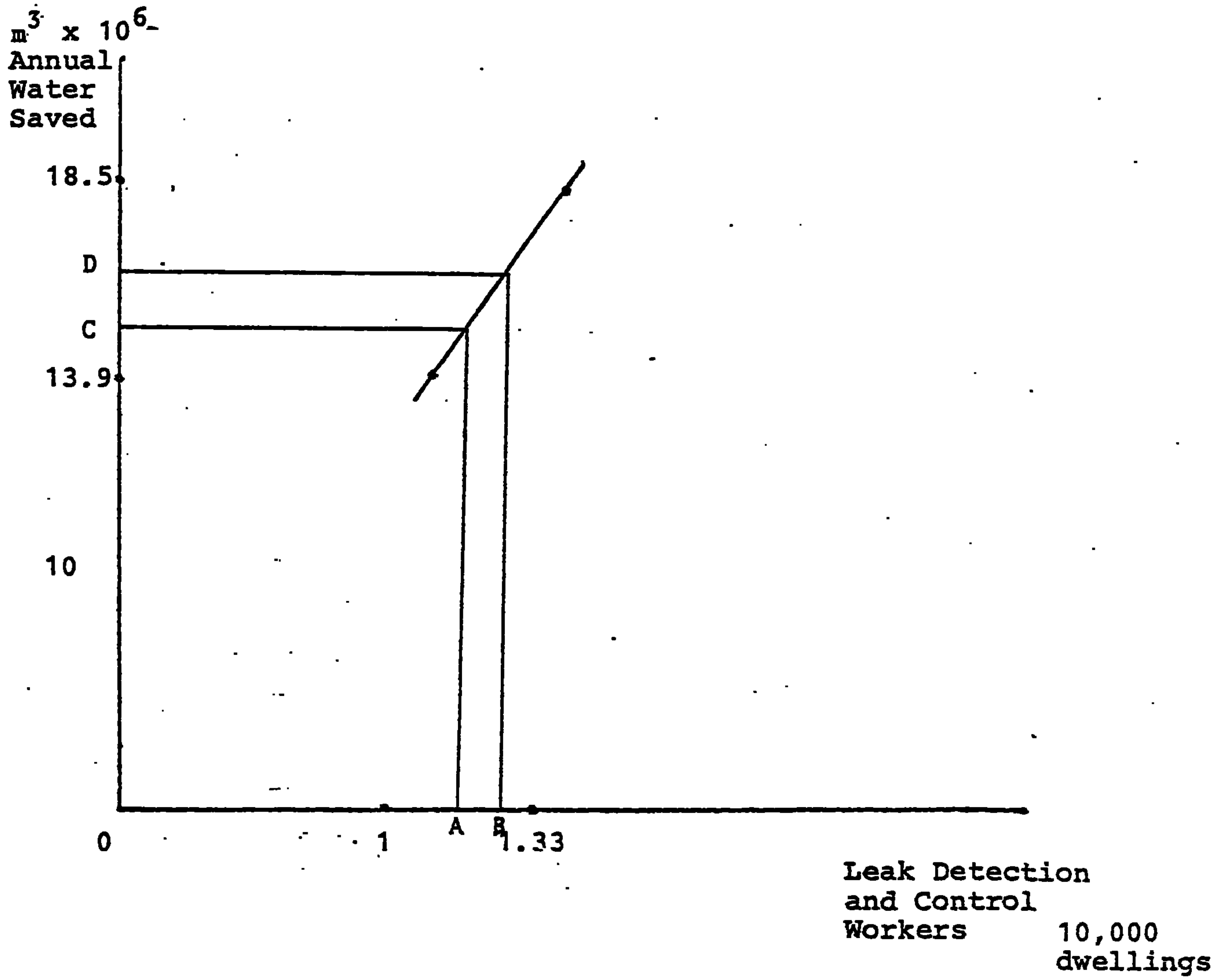
In addition to elasticity estimates, our benefit-cost model requires us to be able to locate the demand or marginal benefit function over the

Table 3.7. The Impact of Water Meters on Residential Use (Boulder, Colorado, U.S.A.)

Type of Use	Water Use* Ratio	Water Use with Meters (as a percent of use without meters)
Domestic	$\frac{2^{-0.62}}{1^{-0.62}}$	65
Sprinkling	$\frac{2^{-0.97}}{1^{-0.97}}$	51

*Note that the exponents in each ratio are the metering elasticities.

Figure 3.1 Production Function for Leak Detection and Control (Perth, Western Australia).



Source: (Binnie International (Australia) Pty.Ltd., et al., 1977) range of consumption and output being considered. Recall that the area under the demand function equals the total benefits of consumption. Therefore, the value of "useful" consumption foregone, F in our benefit-cost model, is determined by measuring the area under the demand function from the consumption level which would exit with the conservation policy to that which would exist without the conservation policy.

If we can specify the demand function mathematically, we can compute the value of the area under the demand function over the relevant range of consumption by taking the integral of the demand function over this range of consumption. For most practical problems, however, we will not have a demand function that can be used for direct computations of "useful" consumption foregone. We often only know the price per m^3 and the level of water use. That is, we only have information about one point on the demand function. In addition, we will be able to make a reasonable estimate of the price elasticity coefficient or a range of price elasticity coefficients. With these parameters, however, we can construct a demand function indirectly, and determine the value of "useful" consumption foregone.

We begin by construction a linear demand curve ($Demand_1$ in Figure 3.2). We know that:

P_1 = the price per m^3 of water in period 1,

Q_1 = water use in period 1, and

e = the price elasticity coefficient.

We also know that for discrete changes in price:

$$e = \frac{\Delta Q}{\Delta P} \cdot \frac{P_1}{Q_1}. \quad (3.3)$$

We can determine the slope of a linear demand function by rearranging (3.3)

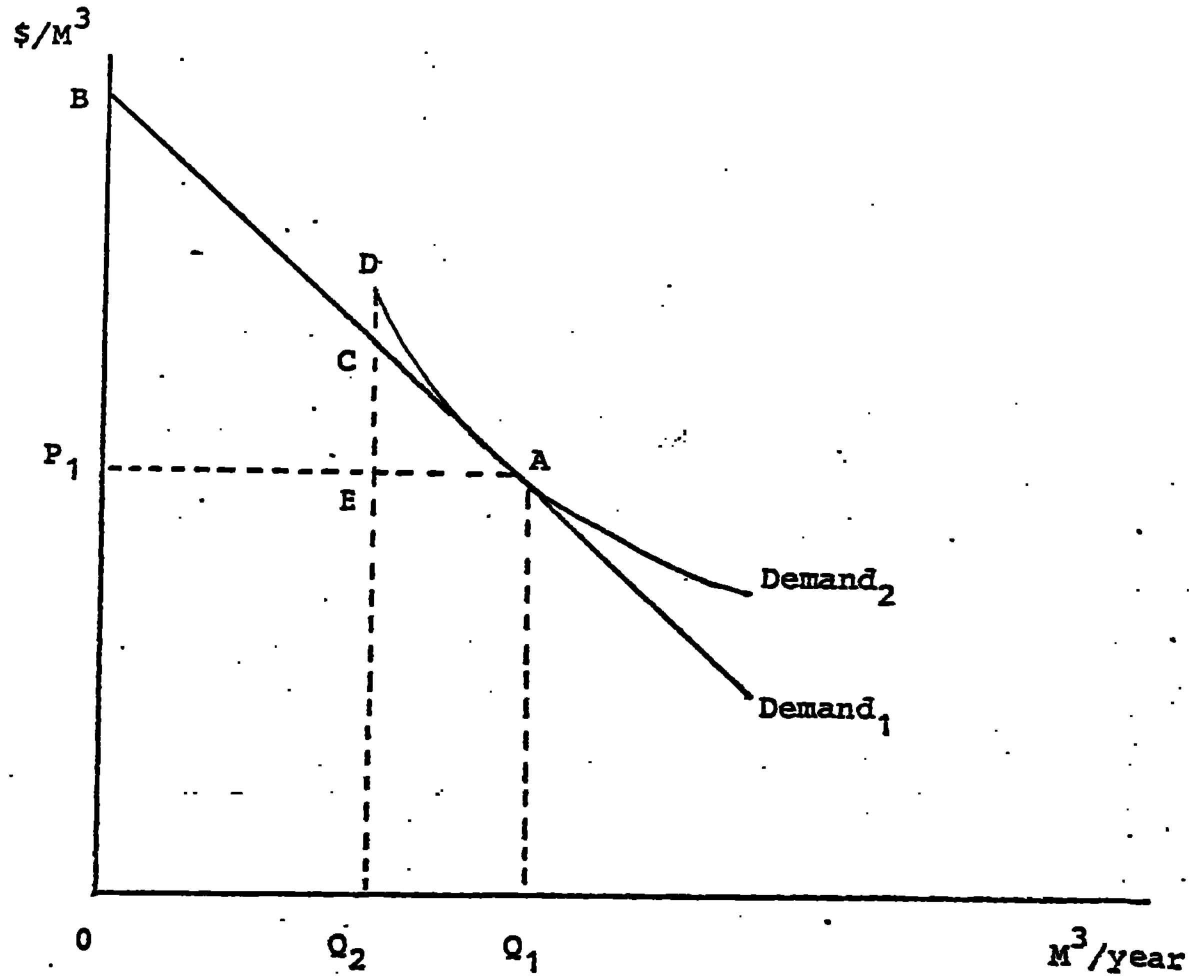


Figure 3.2 The Construction of Demand Functions

$$\frac{\Delta P}{\Delta Q} = \frac{1}{e} \cdot \frac{P_1}{Q_1}. \qquad (3.4)$$

Now let us use our analysis to construct a demand function (Figure 3.2). We know the values of P_1 and P_2. Hence, we know the location of point A. We also know the value of the price elasticity coefficient at point A. By solving Equation 3.4, we can determine the slope of the demand function that bisects point A. By using this information, we can construct a linear demand function ($Demand_1$) that has an intercept on the vertical axis of Figure 3.2 at point B. To compute the value of "useful" consumption foregone that is associated with a reduction in consumption from Q_1 to Q_2, we must:

(1) take the original price (OP_1) times the reduced consumption (Q_2Q_1). This equals the area Q_2EAQ_1 on Figure 3.2.

(2) then take the difference between the original price (OP_1) and a price (Q_2C) that would generate consumption at the new lower level (OQ_2). This difference is CE. We then multiply CE times the reduced consumption Q_2Q_1, and multiply the answer by 0.5. This procedure yields the area CEA on Figure 3.2.

(3) add the results obtained in steps (1) and (2) to obtain F, the value of "useful" consumption foregone. In this case, F is equal to the area Q_2CAQ_1 on Figure 3.2.

Since the absolute value of the price elasticity coefficient increases as we move from point A to point B on our linear demand curve and we usually only have one estimate of price elasticity, it is often desirable to use a constant elasticity demand function to predict changes in water use. Such a constant elasticity demand function is curvelinear, and has the following functional form:

$$Q = a\, P^{e}, \qquad (3.5)$$

where Q = the water use per period, a = nonprice factors that determine water use, P = the price per m^3 and e = the price elasticity coefficient. A constant elasticity demand function is represented by $Demand_2$ on Figure 3.2, and can be derived by using the same method that we employed in the linear case.

It is interesting to note that most conservation programs generate relatively small reductions in use, when compared to the total water used. Therefore, the use of either the linear or curvilinear form of the demand function will generate values for "useful" consumption foregone (F in Equation 2.3) which are very close to each other. For example, if water use is reduced from Q_1 to Q_2 because of a conservation program, the value of F would be equal to the area Q_2CAQ_1 with the linear demand function and Q_2DAQ_1 with the curvilinear demand function. The difference between the two measures of F is equal to CDA, and is relatively small. Hence, even though the constant elasticity demand function is often the most convenient for predicting changes in water use, the linear demand function associated with it can be conveniently used for determining the "useful" consumption foregone.

Chapter 4

MARGINAL COST ANALYSIS

In the last chapter we discussed methods for determining the values for reduced water use and "useful" consumption foregone. We dealt with the demand-side of the conservation problem. In this chapter we deal with the supply-side of the problem and analyze the marginal cost of urban water supply. This allows us to determine the value of another term in our benefit-cost model.

On the Nature of Water Supply Systems

Before we analyze the marginal cost of water supply, it is important to describe the general nature of urban water supply systems, since the measurement of marginal cost is an activity that requires a specialized knowledge of the engineering and technology of the industry. For our purposes it is important to distinguish among three types of works within a water system: (1) water source works, (2) water treatment works, and (3) water distribution works. The water source works include all of the components associated with obtaining water and delivering it to treatment facilities. These components can include reservoirs, groundwater well fields and transmission mains. They are necessary to supply water to treatment facilities or generate annual yield for the water system. They are usually designed to meet average annual daily demands. The size and nature of source works are a direct function of the water used by final users.

In many systems, the raw water generated by the source works requires treatment prior to use. The treatment works usually include a treatment plant and small storage reservoirs. These facilities are generally designed to meet maximum day demands, which usually occur in the summer sprinkling season. The size and nature of these facilities, like the source works, are a direct function of the water used.

After appropriate treatment, the treated water is ready to be distributed. The distribution works can consist of distribution mains, storage reservoirs and tanks. Although these facilities are designed to meet maximum day and maximum hourly use, their size and nature, unlike source and treatment works, are usually a direct function of the number and type of users as well as regulations associated with the provision of water for fire fighting purposes.

On the Relevant Concept of Marginal Cost

The concept of marginal cost that we use depends on our objective. Our application of marginal cost information is for the evaluation of the benefits and costs of water conservation programs, and our objective is to maximize the difference between total benefits and costs of these programs. Hence, we define the marginal cost of water so that it allows us to measure the opportunity cost of using (or saving) an increment of water. To measure these marginal or forward-looking costs, we measure the value of other products that the inputs used to produce water could have been used to produce. This measure differs from the standard, static, neo-classical cost analysis, which was represented in our discussions and diagramatic treatment of costs in Chapter two. Our earlier treatment dealt with an exposition of basic principles and the method of reasoning required in the economic approach. While our earlier treatment was appropriate for pedagogic purposes or what is often termed "textbook economics," it is too simplistic to be useful operationally (Turvey 1969).

A general definition of marginal cost, which allows us to estimate the opportunity cost of water use in operational dynamic terms, is straightforward. To estimate the marginal capital cost for any year, y, we can compute the present worth in year y of planned system costs with a small increment in permanent output starting in year t, where t can equal y. We then subtract from it the present worth in year y of system costs with the increment in permanent output starting in year t+1. This difference is then divided by the size of the permanent increment in use, to obtain the marginal capital cost per unit of output. Hence, the marginal capital cost is a measure of the effect of use upon the total system costs, where the relevant total system costs include only those investments which are planned to satisfy increases in use or demand, and where the opportunity cost is measured in terms of a slowing down or a speeding up of the growth in water use and associated investments.

It should be recognized that the permanent output increment used to estimate marginal capacity costs represents nothing more than a convenient analytical device for estimating the marginal impact, brought about by a small permanent change in output occurring in year t, on the entire future time stream of costs. In a practical sense, we need simply to forecast the future growth (or decline) in the demand for water services up to the end of the planning horizon, superimpose a small constant increment on this forecast, and then observe the change in present worth of the facilities resulting from the constant increment in the forecast.

The marginal running cost per unit of output or use is added to the marginal capital cost, to yield a total marginal cost for each unit of output used. The running costs include only those costs that vary with water use (largely electricity and chemicals). To obtain a marginal running cost for year y, we estimate the total running cost and divide by the total water used in year y.

The economic interpretation of our definition of marginal cost is of particular interest. The definition and measurement of marginal running cost presents us with little difficulty. This results from the fact that the opportunity cost of output occurs at the same time when the output is produced. The marginal capital cost concept, however, is more complex. In this case, there is a displacement in time, between the time when a permanent increment in use or output occurs, and the time when its opportunity cost occurs. For example, when a permanent increment in use utilizes an increment of system capacity, there is often no need for immediate reduction in any alternative outputs, and no opportunity cost occurs at that time. However, resources which could be used to produce something else will eventually have to be used to produce system capacity sooner than was originally planned. This represents the opportunity cost of adding a permanent increment to use today. Our marginal cost concept is designed to measure this "displaced" opportunity costs. If we set prices equal to marginal cost, then consumers will receive a signal as to the opportunity costs that their current use imposes.

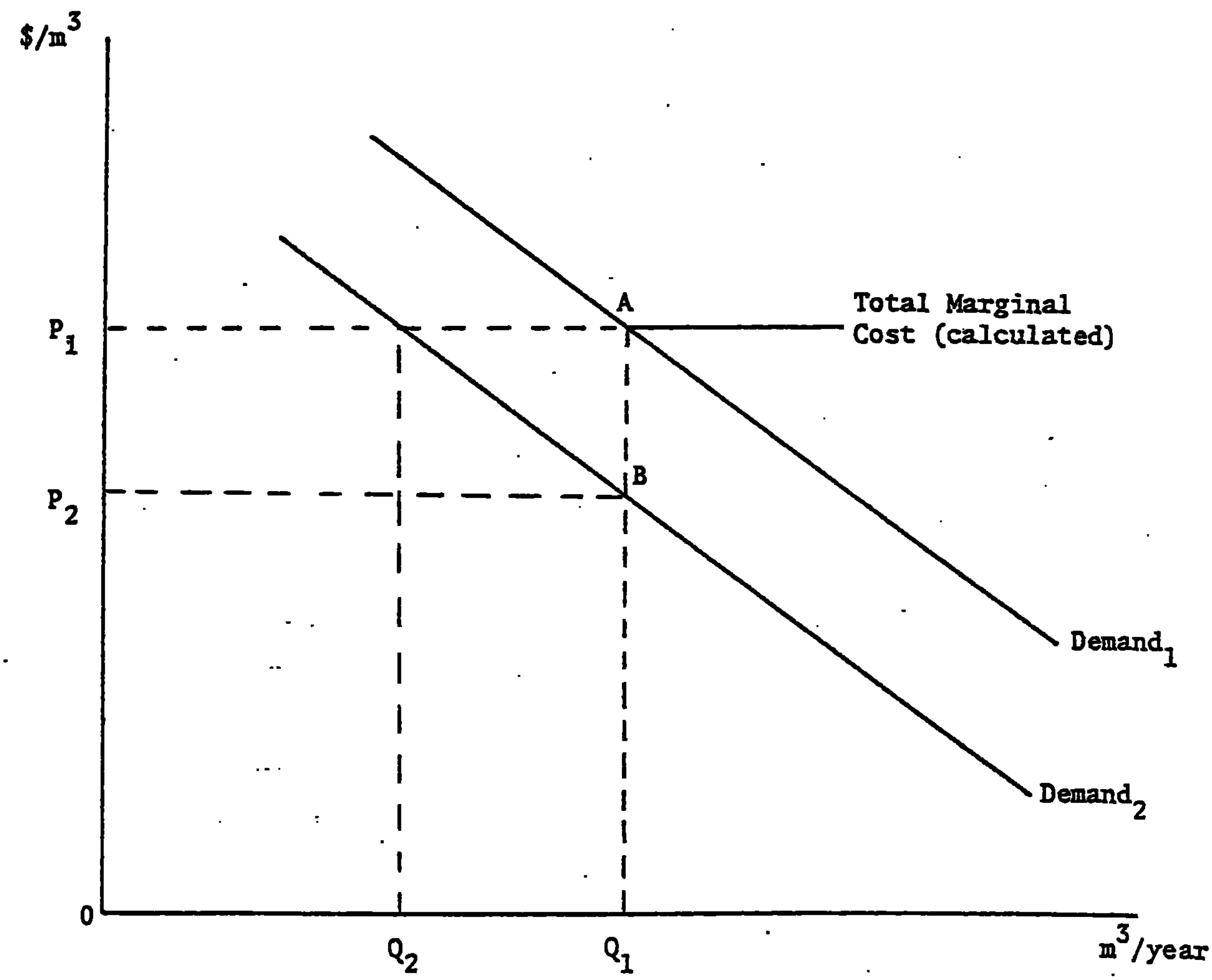
Another example will further illustrate our reasoning. The use of system capacity by a permanent increase in use is analogous to the use of an inventory of raw materials in a production process. If output or use occurs today, the opportunity cost of the use of the raw materials does not occur today. However, the use today results in the inventory having to be replenished sooner than planned. Hence, the use of the inventory today is not without its opportunity cost. It is this future or "displaced" opportunity cost that must be computed as of today, the time when it is caused, if prices of the goods produced are to reflect the real costs of the resources used to produce them. Our marginal cost concept is designed specifically for measuring these "displaced" opportunity costs.

Before computing the marginal cost, it is important to recognize that the total marginal cost, calculated by the method outlined above, may not be the relevant total marginal cost for our benefit-cost model. If, as a result of an original overinvestment in capacity or falling demands, a water utility has capacity that is larger than the efficient level, then the calculated total marginal cost will exceed the relevant total marginal cost.

We illustrate the existence of a divergence between the calculated and relevant marginal cost by evaluating costs in the case where water demands are falling (see Figure 3.1). We begin by observing magnitudes in year one: the current price is OP_1; the currend demand function is $Demand_1$; the current water use and capacity is OQ_1; and the calculated total marginal cost is Q_1A per m^3. If the demand function is falling and is equal to $Demand_2$ in year two, then the calculated total marginal cost exceeds the relevant marginal cost.

The reason for this divergence between the calculated and relevant marginal costs is because a price set at the calculated marginal cost (OP_1) would cause the water use to fall to CQ_2 in year two. Since this use level is below the use level where demand equals existing capacity (OQ_1), waste occurs. Waste can be eliminated by simply reducing the price to OP_2, a

Figure 4.1. Calculated and Relevant Marginal Costs



level that will equate use and capacity in year two. In this example, therefore, the relevant marginal cost is QlB, which is equal to the price level that will equate use to capacity in year two.

The relevant marginal cost is equal to the calculated one, if a price set at the calculated marginal cost equates use with new capacity. If a price set at the calculated marginal cost level causes use to fall below existing capacity, then the relevant marginal cost is not equal to the calculated one. In this last case, the relevant marginal cost is below the calculated one, and is equal to the level at which a price set equal to the relevant marginal cost would equate use with existing capacity. The rule, therefore, for determining the relevant marginal cost is that the relevant marginal cost is equal to the calculated one, unless the calculated one is at a level that exceeds the price that would equate use with existing capacity. If this latter situation exists, then the relevant marginal cost will be lower than the calculated one, and will be equal to the price that equates use and existing capacity. Situations that will cause the calculated marginal cost to exceed the relevant one will occur when demand is falling, per our example, or when the original capacity is too large.

On the Measurement of Marginal Cost

In this section, we use our definition of marginal cost to measure the marginal cost of water for Perth, Western Australia.

Perth, Western Australia[1]- Perth is a rapidly growing city. For example, between 1946 and 1975 the number of water accounts or connections

[1]Note that we will use Perth for purposes of applying our benefit-cost model to various conservation programs (see Chapters 6 and 7). Also, note that, unless stated otherwise, all of our analyses will consider "normal" conditions. That is, all water use, water supply and cost calculations are made on the basis of average (mean) conditions. These are appropriate for all long-term analyses

increased from 96,000 to 245,000. Perth is located on Australia's West Coast at a latitude of 32°S. Its climate includes wet winters and dry summers. Most residents live in detached, single-family dwellings. Suburban sprawl is a common feature, with the density of development being 8.5 dwellings per gross residential hectare.

In 1976 the total water produced was distributed to the following user classes: (1) metered residential in-house use (20 percent), (2) metered residential sprinkling (outdoor) use (36 percent), (3) metered non-residential use (15 percent), (4) unmetered use (14 percent) and leakage (15 percent). In addition to this distribution among user classes, it is of importance to note that 73 percent of the annual water produced occurred in the summer period (November-April).

<u>Water Use and Investment Program</u> - The first step to implement our definition of marginal cost is the preparation of a water use forecast. Table 4.1 represents the forecast of water use for Perth. This forecast is based on the assumption that the policy variables controlled by the utility, such as price, will remain constant (in real terms) over the next 20 years. This forecast is, therefore, a requirements forecast. The important elements of the forecast, for purposes of marginal cost analysis, are the permanent increments in annual use (ΔQ_A), summer use (ΔQ_S) and winter use (ΔQ_W). It is these increments in use that determine the schedule for investments in supply that are strictly a function of water use.

The next step in our analysis is to forecast the investments that are required to meet the growth in water use. Once the water use forecast has been constructed, we sequence and schedule the projects that will meet the requirements in the least costly manner. These are summarized in Table 4.2.

Table 4.1 Annual Water Use and Connections

Year	Q_A	ΔQ_A	Q_S	ΔQ_S	Q_W	ΔQ_W	r	C
1976	193.0		140.9		52.1			254.1
		8.2		6.0		2.2	.042	
1977	201.2		146.9		54.3			263.6
		9.1		6.6		2.5	.046	
1978	210.3		153.5		56.8			274.1
		9.2		6.7		2.5	.043	
1979	219.5		160.2		59.3			284.8
		9.7		7.1		2.6	.045	
1980	229.2		167.3		61.9			295.8
		9.8		7.2		2.6	.042	
1981	239.0		174.5		64.5			307.0
		10.1		7.3		2.8	.043	
1982	249.1		181.8		67.3			318.3
		10.3		7.6		2.7	.041	
1983	259.4		189.4		70.0			229.8
		10.3		7.5		2.8	.040	
1984	269.7		196.9		72.8			341.3
		8.2		6.0		2.2	.030	
1985	277.9		202.9		75.0			351.5
		8.4		6.1		2.3	.030	
1986	286.3		209.0		77.3			362.1
		8.8		6.4		2.4	.031	
1987	295.1		215.4		79.7			373.0
		9.0		6.6		2.4	.031	
1988	304.1		222.0		82.1			384.1
		9.3		6.8		2.5	.030	
1989	313.4		228.8		84.6			395.7
		9.6		7.0		2.6	.031	
1990	323.0		235.8		87.2			407.5
		9.9		7.2		2.7	.030	
1991	332.9		243.0		89.9			419.8
		10.1		7.4		2.7	.031	
1992	343.0		250.4		92.6			432.4
		10.5		7.7		2.8	.030	
1993	353.5		258.1		95.4			445.3
		10.8		7.8		3.0	.031	
1994	364.3		265.9		98.4			458.7
		11.0		8.1		2.9	.030	
1995	375.3		274.0		101.3			472.4
		11.6		8.4		3.2	.031	

Notes: continued ....

Table 4.2 Planned System Investments

Year	I_A	I_S	I_W
1976	$ 7.94	$ 1.62	$ 6.32
1977	6.54	0.86	5.68
1978	4.98	2.97	2.01
1979	9.16	3.84	5.32
1980	8.28	2.80	5.48
1981	4.28	3.01	1.27
1982	5.92	2.46	3.46
1983	7.30	2.22	5.08
1984	7.13	1.90	5.23
1985	6.70	1.54	5.16
1986	8.30	2.45	5.85
1987	10.68	3.40	7.28
1988	21.41	3.79	17.62
1989	18.85	3.24	15.61
1990	13.16	2.05	11.11
1991	24.05	2.85	21.20
1992	18.96	3.10	15.86
1993	12.49	1.43	11.06
1994	12.50	1.50	11.00
1995	13.50	2.50	11.00

Notes: continued ....

Notes: (for Table 4.1)

1. Q_A = Annual water use in $m^3 \times 10^6$
2. ΔQ_A = Change in annual water in $m^3 \times 10^6$
3. Q_S = Summer water use in $m^3 \times 10^6$ (November - April).
4. ΔQ_S = Change in summer water use in $m^3 \times 10^6$
5. Q_W = Winter water use in $m^3 \times 10^6$ (May - October)
6. ΔQ_W = Change in winter water use in $m^3 \times 10^6$
7. r = Annual rate of change in water use
8. C = Number of connections or clients.

Notes: (for Table 4.2)

1. Planned system investments are only those components that are strictly a function of water use as reflected in Table 4.1. These include: source works, trunk and transmission mains, treatment plants and service reservoirs.
2. All costs are in 1976 prices X 10^6.
3. I_A = Total investment to meet growth in annual use (includes all investments noted in 1).
4. I_S = Total investment to meet growth in summer water use (includes trunk mains, treatment plants and service reservoirs).
5. I_W = Total investment required to meet growth in winter and base watch use (average day rate). This includes source works (reservoirs, well fields and transmission mains.

Note that only those investments whose capacity and timing are determined strictly by changes in water use are included in Table 4.2. It is only these investments that are relevant for our analysis, since the marginal cost concept is based on the measurement of the opportunity cost of using more (or less) water.

For Perth's system, these investments include the construction of source works (both reservoirs and wells), transmission mains, treatment facilities and associated service reservoirs. Until the latter part of the 1980's, water resources of a quality similar to those currently being exploited will be developed, then ground water of a relatively low quality is scheduled for development. Although other investments are planned -- the expansion of the distribution system, expenditures for routine replacement and the upgrading of certain parts of the system -- we do not include them in Table 4.2. They do not represent an opportunity cost of water use and are not relevant for the determination of the marginal cost of water.

The scheduled investments that are relevant for marginal cost analyses can be classified in several ways. First, if we wish to compute a marginal capital cost for water use on an annual basis, we must aggregate all relevant investments scheduled for each year (see second column of Table 4.2). In this case, I_A provides the basis for computing the marginal capital cost for water use, a cost that is uniform throughout the year. Second, if we wish to compute two marginal capital costs for water use, which are differentiated by season (summer and winter), we must disaggregate the relevant investments scheduled for each year (I_A) into summer investments, I_S (see third column of Table 4.2), and winter and base investments, I_W (see fourth column of Table 4.2).

In the case of Perth, I_A consists of all investments which were mentioned previously as being a function of water use. The summer investments, I_S, include those that are designed to meet maximum day and week use, which occurs in the summer period. Trunk mains, treatment plants and associated service reservoirs are included in I_S. The winter and base investments, I_W, include all source works and associated transmission mains, since these components are designed to generate annual yield for the system.

Calculated Marginal Costs - Given our projected water use, planned investments and a real (inflation free) rate of interest of 10 percent, we are ready to calculate marginal costs for 1976. We begin by computing the total annual marginal cost (see Table 4.3). This marginal cost is uniform throughout the year. It contains two components: (1) the total annual marginal capital cost of 1976 use, which is equal to $0.47/m^3 and (2) the expected marginal running cost of 1976 use, which is equal to $0.04/m^3. Hence, the total annual marginal cost is $0.51/m^3. This marginal cost can be interpreted as the average marginal cost of 1976 use, since we have allocated all investments (I_A) over the annual permanent increment in 1976 use (ΔQ_A).

Note that we have used a ten-year horizon for purposes of computing marginal cost. Given our ability to forecast water use and related investments, we believe that a ten-year horizon is the most appropriate one for our computations. For purposes of computing marginal cost, therefore, we recommend that a ten-year rolling plan for water use and investments be formulated in each year. For computations in 1976, this would result in a forecast from 1976-1985, and for 1977, we would revise our forecasts to include the period 1977-1986. The values for the period 1977-1986 may not necessarily, therefore, be the same as those presented in Tables 4.1 and 4.2 since we will have had one more year's experience and an opportunity to reformulate our forecasts.

Table 4.3 Total Annual Marginal Cost Calculations

Year	1976 Present Worth of I_A with Permanent Increment in Use	1976 Present Worth of I_A without Permanent Increment in Use	Change in Present Worth
1976	$ 7.22	$	$ + 7.22
1977	5.40	6.56	- 1.16
1978	3.74	4.92	- 1.18
1979	6.25	3.40	+ 2.85
1980	5.14	5.68	- 0.54
1981	2.42	4.67	- 2.25
1982	3.04	2.19	+ 0.85
1983	3.41	2.76	+ 0.65
1984	3.03	3.09	- 0.06
1985	2.58	2.75	- 0.17
1986		2.35	- 2.35
Total	42.23	38.37	+ 3.86

(1) Total Change in 1976 Present Worth = $ 3.86×10^6

(2) Permanent Increment in Use (ΔQ_A) = $8.2\ m^3 \times 10^6$

(3) Total Annual Marginal Capital Cost of 1976 Use = (1)/(2) = $ $0.47/m^3$

(4) Marginal Running Cost of 1976 Use = $ $0.04/m^3$

(5) Total Annual Marginal Cost of 1976 Use = (3)+(4) = $0.51/m^3$

Notes: 1. Present Worth is computed by using a real (inflation apart) discount rate of 10%. For estimates of real rates, see: (Hanke and Anwyll, 1980).

2. The marginal running cost is calculated by dividing the annual purification power and pumping costs by the total water use.

For some purposes the total annual marginal cost calculations may be too "crude" a measure (Hanke, 1975). Our next set of marginal cost calculations avoids some of this "crudeness" by focusing in more detail on the nature of marginal costs within the year 1976. Instead of averaging the marginal costs over the entire year, we break the year into two seasons: the winter season (May-October) and the summer season (November-April). The purpose of this division is to identify forward-looking or marginal costs with more precision.

We know that in Perth, summer water use requires relatively more investments in supply than does winter water use. Seasonally differentiated marginal cost colculations allow us to reflect these cost differentials. We begin by computing what are defined as winter and base marginal costs (see Table 4.4). To do this, we allocate I_W investments, which are the investments required or designed at rates not to exceed the average day use, over the annual increment in use for 1976. This yields a winter and base marginal capital cost of 1976 use of \$0.31/m^3. To obtain the total winter and base marginal cost of 1976 use, we must add to the \$0.31/m^3 figure the marginal running cost of \$0.04/m^3. This yields a total of \$0.35/m^3.

The next step is to compute the summer marginal cost (see Table 4.5). To do this we allocate I_S investments, which are the investments required or designed at rates that exceed the average day use (for example, maximum day and hour rates) over the increment in 1976 summer use. This yields a summer marginal capital cost of \$0.22/m^3. To obtain the total summer marginal capital cost, we add the base marginal capital cost of \$0.31/m^3, which represents the marginal cost of serving average day demands. This yields a total summer marginal capital cost of \$0.53/m^3. By adding the marginal running cost of \$0.04/m^3 to this figure, we obtain a summer marginal cost of 1976 use of \$0.57/m^3.

Table 4.4 Winter and Base Marginal Cost Calculations

Year	1976 Present Worth of I_W with Permanent Increment in Use	1976 Present Worth of I_W without Perment Increment in Use	Change in Present Worth
1976	$ 5.75	$	$ + 5.75
1977	4.69	5.22	- 0.53
1978	1.51	4.27	- 2.76
1979	3.63	1.37	+ 2.26
1980	3.40	3.30	+ 0.10
1981	0.72	3.09	- 2.37
1982	1.78	0.65	+ 1.13
1983	2.37	1.61	+ 0.76
1984	2.22	2.15	+ 0.07
1985	1.99	2.02	- 0.03
1986		1.81	- 1.81
	Total 28.06	25.49	2.57

(1) Total Change in 1976 Present Worth = $ 2.57×10^6

(2) Permanent Increment in Use (ΔQ_A) = $8.2\ m^3 \times 10^6$

(3) Winter and Base Marginal Capital Costs of 1976 Use = (1)/(2) = $ $0.31/m^3$

(4) Marginal Running Cost of 1976 Use = $ $0.04/m^3$

(5) Total Winter and Base Marginal Cost of 1976 Use = (3)+(4) = $ $0.35/m^3$

Notes: 1. Present worth is computed by using a real (inflation apart) discount rate of 10%. For estimates of real rates, see: (Hanke and Anwyll, 1980).

2. The marginal running cost is calculated by dividing the annual purification, power and pumping costs by total water use.

3. Note that I_W represents the capital required to meet growth in average daily demands (Q_A/365); therefore, the permanent increment in use for our calculations in this table is the annual figure ΔQ_A, and the marginal cost is for all winter use and the non-peaking or base part of the summer use.

Table 4.5 Summer Marginal Cost Calculations

Year	1976 Present Worth of I_S with Permanent Increment in Use	1976 Present Worth of I_S without Permanent Increment in Use	Change in Present Worth
1976	$ 1.47	$	$ + 1.47
1977	0.71	1.34	- 0.63
1978	2.23	0.65	+ 1.58
1979	2.62	2.03	+ 0.59
1980	1.74	2.38	- 0.64
1981	1.70	1.58	+ 0.12
1982	1.26	1.54	- 0.28
1983	1.04	1.15	- 0.11
1984	0.81	0.94	- 0.13
1985	0.59	0.73	- 0.14
1986		0.54	- 0.54
	Total 14.17	12.88	1.29

(1) Total Change in 1976 Present Worth = $\$1.29 \times 10^6$

(2) Permanent Increment in Use (ΔQ_S) = $6.0\ m^3 \times 10^6$

(3) Total Summer Marginal Capital Cost of 1976 Use = (1)/(2) = $ 0.22/m^3 + (3) from Table 4.4 ($ 0.31/m^3) = $ 0.53/m^3

(4) Marginal Running Cost of 1976 Use = $ 0.04/m^3

(5) Total Summer Marginal Cost of 1976 Use = (3)+(4) = $ 0.57/m^3

Notes: 1. Present worth is computed by using a real (inflation apart) discount rate of 10%. For estimates of real rates, see: (Hanke and Anwyll, 1980).

2. The marginal running cost is calcualted by dividing the annual purification, power and pumping costs by total water use.

3. The marginal winter and base capital cost, without I_S, has been computed on an annual basis (see Table 4.4). To obtain the total summer marginal capital cost, we must add the marginal base capital cost ($ 0.31/m^3) to the marginal capital cost of summer marginal capital cost ($ 0.22(m^3), which is computed on the basis of I_S alone, to obtain the total summer marginal cost of 1976 use of $ 0.53/m^3. For a more complete treatment of this topic, see: (Hanke, February 1981).

<u>The Relevant Marginal Costs</u> - In 1976 the price which balances demands with system capacity is $0.106/m^3. This price is charged for all water used during the year, and is much lower than the marginal costs which we have calculated for 1976 use. Since this price balances demands with supplies, it is the relevant marginal cost for 1976 use. The reason that it is lower than the calculated marginal costs is because Perth has used the traditional approach to water supply planning. That is, they have forecast requirements and have built capacity to meet them. As a result, the existing capacity is too large, when viewed from an economic perspective.

We estimate the price elasticity coefficients for water use to be -0.24, -0.29 and -0.10 for annual, summer and winter periods, respectively. Therefore, if we charge prices equal to our calculated marginal costs (on either a uniform annual basis of $0.51/m^3 or a summer-winter basis of $0.57/m^3 for summer water and $0.35/m^3 for winter water), water use would be less than the 1976 levels, and idle capacity would result. To compute the relevant marginal cost under these conditions, we must simulate the prices which would balance demands with 1976 use levels (our target). These simulated prices are equal to the relevant marginal costs for each year, until they reach the level of our calculated marginal cost. At this point, new investment in supply capacity is finally justified, and the calculated marginal cost becomes the relevant marginal cost.

We have computed the relevant marginal costs for annual and the summer-winter season. These are presented in Tables 4.6, 4.7 and 4.8. These computations are of particular importance for our analyses of water conservation in Perth, since our benefit-cost model always requires that we use relevant marginal costs, when making benefit calculations. It is of interest to note

Table 4.6 Simulated Relevant Annual Marginal Costs

Year	Q_A	Relevant Marginal Cost
1976	193.0	\$ 0.106
1977	193.3	0.125
1978	193.5	0.150
1979	193.7	0.178
1980	193.9	0.213

Notes: 1. Q_A in $m^3 \times 10^6$

2. Relevant Marginal Cost in $\$/m^3$

3. Growth in yearly use is based on values for r in Table 4.1.

4. Elasticity for Q_A = e = 0.24

5. The values r and e are used in the model for integrating demand and supply which is presented in Chapter 5.

Table 4.7 Simulated Relevant Summer Marginal Costs

Year	Q_S	"Relevant" Marginal Cost
1976	140.9	$ 0.106
1977	141.0	0.122
1978	141.1	0.142
1979	141.1	0.164
1980	141.3	0.190

Notes:

1. Q_S in $m^3 \times 10^6$
2. Relevant Marginal Cost in $\$/m^3$
3. Growth in yearly use is based on values for r in Table 4.1
4. Elasticity for $Q_S = e = -0.29$
5. The values of r and e are used in the model for integrating demand and supply which is presented in Chapter 5

Table 4.8 Simulated Relevant Winter Marginal Costs

Year	Q_W	"Relevant" Marginal Cost
1976	52.1	$ 0.106
1977	52.1	0.159
1978	52.1	0.247
1979	52.5	0.350
1980	54.9	0.350

Notes:
1. Q_W in $m^3 \times 10^6$
2. Relevant Marginal Cost in $/$m^3$
3. Growth in yearly use is based on values for r in Table 4.1
4. Elasticity for Q_W = e = . 0.1
5. The values fo r and e are used in the model for integrating demand and supply which is presented in Chapter 5

that from 1976-1980 the relevant marginal costs, when computed on an annual basis, are less than the calculated marginal costs. This indicates that no increment in investment is justified during this period. By reviewing Tables 4.7 and 4.8, we also observe a divergence between calculated and relevant marginal costs, when we divide water use and costs into summer-winter seasons. However, if we use the summer-winter division, investments are justified for the winter and base period in 1979 (see Table 4.8). The relative rapid rise in relevant marginal costs in the winter results from the fact that water use in this period is relatively insensitive to price changes. Hence, prices must be raised more rapidly in the winter than in the summer to hold water use to the 1976 target levels.

Chapter 5

ON DEMAND-SUPPLY INTEGRATION

For purposes of calculting water use without and with conservation, Q in our benefit-cost model, simulating the relevant marginal costs (Tables 4.6-4.8) and predicting the level of any conservation policy which will balance demands with supplies, it is convenient to develop a demand-supply model.

The Demand-Supply Model[1]

As we have shown in Chapter 3, there are numerous determinants of the demand for water which can be controlled by water utilities. We shall call these determinants policy parameters. As we increase the level of any of these policy parameters, the level of water use or production will be reduced.

The sensitivity of water use to changes in the real level of a policy parameter is its elasticity. One relationship between water use and the policy parameter can be expressed as follows:

$$Q = a\,P^{e}, \tag{5.1}$$

where Q = the quantity of water use, P = the real value of the policy parameter, a = a constant, and e = the policy parameters' elasticity, which is always negative.

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[1]A program that allows us to implement, on a programable calculator, the concepts presented in this chapter is presented in Appendix 1. The policy parameter which allows us to integrate demand and supply is price.

Equation 5.1, the policy-water use equation, is the basic equation for integrating demand and supply. To predict water use over time, however, we need to know how variables, other than the policy parameter, affect water use. In our model we can accommodate this by the use of the following equation:

$$(5.2) \qquad Q_2 = r\, Q_1,$$

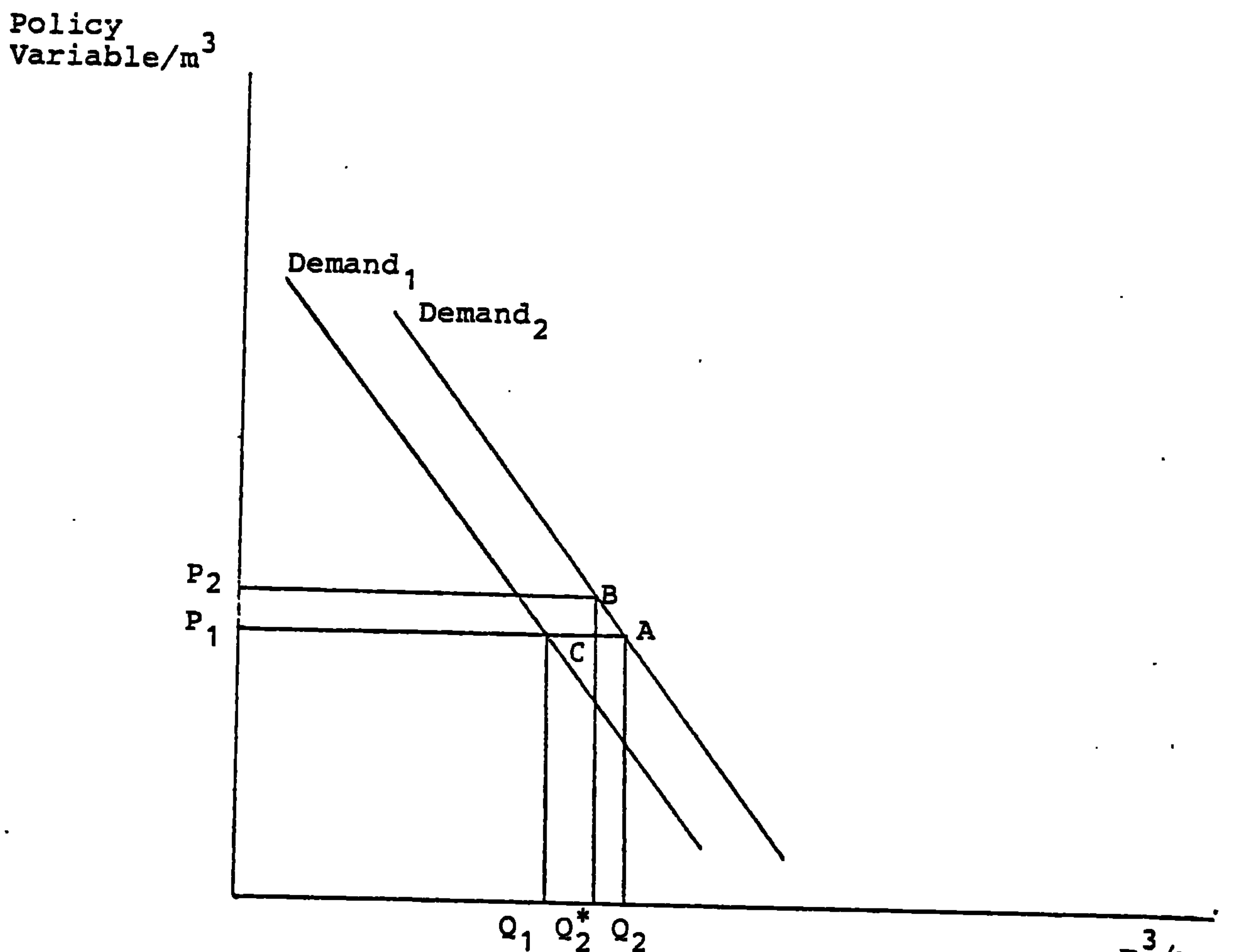
where Q_2 = water use in period two, when the real value of the policy parameter in period two is equal to that in period one; r = the growth rate in water use from period one to two plus 1.0, when the real value of the policy parameter in period two is equal to that in period one; and Q_1 = water use in period one. If the real value of the policy parameter changes from period one to period two, Equation 5.3 is required to determine the final equilibrium water use in period two:

$$(5.3) \qquad Q_2^* = \left(\frac{P_2}{P_1}\right)^e Q_2,$$

where Q_2^* = water use in period two, when the real value of $P_2 \neq P_1$; P_2 = the real value of the policy parameter in period two; P_1 = the real value of the policy parameter in period one; and e = the policy parameters' elasticity.

The operation of Equations 5.2 and 5.3 can be seen by reference to Figure 5.1. The initial level for our policy parameter is P_1. With this policy and the demand function for period one ($Demand_1$), we observe that the quantity of water demanded in year one is Q_1. To predict water use in year two, with no change in the real value of the policy parameter, we use Equation 5.2. By multiplying Q_1 by r, we obtain Q_2. This value, Q_2, is read off the demand function that exists in period two ($Demand_2$). To

Figure 5.1 Predicting Water Use



predict the impact of an increase in the value of the real policy parameter in period two, we apply Equation 5.3. This operation causes us to move leftward along the demand curve ($Demand_2$) in period two (from A to B), and results in a final prediction of water use in period two of Q_2^*. This final prediction takes into account both the "natural" growth, r, and the elasticity impact of increasing the real value of the policy from P_1 to P_2.

For any level of supply, therefore, we can use our model to change the value of a policy parameter to balance demand and supply. To illustrate this point, the reader is referred to Figure 5.6 of the last chapter. If we wish to constrain water use (demand) to the level OQ_A, we must set the prices so that they are equal to the simulated marginal cost for each year. We will illustrate further applications of this model in Chapters 6 and 7, where we discuss price and nonprice rationing methods for water conservation.

Chapter 6

RATIONING BY PRICE

Water can be rationed and demands balanced with supplies by using two different types of policy parameters: price and nonprice policies. In this chapter we discuss the use of price as a conservation device (see also: Hanke, 1972; Hanke, 1978; and Hanke, February 1981).

Prices and Benefit-Cost Analysis

Our benefit-cost model allows us to evaluate whether increases in prices are an economic conservation policy. We recall that our benefit-cost model (Equation 2.3) is

$$Q \cdot MC \geq U + E + F, \qquad (6.1)$$

where Q = reduction in use resulting from a conservation policy, MC = relevant marginal cost, U = resource cost to the utility of adopting a conservation policy, E = resource cost to the consumers of adopting a conservation policy and F = the value of "useful" consumption foregone. Moreover, recall that the left-hand side of this equation equals the benefits from conservation and the right-hand side equals the costs. Hence, to achieve maximum net benefits, we should apply a conservation policy as long as $Q \cdot MC \geq U + E + F$.

If we are using price to balance demands and supplies, we know that a price set equal to the marginal cost will lead to an efficient allocation of resources and a maximization of net benefits in the context of benefit-cost analysis.[1] We demonstrate this fact by the use of our benefit-cost

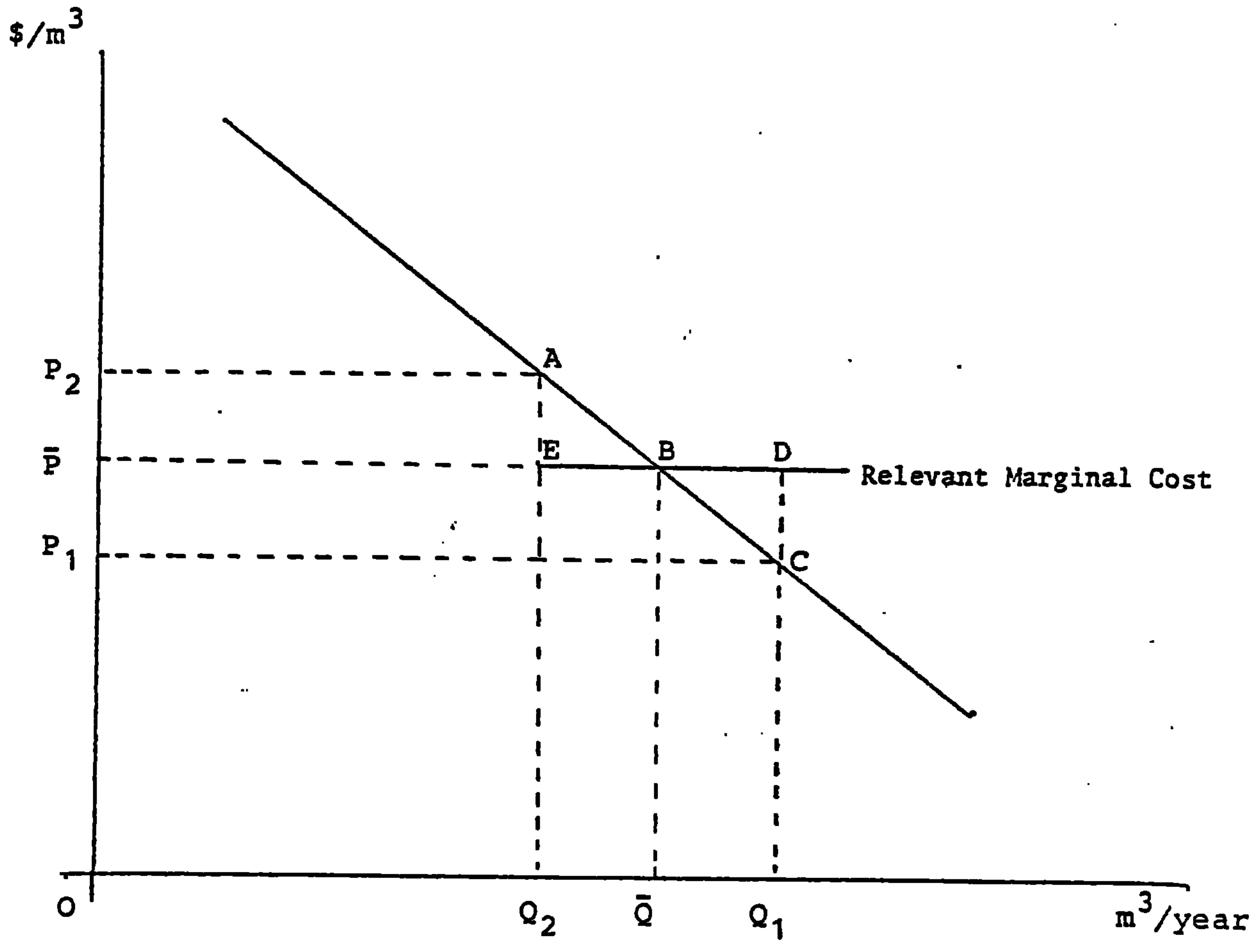
[1] For this demonstration to be always true, we must assume that E and U equal zero, which is a reasonable assumption for price increases for metered customers.

model. Annual marginal costs for any year are constant, given our approach to marginal cost analysis. Marginal benefits, as represented by the demand function, are always negatively related to water use. We also know that marginal benefits equal the marginal cost where the two functions intersect (see Figure 6.1). Therefore, we know that the incremental benefits generated by increasing price from a level below the marginal cost to the marginal cost level must exceed the costs of such a change. In Figure 6.1, if price is P_1 and use is Q_1, a small price increase will generate benefits of Q_1D and costs of Q_1C per m^3. The benefits of conservation will continue to exceed costs until we reach a price of $\overline{P}$ and use of $\overline{Q}$. At this level, price will equal the marginal cost, and the price increase from P_1 to $\overline{P}$ will have increased net benefits by the area BDC. Net benefits from increasing price will be at a maximum at this price ($\overline{P}$). Further increases will add to the costs of conservation, represented by "useful" consumption foregone, by more than they add to the benefits. For example, a price change from $\overline{P}$ to P_2 will generate net costs equal to the area AEB. Hence, in all cases a price set equal to the marginal cost will maximize net benefits, and any deviation in price from the marginal cost will be wasteful.

On the Benefits and Costs of Marginal Cost Pricing in Perth

Uniform Annual Price - We apply by using data from Perth, Western Australia for the year 1977, the economic principles of pricing outlined in the preceding section. Our purpose is to perform a benefit-cost analysis for marginal cost pricing as a conservation device. We wish to evaluate the economic consequences of increasing the level of prices to the marginal cost (with conservation), rather than leaving the prices at their existing real level (without conservation). We begin our analysis by evaluating uniform marginal cost pricing, with the marginal cost and prices being determined on an annual basis. In this case, the same price is changed for all water used throughout the year.

Figure 6.1 Pricing Policies and Benefits and Costs



The first step to evaluate the benefits and costs of marginal cost pricing for Perth is to determine the marginal cost in 1977. This computation has been made by simulating the relevant marginal costs. The results are displayed in Table 4.6. For 1977, the marginal cost is $\$0.125/m^3$ (see the second column of Table 6.1). Recall that since the existing system capacity is too large, the relevant marginal cost of $\$0.125/m^3$ is less than the calculated marginal cost of $\$0.51/m_3$. Also, note that the relevant marginal cost is the one that is necessary, so that a price set equal to it will approximately balance demand with the target capacity of 193.0 $m^3 \times 10^6$.

The next step is to compute the change in water use resulting from the conservation increasing the price from $\$0.106/m^3$ to a price set at the marginal cost of $\$0.125/m^3$. We must obtain a value for Q. In this case, water use without a price increase would equal 201.2 $m^3 \times 10^6$, and would exceed our target capacity. While with a price increase to the relevant marginal cost, water use would be reduced to 193.3 $m^3 \times 10^6$. Hence, Q is equal to 7.9 $m^3 \times 10^6$ (201.2 $m^3 \times 10^6$ - 193.3 $m^3 \times 10^6$).

To compute the change in benefits which result from increasing the price to the relevant marginal cost, we must multiply Q times MC. In this case, the change-in benefits are equal to $987,500 (see the first three columns of Table 6.1).

We now turn to the computation of the costs of this conservation program. We assume that both U and E will be equal to zero for price increases. Therefore, the value of "useful" consumption foregone, F, becomes the only cost associated with increasing the price. To compute F, we compute the value of the area under the demand function between 193.3 $m^3 \times 10^6$ and 201.2 $m^3 \times 10^6$ by using the techniques presented in the last section of Chapter 3. This calculation yields a figure for "useful" foregone consumption of $912,450.

Table 6.1 Benefits and Costs of Price Rationing

Reduced Use ($m^3 \times 10^6$)	Marginal Cost ($)	Change in Benefits ($)	Water Utility Costs ($)	Water Consumer Costs ($)	Value of "Useful" Consumption Foregone ($)	Change in Costs ($)	Net Benefits ($)
Q	MC	Q · MC	U	E	F	U + E + F	[Q·MC] - [U+E+F]
7.9	0.125	987,500	0	0	912,450	912,450	75,050

Notes:

1. Q = 201.2 - 193.3 = 7.9 (see Tables 4.1 and 4.6)

2. For MC, see Table 4.6

3. F is computed by using the technique presented in Chapter 3. With a price elasticity of -0.24, F is equal to $0.106 X 7,900,000 = $837,400, plus ($0.125-$0.106) = $0.019 X 7,900,000 X 0.5 = $75,050, or a total of $912,450. This amount can be visualized by viewing Figure 5.1. The amount is analytically represented by the following: $(OP_1) \times (Q_2-Q_2^*) = CAQ_2Q_2^*$, which is $837,400 for Perth; plus $(P_2-P_1) \times (B-C) \times 0.5 = ABC$, which is $75,050 for Perth; or a total of $BAQ_2Q_2^*$, which is $912,450 for Perth.

As our theoretical demonstration showed, a price increase to the marginal cost level will always generate net benefits. In the case of Perth for 1977, these benefits are $75,050.

Summer-Winter Prices - It can be demonstrated that, when marginal costs are different in the summer season than in the winter season, seasonally differentiated prices set separately at the summer and winter marginal costs yield net benefits, when compared with a policy of setting prices on an annual basis at the annual marginal cost (Hanke, 1971). However, this demonstration is one of the general principle. It does not take into account the increased administrative costs associated with switching from uniform annual prices to summer-winter prices. Therefore, it is necessary to use benefit-cost analysis to determine whether an annual uniform or seasonsl pricing structure is the most desirable.

For Perth in 1977, it is important to remember that the system is not in economic equilibrium; capacity is too large. Hence, if prices are set at the level of the calculated marginal costs, water use would be reduced to a level well below existing system capacity. This would result in unused capacity and economic waste. Therefore, we simulated demands and supplies, to determine the relevant marginal costs (Tables 4.6, 4.7 and 4.8). These were lower than the calculated marginal costs. Moreover, given the fact that the absolute value of the price elasticity is less in the winter (-0.1) than in the summer (-0.29), smaller summer price increases are required to constrain summer use to its original target level than is the case for winter prices and use. The result, in this ease, is a situation in which the relevant marginal costs for the winter (the off-peak) season are higher than during the summer (peak) season. This situation reverses itself after the system comes into an economic equilbrium and capacity is adjusted to its proper level. As we would normally expect, when the system is in an economic equilibrium, the calculated marginal costs are equal to the relevant costs, and they are higher in the summer (peak) season than in the winter (off-peak) season.

With this background information, we now evaluate the benefits and costs of switching from the current uniform pricing system to a summer-winter system in which the summer and winter prices are set at their respective relevant marginal costs for 1977. Using the same approach as we employed for uniform prices, we generate benefit-cost data. These are presented in Table 6.2. The result of using seasonal prices is a net loss of $394,500 for 1977. Losses result because the seasonal pricing structure would require the utility to read meters quarterly, instead of annually, so that the utility could render seasonal bills. This additional meter reading results in an increase in the utility's costs of $500,000.

We should also mention that a switch to summer-winter prices would require the winter prices to exceed those for the summer, during the period when the system was out of economic equilibrium. Since the summer-winter marginal cost relationship would change when the system come into equilibrium, the summer-winter price relationship would also change. These changes, would no doubt, be difficult to justify to consumers. Hence, they would require yet more expenditures for public education, and would increase U above the value which we have estimated.

Concluding Observations on Pricing

Our analysis allows us to make the following observations: (1) In cases where meter reading and billing expenses remain constant, we know

Table 6.2 Benefits and Costs of Seasonal Price Rationing

Season	Reduced Use ($m^3 \times 10^6$)	Marginal Costs (S)	Change in Benefits ($)	Water Utility Costs ($)	Water Consumer Costs ($)	Value of "Useful" Consumption Foregone ($)	Change in Costs (S)	Net Benefits ($)
	Q	MC	Q · MC	U	E	F	U + E + F	[Q·MC] - [U+E+F]
Summer	5.9	0.122	719,800			672,600		
Winter	2.2	0.159	349,800			291,500		
Total	8.1		1,069,600	500,000	0	964,100	1,464,100	- 394,500

Notes:

1. The input data required to construct this table are contained in Tables 4.1, 4.7 and 4.8.
2. U has been estimated on the basis of costs required to read water meters four times per year with seasonal prices, rather than the current practice of annual readings with uniform prices.

that a switch from uniform annual prices set below marginal cost to a uniform annual price set equal to the marginal cost will always generate net benefits. (Note that this is also true for a switch from uniform annual prices set above the marginal cost to a uniform annual price set equal to the marginal cost.) This means that formal benefit-cost analysis is not required in this case. However, the analysis may be desirable to demonstrate to regulators the gains associated with this change in pricing policy. If the utility costs are increased by making the switch to uniform annual prices set at the marginal cost, we do not know if the switch will be desirable *a priori*. Hence a formal benefit-cost calculation must be performed to determine the desirability of the change in policy.

(2) Since additional meter reading and billing expenses, as well as expenditures for public education, will usually be required when switching from uniform annual prices to summer-winter prices set at marginal costs, a formal benefit-cost analysis of the policy change will always be required.

Chapter 7

RATIONING WITH AND WITHOUT NON-PRICE CONSERVATION POLICIES

In Chapter 3 we reviewed several nonprice methods of water conservation, These included: leak detection and control, water meters and water use restrictions. Since these policies are not necessarily associated with marginal cost pricing, we must evaluate the benefits and costs of each to determine its desirability. This chapter is devoted to this task. Again, we use Perth, Western Australia for our analysis.

Leak Detection and Control

Our benefit-cost model can be used for the purpose of evaluating waste control programs (Hanke, April 30, 1981). Those programs reduce leakage in water system. They, therefore, reduce the quantity of water that a water company must produce, without reducing the quantity of water that consumers use. Since this type of conservation program does not directly affect consumers, two variables, E and F, can be eliminated from our model. The appropriate decision rule for evaluating the desirability of waste control programs, therefore, becomes:

$$Q \cdot MC \geq U \quad (7.1)$$

Equation 7.1 shows us that waste control is economic if the change in benefits, which is the product of the quantity of water saved by repairing system leaks (Q) and the marginal cost of water (MC), exceeds or is equal to the change in the costs of detecting and repairing leaks (U).

For Perth, leakage is 15 percent of total production, and is equal to 30.2 $m^3 \times 10^6$ in 1977. We evaluate the benefits and costs of two waste control policies. The first policy (Option I) would reduce system leakage to 7.5 percent of the total production or 15.1 $m^3 \times 10^6$, and the second policy (Option II) would reduce leakage to 5 percent of the total production or 10.1 $m^3 \times 10^6$.

To compute the benefits of these two options, we evaluate the left-hand side of Equation 7.1. Reduced water production (Q) is the first variable in 7.1. Option I would yield a total reduction in production of 15.1 $m^3 \times 10^6$, while Option II would yield a reduction of 23.1 $m^3 \times 10^6$ (see Table 7.1 for a display of our results).

By multiplying the reduced water production (Q's) by the appropriate marginal cost (see Chapter 4, Table 4.6), we compute the values for change in benefits from each leakage control option. The values for the change in benefits is given in the fourth column of Table 7.1. Option I would yield $1,887,500 and Option II would yield $2,887,500 in 1977.

Next, we compute the change in the costs of detecting and repairing system leaks for both options or the right-hand side of Equation 7.1. These costs are given in the fifth column of Table 7.1. The cost of Option I would be $280,000 and of Option II would be $382,500. These estimates are based on the following assumptions:[1] (1) under both options a specialized waste control team would be established; (2) 80 percent of its costs would be for labor and the remainder capital equipment; (3) Option I would require one waste prevention worker per 10,000 dwellings; and (4) Option II would require one worker per 7,500 dwellings. It is important to realize that

[1]These assumptions are reflected in Figure 3.1, which is the production function for leak detection and control in Perth.

Table 7.1 Benefits and Costs of Waste Control

Waste Reduction Option	Reduced Leakage	Marginal Cost	Change in Benefits	Change in Costs	Net Benefits
	$Q(10^6 m^3)$	MC ($)	Q•MC ($)	U ($)	Q•MC U ($)
I 7.5% of Total Production	15.1	$0.125/m^3$	1,887,500	280,000	1,607,500
II 5% of Total Production	23.1	$0.125/m^3$	2,887,500	382,500	2,505,000

Perth's projected leakage detection costs are lower than would be expected for many other water systems. Routine capital replacement occurs now without the aid of a specialized waste control program. The primary purpose of Perth's waste control program would be to redirect capital replacement expenditures to those areas where leakage is greatest. Hence, neither Option I nor Option II would increase the level of Perth's capital replacement expenditures. Both options, however, would greatly increase the productivity of these expenditures.

By subtracting the change in costs from the change in benefits, we obtain the net benefits from waste control for both options (see column six of Table 7.1). Given our objective of maximizing net benefits and our decision rule , Option II is clearly superior to Option I. Furthermore, we should consider increasing our waste control efforts beyond those of Option II, since the incremental benefits of moving from Option I to Option II are $897,500, while the incremental costs are only $102,500. This indicates that additional net benefits could be generated by applying detection and control effort beyond Option II.

Water Meters

The installation of water meters is often considered as a water conservation policy (Hanke, February, 1982). This option does exist in Perth, since in 1977, 17,968 of its customers were not metered. This group consisted of small residential users and commercial establishments. Unmetered water use is estimated to be 14 percent of the total production or 28.2 $m^3 \times 10^6$ in 1977.

We evaluate the conservation policy of universal metering, which would require the installation of 17,968 water meters. To compute the benefits of this policy, we first evaluate the resulting reduction in water use. We predict that the metering of unmetered users will reduce their use by $9.9\ m^3 \times 10^6$ or by 35 percent. (We estimate this figure by applying a water use ratio, which is based on data presented in Chapter 3, Table 3.6). If we multiply this reduction by the marginal cost, we obtain the change in benefits (see Table 7.2).

To evaluate the change in costs associated with universal metering, we first compute the change in the water company's resource costs. These costs include the annualized costs of 17,968 new water meters and their installation as well as the increased costs of reading these meters one time per year. This annual cost is equal to $241, 342. It is displayed in the fifth column of Table 7.2.

The next cost term in our model is E. It represents the resource costs to consumers of metering. These costs are represented primarily by increased effort to repair leaks inside commercial and residential buildings and also increased time devoted to monitoring water use activities. We do not make an estimate of these costs because of a lack of data. However, it is important to realize that these costs are probably quite small (Hanke, 1970(b)).

The last cost term in our model is F, or the value of "useful" consumption which is foregone because water use is reduced by the installation of water meters. We use the techniques presented in the last section of Chapter 3 to evaluate this term. The numerical values are displayed in the seventh column of Table 7.2.

Now we are ready to compute the change in costs, U + E + F. The values for the change in costs are given in the eighth column of Table 7.2. The total change in costs for the period under study is $766,042.

Table 7.2 Benefits and Costs of Water Meters

Reduced Use	Marginal Cost	Change in Benefits	Water Company Costs	Water Consumer Costs	Value of "Useful" Consumption Foregone	Change in Costs	Net Benefits
$Q(m^3 x 10^6)$	MC($)	Q · MC($)	U($)	E($)	F($)	U + E + F	[Q·MC][U+E+F]
9.9	$0.125/m^3$	1,237,500	241,342		524,700	766,042	471,458

Notes: 1. This figure is based on the assumption that 17,968 meters were purchased at $ 55.65/meter. Annualized at 10 percent interest over seven years, the initial investment of $ 1,000,000 equals $ 205,406 per year. To obtain U, we added to this annual cost $ 35,936, which reflects extra meter reading costs.

By subtracting the change in costs from the change in benefits, we obtain the net benefits from metering. Given our objective of maximizing net benefits and our decision rule, universal metering for Perth would be an economic conservation policy, since it would generate net benefits of \$471,458 in 1977.

Water Use Restrictions

Water use restrictions are yet another conservation policy that can be evaluated by use of our benefit-cost model (Hanke, 1980(a) and Hanke, 1980(b)). In Perth, water use restrictions have only been used in the dry summer months of December, January and February. We limit our analysis of restrictions to these months. We begin by estimating the impact of restrictions on water use. To accomplish this task we use water use ratios of 86.2, 85.7 and 89.4 for the months of December, January and February, respectively (see Table 3.3). These ratios indicate the water use with restrictions, as a percent of water use without restrictions. By applying these water use ratios to water use without restrictions of 29.6, 28.0 and 27.8 $m^3 \times 10^6$ for December, January and February, respectively, we obtain use with restrictions. If we subtract these latter values from the former, we obtain values for Q in our benefit-cost model. These values are displayed in the second column of Table 7.3.

With a marginal cost of $\$0.125/m^3$ for each month, we can compute the monthly change in benefits by multiplying the values for reduced water use by the marginal costs. The results are displayed in column four of Table 7.3.

We now move to the cost side of our benefit-cost model. We assume that the costs to the utility are equal to zero. This will lead to an understatement

Table 7.3 Benefits and Costs of Water Use Restrictions

Month	Reduced Use ($m^3 \times 10^6$) Q	Marginal Costs ($) MC	Change in Benefits ($) Q·MC	Water Utility Costs ($) U	Water Consumer Costs ($) E	Value of "Useful" Consumption Foregone ($) F	Change in Costs ($) U+E+F	Net Benefits($) [Q·MC]-[U+E+F]
December	4.09	0.125	511,250			576,690		
January	4.00	0.125	500,000			572,000		
February	2.94	0.125	367,500			455,700		
Total	11.03		1,378,750	0	0	1,604,390	1,604,390	- 225,640

Notes: 1. To estimate F, we use the techniques presented in the last section of Chapter 3, with a summer price elasticity for the demand function in each month of E = - 0.29.

of the total costs of restrictions, since the utility will have to administer the restriction program. However, we have no reliable information on this cost component. Furthermore, these costs will probably be relatively small when restrictions are imposed for short durations. They will increase with the length of time that restrictions are used, since the prolonged use of restrictions will require some type of semi-permanent administrative staff for policy-making and compliance purposes.

We also assume that the customer costs (E) will be zero. Again this assumption is based on a lack of reliable data. It does not imply that these costs do not exist, since customers will have to spend more time tending to their lawn sprinkling with restrictions than without them.

The only cost element associated with restrictions that we estimate is the value of "useful" consumption foregone. To estimate the value of "useful" consumption foregone, we use the techniques presented in Chapter 3. The results of our analysis are presented in column seven of Table 7.3. It is important to realize that our estimate of F might be somewhat lower than the actual value. Our estimate of F is based on the assumption that the lowest valued uses of water will be the ones eliminated by restrictions first. Even though this is the objective of most water system planners, in reality some "high-valued" use is probably included with "low-valued" use that is restricted from the market (for a discussion, see Chapter 2). As a result, our estimate of the F values is probably too low (Hanke, 1980(b)).

Our analysis indicates that under "normal" (mean) conditions, water use restrictions would not be economic in Perth. The type of restrictions that have been and in Perth are too strong to be economic, under "normal" conditions, and conservation at the levels analyzed is wasteful.

Let us turn from "normal" supply conditions to the situation of drought conditions. In this case, "normal" capacity and cost figures (the ones we have used to this point) are not the relevant figures. During drought, effective capacity or supply is reduced, and therefore, the relevant marginal cost -- the marginal cost level at the point where demands equal to new effective capacity -- is higher than normal.[1] Therefore, the marginal value of the last unit of water available in droughts is higher, and restrictions might be economic under some drought cases. We now analyze those cases.[2]

We begin with the "normal" conditions which are represented in Table 7.3. This means that under "normal" conditions supply and demand are balanced at 29.6, 28.0 and 27.8 $m^3 \times 10^6$ for December, January and February, respectively. This balance occurs at a real price in 1976 of $\$0.106/m^3$. Although water use restrictions of the type used in Perth, are not economic as a long-term policy. We wish to analyze how serious drought must become before restrictions would be justified.

By using the "normal" conditions as a baseline or starting point, we simulate, by using our demand-supply integration model developed in Chapter 5, the relevant marginal costs that would be associated with "effective" capacity levels under drought conditions. We determine the "effective" capacity level, so that marginal costs -- those where demand is equated

[1]Note that the relevant marginal costs under drought conditions are simulated by using the demand-supply integration model presented in Chapter 5.

[2]Note we have not analyzed price, leak detection and control or water meters in the "abnormal" case, since each of them, in a practical sense is designed as a long-term policy to respond to "normal" conditions.

to the new "effective" capacity -- are just high enough to generate changes in benefits (Q • MC) which equal the change in cost figures. These simulated "effective" capacities and marginal costs are displayed in Table 7.4. Our analysis indicates that restrictions can be justified under drought conditions, when "effective" capacities in December fall from the "normal" level of 29.6 to an "effective" level of 27.3 $m^3 \times 10^6$, in January from 28.0 to 25.7 $m^3 \times 10^6$ and February from 27.8 to 24.9 $m^3 \times 10^6$. Therefore, restrictions, which are designed to meet short-term emergencies, are indeed justified under certain drought conditions, even though they are not justified under "normal" conditions.

ɔle 7.4 Benefits and Costs of Water Use Restrictions - A Break-Even Analysis

ıth	Reduced Use ($m^3 x 10^6$) Q	Marginal Costs ($) MC	Change in Bene-fits ($) Q·MC	Water Util-ity Costs ($) U	Water Con-sumer Costs ($) E	Values of "Useful" Consump-tion Foregone ($) F	Change in Costs ($) U+E+F	Net Benefits ($) [Q·MC]-[U+E+F]	"Normal" Capacity Levels (m^3 x 10^6)	Break-Even "Effective" Capacity Levels (m^3 x 10^6)
ːember	4.09	0.141/m^3	576,690			576,690	576,690	0	29.6	27.3
ıuary	4.00	0.143/m^3	572,000			572,000	572,000	0	28.0	25.7
ɔruary	2.94	0.155/m^3	456,000			455,700	455,700	300	27.8	24.9

ːes: 1. To estimate F, we use the techniques presented in the last section of chapter 3, with a summer price elasticity for the demand function in each month of ė = 0.29.

2. The baseline or strating point for this analysis is the state of "normal" conditions.

3. Marginal costs simulated for "effective" capacity level which are balanced with demand at levels which generate "relevant" short-term marginal costs that when multiplied by Q's will generate change in benefit figures equal to the change in cost figures. These capacities are 27.3, 25.7, and 24.9 m^3 x 10^6 for December, January and February, respectively, as opposed to "normal" capacities of 29.6, 28.0 and 27.8 m^3 x 10^6.

Chapter 8

CONCLUDING OBSERVATIONS

Water conservation is the major policy that is currently being debated by water utilities throughout the world. These policies are seen by many water supply planners as a solution to their financial problems. We have used an economic approach to analyze these policies, and have concluded that water conservation (the balancing of demands with supplies at lower levels of use) can only be justified when its incremental benefits exceed its incremental costs. To demonstrate this fact, we have presented the principles and tools required to analyze the problem. We have also applied them to a water utility in Perth, Western Australia. In the case of Perth, we reached some useful conclusions about the economics of conservation (see Table 8.1).

The mix of policies that would allow Perth to solve its problems of revenue insufficiency, avoid economic waste and improve economic efficiency would include:

(1) the adoption of a uniform marginal cost tariff schedule, with the same price per m^3 being charged throughout the year and being set at the relevant marginal cost in each year. This will mean that the real prices of water in Perth should be increased each year to balance demands with existing capacity(see Table 4.6). It also implies that future capacity expansion, that would be required if the traditional planning approach was retained, can be deferred. No new capacity will be required until the price (the relevant marginal cost) reaches $0.51/$m^3$ (see Table 4.3). This deferral will result in a significant reduction in Perth's financial requirements.

Table 8.1 Desirability of Conservation Parameters (Perth

Policy Parameter	Desirability of Conservation ("Normal")	Desirability of Conservation (Drought)
Uniform Marginal Cost Prices	Yes	Not analyzed
Summer-Winter Marginal Prices	No	Not analyzed
Leak Detection and Control	Yes	Not analyzed
Meters	Yes	Not analyzed
Restrictions	No	Yes

(2) the adoption of a systematic leak detection program. Again, the use of the economic approach will allow Perth's water system planners to demonstrate, in a systematic way, that economic waste could be eliminated by a leak detection program.

(3) the adoption of universal water metering. The economic approach demonstrates the advantages of universal metering for Perth.

Before concluding, it is important to realize that, to determine the desirability of water conservation, we must have data to operationalize our benefit-cost model. In particular, we need data on the determinants of water use and the elasticities of each. In addition, data on the relevant marginal costs should be calculated and/or simulated. At present, these data are not generally available for most water utilities. Therefore, to evaluate water conservation policies, water utilities must first begin to collect and analyze data that have economic significance. If this is done, then debates on the desirability of balancing demands with supplies at lower levels of use can be framed in a more useful context. Moreover, water supply planners will be able to justify their proposed policies before regulatory bodies and the public in a more systematic and rigorous way.

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Appendix 1

A PROGRAM FOR INTEGRATING DEMAND AND SUPPLY

The model for integrating demand and supply, which we presented in chapter 5, can be made operational with the use of a computer or a programmable calculator. For most purposes, however, a programmable calculator provides the most flexible and efficient means of operationalizing our model.

In this appendix, we present a program for use on a programmable calculator, the Texas Instruments model 58c. This calculator and program were used to make the calculations for demand-supply integration which appear in the text.

As noted in chapter 5, two equations are needed to integrate demand and supply:

$$(A1.1) \qquad Q_2 - r\, Q_1 \quad ,$$

where Q_2 = water use in period two, when the real price of water in period two is equal to that in period one; r = the growth rate in the water use from period one to period two plus 1.0, when the real price of water in period two is equal to that in period one; and Q_1 = the water use in period one. If the real price of water changes from period one to period two, equation (2) is required to determine the final equilibrium water use in period two:

$$(A1.2) \qquad Q_2^* = \left(\frac{P_2}{P_1}\right)^e Q_2 \quad ,$$

where Q_2^* = water use in period two, when the real price of water in period two is different from that in period one; P_2 = the real price in period two; P_1 = the real price in period one; and e is the price elasticity of demand coefficient; which is always negative.

To program these equations on the Texas Instrument 58c, we key in the following information:

Step Number	Key Entry	Press
1	76	L61
2	11	A
3	43	RCL
4	00	00
5	65	X
6	43	RCL
7	01	01
8	95	=
9	42	STO
10	05	05
11	43	RCL
12	02	02
13	55	÷
14	43	RCL
15	03	03
16	95	=
17	45	y
18	43	RCL
19	04	04
20	95	=
21	65	X
22	43	RCL
23	05	05
24	95	=
25	42	STO
26	06	06
27	43	RCL
28	01	01
29	32	$x \gtrless t$
30	43	RCL
31	06	06
32	77	$x \geq t$
33	10	E'
34	25	CLR

Step Number	Key Entry	Press
35	08	8
36	08	8
37	08	8
38	08	8
39	08	8
40	08	8
41	08	8
42	08	8
43	08	8
44	08	8
45	91	R/S
46	42	STO
47	10	10
48	43	RCL
49	02	02
50	75	−
51	43	RCL
52	10	10
53	95	=
54	42	STO
55	02	02
56	55	÷
57	43	RCL
58	03	03
59	95	=
60	45	Y^x
61	43	RCL
62	04	04
63	95	=
64	65	X
65	43	RCL
66	05	05
67	95	=
68	42	STO
69	06	06
70	77	$X \geq t$
71	10	E'

Step Number	Key Entry	Press
72	61	GTO
73	00	00
74	47	47
75	91	R/S
76	76	Lb1
77	12	B
78	42	STO
79	00	00
80	91	R/S
81	76	Lb1
82	13	C
83	42	STO
84	01	01
85	91	R/S
86	76	Lb1
87	14	D
88	42	STO
89	02	02
90	91	R/S
91	76	Lb1
92	15	E
93	42	STO
94	03	03
95	91	R/S
96	76	Lb1
97	16	A'
98	42	STO
99	04	04
100	91	R/S
101	76	Lb1
102	10	E'
103	91	R/S
104	76	Lb1
105	17	B'
106	43	RCL
107	02	02
108	91	R/S
109	00	

Now, we are ready to use our demand-supply integration program:

Step Number	Key Entry	Press	Display
1	r	B	r
2	Q_1	C	Q_1
3	P_2	D	P_2
4	P_1	E	P_1
5	e	A'	e
6		A	Q_2^* or 8888888888
7	If 8888888888 ($Q_2^* < Q_1$)	CLR	
8	Decrease in P_2	R/S	Q_2^*
9		B'	P_2