Pricing and Water Consumption in the Boston Metropolitan Area

by

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by

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ABSTRACT

A regression analysis of the cities and towns of the Boston metropolitan area was carried out looking at the relationship between the dependent variable water consumption and such independent variables as population, employment, age distribution of the population, age of the housing stock, income and the rate charged the average residential customer.

The conclusions drawn from the regression equations are that the rate elasticity of demand is -.2 at the mean rate of 60 cents per hundred cubic feet of water, there is no income effect, and population and total employment are the most important factors in determining the water consumption in a municipality.

It is suggested that a price structure be based on the premise that the price to a consumer reflects the costs that that increased demand places on the system. Elements of such a price structure for the Boston metropolitan area include: the price should vary over time in relation to system load; the price should not vary over distance; price should encourage recycling by large scale users who are most able to make dramatic reductions in water used; an ascending block rate should be adopted to disccurage excessive use; the price should reflect the availability of additional supply; and prices should be the same for all like consumers.

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Introduction

> "The finite character of Massachusetts' water resource, and the concomitant necessity to properly manage that asset, have at long last been recognized. The development of a sensible, effective management system which maximizes the benefits of this resource will necessitate changes in deeply ingrained attitudes and habits regarding the use of water and its provision."
>
> (Report of the Special Commission Relative to Determining the Adequacy of Water Supply in the Commonwealth, January 1979)

The basis of a sensible, effective water management must be an understanding of the structure of supply and demand. Most water utilities have only been concerned with the management of the physical elements of supply--how to build a reservoir, what type of mains to use, water purification methods, etc. The economic aspects have been overlooked, except as a source of revenue.[4] It is the premise of this paper that pricing can be used to curtail demand and allocate current water supplies more efficiently and equitably.

To look at pricing it is necessary to look at both supply and demand. This was done by a review of current documents as well as a study of the Boston Metropolitan Area for the years 1960, 1970 and 1975.

Traditionally demand has been taken as a given, with an assumed elasticity of zero. [23] Regression analysis of 57 cities and towns yielded a rate elasticity of -.2 at the mean for 1975 data. This may not seem elastic enough to be used in reducing demand but elasticity increases with the price. [10,49] The elasticity at a rate of 80 cents per 100 cubic feet of water is -.68. At higher ranges the price has a significant effect on demand.

Demand manipulation is of increasing importance as supplies are being depleted. While the state has adopted conservation as the cornerstone of its water policty, it alone can not avoid the need for supply augmentation. It depends on the good will and awareness of the consumers and offers no incentives for compliance. Conservationists talk of a 25 to 50 percent savings of water possible with current technologies but savings in the 10 to 15 percent range seem more reasonable. Even at the higher conservation rate eastern Massachusetts can not get by without supplementing its water supply. [20] A report to the state legislature estimates that with a very moderate population growth by 1990 155 communities in the state will have water deficits. [30]

While pricing policies can not do away with the need for increased water supplies they can delay it and make sure that expansion is in response to real demand and not in response to inflated demands based on water priced below its actual socioeconomic costs.

The following chapters discuss the theoretical aspects of supply, demand and the pricing of water as well as the particular situation found in the Boston metropolitan area. The analysis is based on data available from current planning documents and from a regression analysis done of the metropolitan area.

In brief the conclusions drawn from the regression equations are that the rate elasticity is -.2 at the mean, there is no income effect and population and total employment are the most important factors in determining the water consumption in a municipality. In the 1975 regressions the age distribution of the population is significant until the age of the housing stock is introduced. This is probably due to presence of larger numbers of children in the suburbs which also have newer systems and less leakage.

The information gathered on supply, demand and pricing forms the basis for recommendations on changes in the current pricing policy which would result in a more efficient and equitable use of available water resources.

Supply

Water supply planning in Massachusetts must deal with three problems: 1)water is seen as an abundant natural good; 2)there are competing uses for the water that is available; and 3)the spatial distribution of supply is different than that of the users. Within the metropolitan area planners must also deal with the problems of increasing demand in the face of fixed short run supplies and the degradation of local wells by such pollutants as road salt, hazardous chemicals and organics.

Water is considered to be an almost limitless resource. This may seem a reasonable assumption, as it is a renewable resource available in large quantities. Consumptive use is theoretically limited by the stream flow, which is approximately 1600 gallons per capita per day (gpcd) for Massachusetts. This is far greater than the national average domestic use of 60 gpcd. [31] However, the practical limits on utilizing stream flow are much less than 1600 gpcd. There is no data on how much water is really needed for public health and safety as well as economic health. Data does indicate that current use tends to be inflated and highly consumptive. [49]

Massachusetts's water is used not only for domestic purposes; it is used for industrial use, for waste assimilation, for recreation and open space, and for the recharge of water tables. All of these uses compete for the water available.

A further complication of the state's water picture is the location of its water supply. Even if the water supply is sufficient to meet the demand, its distribution does not follow the pattern of residential and industrial settlement. Two thirds of the state's population is located in the eastern third of the state, but the major water sources are in the other two thirds.[31] By exporting western water to the eastern part of the state the water supply is diminished; the water which passes through the system is discharged into another watershed and cannot replenish the source.

Sources of Water

Currently there are two major sources of water--ground water and surface. Surface supplies require large areas of land for both storage and watershed maintenance. In this state only the Connecticut and Merrimack River basins have the size, surface water quantities, and topography suitable for large offstream storage reservoirs.[31] Ground water is of limited use for the major urban areas. Most of the land within Route 128 is "Boston Blue Clay" which is a dense, silty soil bearing relatively little water. The small amount of water found in the Boston area is brackish and of poor quality. It is further degraded by man-made pollutants including road salt, minerals, viruses, chemical wastes, bacteria, and induced salt water intrusion. In addition, new growth which leads to increased demand for water is often on top of the very watershed or aquifer which is needed to expand the supply. There is little a town can do about this as ground water is legally part of the property it lies beneath.

Surface water is the primary source for large, urban systems. Ground water can be used to augment local supplies, but is of limited use as a primary source except in areas such as Plymouth County and the Cape which lie outside the metropolitan region. The supply issues facing individual metropolitan municipalities will be discussed later. First there will be a general discussion of ground and surface water supplies.

Ground water as a local water source has advantages over surface water. The <u>Report of the Southern New England Study</u> (SENE) estimates it costs ten cents per thousand gallons including chlorination, while a study by the U.S. Department of the Interior cites a cost as low as one and a half cents per thousand gallons for large supplies in the Northeast.[46] (see Table 2-A) Not only is the cost low, but the capital construction can be phased so the costs can be spread out. Because the soil layer above the supply offers protection from organic pollution, the water generally does not require much treatment; this means that the land can be used for some types of development. Other advantages of ground water are that the water stays at a fairly constant temperature and is protected from evaporation.

TABLE 2-A

WATER SUPPLY AND TREATMENT COSTS

Water Costs		
Ground Water Supply	SENE estimate	10¢/1000 gallons
	DOI estimate	1.5-5¢/1000 gallons
Surface Water Supply new reservoirs		20-21¢/1000 gallons
Desalinization		$1.50-3.00/1000 gallons
Treatment Costs		
for the removal of:		
organics		6¢ /1000 gallons
microbiological organisms and turbidity		8-10¢/1000 gallons
dissolved solids		25-80¢/1000 gallons

Source: Massachusetts Water Supply Policy Statement, May 1978.

The disadvantages of ground water include its susceptibility to pollution by iron, highway salt, and salt water intrusion. It can be high in dissolved solids. Although land use above the supply is not precluded, a recharge area of approximately one square mile for each million gallons per day (mgd) yield is needed.[31] The problem of recharge is aggravated by public sewers which often deposit the used water into another watershed system or into the ocean. Ground water is also uneconomical where the demand is large. If the demand is greater than three to five mgd, when more than one well is required, or when the demand is greater than the average well flow it may be more economical to use surface water.

Surface water is found in man-made reservoirs and natural water bodies such as ponds and lakes. Its advantages include the ability to replenish the supply quickly by diversion of flood waters, the ability to withdraw water in excess of the safe yield for a period of time, the aesthetic and recreational values of the open space, and the natural treatment which occurs through settlement and sunlight.

Among the drawbacks to a surface system are its susceptibility to evaporation and drought, the presence of pathogenic organisms and suspended solids which require treatment, the high costs of development including land acquisition and the dislocation of current users in the area, and the difficulty in managing the large recharge area.

The Massachusetts Water Supply Policy Statement contains some estimates of the cost of surface water development. (see Table 2-A) The 1972 costs of a reservoir south of Boston are approximately 21 cents per thousand gallons, with a yield of 6.5 mgd. Another project which would yield 2 mgd is expected to cost 20 cents per thousand gallons for untreated water. These costs include estimates of capital cost of dam and reservoir construction, land appraisal and acqusition, engineering costs, amortization, and maintenance costs. They are based on information gathered by the Office of Environmental Affairs staff during interviews with engineers and water managers recently involved in reservoir construction. Because of the high development costs it is unlikely that an individual town will use surface water as the source for a municipal system. The amount of intertown cooperation has been limited in the past, and great changes in coordination are not anticipated.

As with ground water, the best sources for surface water lie outside the metropolitan area. Even the excellent sites available in the western part of the state face the opposition of those now occupying the sites as well as environmentalists' resistence to damming for on-stream reservoirs.

Water Augmentation Techniques

In addition to the two major sources of water, there are techniques available to augment supply. Water can be diverted from other watersheds; it may be skimmed from flood waters and stored for future use; rainfall may be increased by cloud seeding; or currently unusable water may be treated and used. The first two methods, diversion and flood skimming are in current use, and a major planned expansion of the MDC supply will use them.

Cloud seeding is not now viable but there is some promise. One problem is the lack, in times of drought, of enough moisture to form clouds.

Water treatment is generally not used in Massachusetts, but the techniques which exist should be adequate for current needs. As discussed in chapter five of the Massachusetts Water Supply Policy Statement (see Table 2-A) standards for turbidity and microbiologial organisms can be met by the use of coagulation, sedimentation filtration, and disinfection at a cost of eight to ten cents per thousand gallons in large systems (over ten mgd). The cost for smaller systems is much greater. These techniques can also remove heavy metals, although the water might not be up to standard in all cases. Organics can also be removed by carbon abscrption, with or without preoxidation with chlorine or ozone, at a cost of six cents per thousand gallons in large systems. Road salt, heavy metals and other dissolved solids can be removed by osmosis, electrodialysis and ion exchange at prices ranging from 25 to 80 cents per thousand gallons. The cost depends on the concentrations in the raw water and various site factors. Research is being conducted on reducing the costs.

The last form of treatment is desalinization. It is energy intensive and has serious environmental impacts. The cost depends on the standard desired. The U.S. Public Health Service recommends a maximum of 500 ppm (particles per million) salt with 250 ppm chlorides or sulfates. This far excedes the 20ppm sodium allowed to a person on a low sodium diet. The cost of desalinization varied from $1.50 to $3.00 per thousand gallons at the 1,035 desalting plants in operation world wide in 1975. These plants produce 525 mgd. They are located in extremely dry and water poor areas. Desalinization is not an option for New England in the foreseeable future.

Supply Planning: The Institutional Framework

Most water supply planning and development is done at the local level but there are many other agencies which have jurisdiction. The federal government's passage of the Clean Water Act has had a major impact on water use by requiring sewer discharge costs if a town is to be eligible for federal sewage system funds. This is beginning to have an effect as industries increase their inplant recycling in response to the sewer charges. The Safe Drinking Water Act, which requires modernization of old systems susceptible to drought, leakage, and breakdown, is expected to have a major impact on the many older systems in the metropolitan area.

At the state level water supply policy is affected by actions of the legislature which must approve development outside a local jurisdiction and diversion from one watershed to another. Hundreds of special laws have been passed, dating as early as 1788, which have altered the natural distribution of water. The Office of Administration and Finance must approve many of the capital expenditures necessary to run the system while the Department of Public Health approves municipal water quality. The Executive Office of Environmental Affairs controls wastewater disposal which effectively controls the volume and quality of the water supply. The Water Resources Commission is empowered to coordinate a state resource policy and programs.

Regional planning agencies have A-95 review powers. They identify the needs of the regions and recommend change.

All levels of the court are involved with litigation entered around the issues of supply and water rights.

The Local Water Supply Picture

The Metropolitan District Commission, also known as the MDC, is the major supplier within the sample area. It supplies roughly 50 percent of the towns and 73 percent of the population. (see Table 2-B for a list of the towns served by the MDC) The mainstays of the MDC system are the Quabbin and Wachusett Reservoirs located in the center of

TABLE 2-B

SAMPLE TOWNS SERVED BY THE MDC WATER DISTRICT

Arlington
Belmont
Boston
Brookline
Cambridge*
Canton*
Chelsea
Everett
Lexington
Malden
Marblehead
Medford
Melrose
Milton
Nahant
Needham*
Newton
Norwood
Peabody*
Quincy
Revere
Saugus
Somerville
Stoneham
Swampscott
Wakefield*
Waltham
Watertown
Winchester*

*partial supply

the state. The system has a safe yield of 300 million gallons of water per day (mgd). [35] The safe yield is the amount which can be depended upon during a dry period. Since 1970 the average amount of water supplied has exceded this by 7 mgd. The MDC feels it is necessary to augment its supply, as the demand is expected to increase because of population growth, increasing per capita water consumption, contamination of local wells, communities which have no means to expand their water supplies except to join the MDC, and probability of future droughts. The system has been able to get by with exceding the safe yield because there have been no extended dry spells such as occurred in 1910, 1929, 1939, and 1963.

Estimates of the number of towns which will have no option but to join the MDC are as high as 24 in a study done by the U.S. Army Corps of Engineers. [37] The study by the New England River Basin Commission does not find the need as great, due to lower population projections and a differrent interpretation of potential local resources, but does see a need for expansion of the MDC system.

The state Environmental Affairs Office does not feel that the supply should be augmented from non-local sources until all local supplies have been developed, unlike the past when a town joining the MDC system had to agree to buy a certain percent of its supply from the MDC. Reactivation of local water supplies could relieve some of the strain on the sytem, but many of the old wells will require extensive treatment. Some were closed down in the past few years because of hazardous waste contamination and pollution from road salt runoff. Such continued closings may negate the gains from reactivation of old wells.

The state would also like to see the MDC adopt a strong conservation program. Helen Linsky, a consultant to the MDC, has said that so far the MDC has only piggybacked water conservation on to energy conservation programs. [27] However it is in the process of developing an overall conservation program including such features as an education campaign, comprehensive metering and meter maintenance, installation of water-saving devices, rewards for a conservation-oriented pricing policy and incentives to recycle water. [35]

There are two supply augmentation projects under study by the MDC, the Northfield Mountain Water Supply Project and the Upper Sudbury River Project. Stephen Lathrop, a senior resource planner at the New England River Basins Commission, feels that the Upper Sudbury project is more likely to go through. The Sudbury Reservoir was used as a supply source for the Boston area in the 1800's and early 1900's, until the water developed color and odor problems. At that time it was cheaper to develop new sources than to treat the water. The MDC controls the reservoir and uses the water in emergencies. If the Sudbury project is developed it would supply as much as 20 mgd of water, enough to make up the current deficit. [35] An environmental impact report is being prepared, but it will be several years before the Sudbury project can increase the MDC's supply.

The Northfield Mountain Water Supply Project involves the construction of a tunnel to divert flood waters from the Connecticut River to Quabbin Reservoir, increasing the average annual yield by 72 mgd. [35] The project has already been authorized by the state Legislature but faces stiff opposition from the Connecticut River interests. [24] It is expected that the environmental impact report will take at least two years to complete. This report will not only include the impact of the proposed diversion but will explore all realistic alternatives to the project, including conservation.

Neither of these projects could supply water to the MDC communities in less than five years, so the MDC faces a continued deficit unless it can reduce consumption. The MDC hopes this can be accomplished by the use of water-saving devices, education programs, pricing to discourage excessive use, etc.

The towns which are not served by the MDC also face quantity and quality issues. (see Table 2-C for a list of these towns and the river basins in which they lie) The Ipswich River Basin includes the towns of Burlington, North Reading, Wenham and Wilmington. The biggest problem there is point source pollution. Over half the population relies

TABLE 2-C
SAMPLE TOWNS WITHOUT MDC WATER

Town	River Basin
Bedford	Suasco
Beverly	North Coastal
Braintree	Weymouth
Burlington	Ipswich
Cohasset	Weymouth
Concord	Suasco
Danvers	North Coastal
Duxbury	North and South
Framingham	Suasco
Hanover	North and South
Lincoln	Lower Charles
Lynn	North Coastal
Manchester	North Coastal
Medfield	Upper Charles
Natick	Lower Charles
North Reading	Ipswich
Reading	Ipswich
Rockland	North and South
Salem	North Coastal
Scituate	North and South
Sharon	Neponset
Sudbury	Suasco
Wayland	Suasco
Wellesley	Lower Charles
Wenham	Ipswich
Weymouth	Weymouth
Wilmington	Ipswich
Woburn	Mystic

on septic ranks for sewerage. [33] The predominant pattern of low density residential land use is expected to continue, increasing the demand for new water supplies. North Reading and Wilmington have sodium and other chemical contamination of their public wells. [42] The health effect of sodium in the water is not known, although one study suggests it might lead to elevated blood pressure. [31] The federal government has never set standards for the sodium content of water.

The North Coastal River Basin contains the towns of Beverly, Danvers, Lynn, Manchester and Salem. These are established communities undergoing slight growth. All these towns have elevated levels of sodium in the public water supplies.

The Sudbury, Assabet and Concord Rivers comprise the Suasco Basin, including Bedford, Concord, Framingham, Sudbury and Wayland. It is an area of rapidly growing, relatively affluent suburban towns. Most of the growth is expected to be in single family residences. Currently Bedford and Concord have chemical contamination of their wells and buy water from a neighboring town. [42]

Woburn in the Mystic River Basin also faces contamination of its public water supply. Its water quality problems include stormwater runoff, industrial discharges, road salt, and the loss of critical recharge areas. Dense development has covered most of the area with impervious surfaces. The major bodies which do exist are under the control of the MDC.

The North and South Rivers Basin is the fastest growing area in southeast New England. [33] Most of the growth is residential, although there has been some increase in manufacturing. Duxbury, Hanover, Rockland and Scituate are in this basin. Both Rockland and Scituate have soidum contamination of their public wells.

Medfield in the Upper Charles River Basin has no immediate supply threats although it is in an area of rapidly growing, relatively affluent suburban development which may eventually overtax the supply. In contrast, the Lower Charles River Basin which contains Lincoln, Natick and Wellesley is an area of old development with little room for new growth, and the towns not in the MDC all have sodium in the public water supplies.

Sharon is a part of the Neponset River Basin. The town has sufficient ground water supplies to meet future needs although quality of that water may be a problem as there is sodium present.

The Weymouth Basin includes the towns of Braintree, Cohasset and Weymouth. Braintree, along with Holbrook and Randolph, is served by the Great Pond Reservoir. Increased needs can be met by diverting water from the existing Richardi Reservoir. Weymouth uses ground water sources whose yield can be increased by treating the water. Cohasset has sodium in the public water.

Conclusion

Within the metropolitan area there will be a shortage of water by 1990, even using the low population growth figures of the State Office of Environmental Affairs. The water supply development projects which have been suggested could not provide water until the late 1980's, and it is possible that some of the projects may never be undertaken. Under the most optimistic of scenarios there will still be an interim water deficit in the 1980's which can only be reduced by conservation of water. Conservation, along with recycling, is the short run solution to the supply problems faced by the state.

Demand

Water demand is not monolithic. Rather it exists as a continuum of demand ranging from the essential to the discretionary. All water demand has been viewed as essential, and therefore accommodated in future plans as necessary. It has been the persistant tendency of water resource planning to issue single value projections of water demand which assume a continuation of present water use. [47] Traditionally future water needs have been calculated by taking the projected change in population and multiplying it by the current average per capita water use or by an increased water use based on straight line projections of historically increasing per capita use. [13,31] This unquestioning acceptance of increased water demand has been self-perpetuating. Water projects are undertaken to meet the increased demand, and, once available, water is priced to encourage full utilization of the facility. The lower price encourages overconsumption until the demand again excedes the supply and further expansion is undertaken.

One reason all water demand is taken as essential is that there is no data or analysis on how much water is actually needed to maintain public health, safety, and economic and social well being. [31] Lacking this information, it is safer to take the demand as given and to keep the system in adjustment by working with the supply side.

This tension between the essential nature of water and its other demand factors is reflected in the price placed on water. Generally the price is low and water is available in the quantity desired. This reflects the abundance as well as the essential nature of water. Water is essential and very valuable only in small quantities, so the price is low, making it available to all and coinciding with the low marginal value of the last unit consumed.

The primary component of demand is the amount essential for human consumption as well as the amount needed to maintain the hydrologic cycle. Water supply planning must balance these needs or it will jeopardize future water supplies. However, this paper is concerned with the human demands on the water supply and will not deal with the needs of the hydrologic cycle except to acknowledge that there is a limit to the amount of water which can be made available for consumption within the state.

The future discretionary demand depends on the rate of national population and income growth, the level of per capita energy consumption, such factors as fashion and taste which affect the demand for food and fibers, those government programs dealing with resource development and distribution, the rate of technologic change, the various recreational water uses, and the price of water. [47] This paper is concerned with this last factor and how it can be used to keep consumption in line with available supplies.

Water Users

The national average per capita consumption of water has risen steadily from 95 gallons per capita per day (gpcd) in 1900 to 150 gpcd in 1970.[9] The per capita distribution among classes of use of water supplied by public agencies is found in Table 3-A; it includes the national figures, the Army Corps of Engineers' estimation for those areas of eastern Massachusetts not in the MDC system and MDC figures.

Residential demand in Massachusetts accounts for over 50 percent of the demand placed on public supplies, while national estimates put it at 46 percent. Per capita residential consumption continues to rise. The Corps of Engineers sees the state's use increasing as much as 1.2 gpcd per year while the senior resource planner at the New England River Basins Commission sees the increase tapering to .8 gpcd a year.[31,24]

Greenberg and Hordon feel that much of the 60 percent increase in national per capita consumption over the last half century may be attributed to higher income, a better standard of living, and technologic change. They believe that higher incomes allow the purchase of water-using appliances such as washing machines and garbage disposals. This may have been true over the last fifty years, but the changes in consumption during the study period are probably not due to the ability to purchase water using devices. In 1930 washing machines may have been uncommon, but they aren't

TABLE 3-A

WATER DEMAND BY CLASS OF USER
(Percent of Total Use)

	Nation-wide	Eastern Massachusetts (Non-MDC)	MDC
Residential	46	61	51
Industrial	23	23	20
Commercial	18	7	18
Public and Other	13	9	11
Total	100	100	100

Sources: Nation-wide: Greenberg and Hordon, Water Supply Planning
Massachusetts: Army Corps of Engineers as cited in Massachusetts Water Supply Policy Statement

today. Other earlier studies done on consumption of water found that income was a significant factor. For instance, the Larson and Hudson study of 1951 [23] found an apparent relationship between income and use but this was in a study in which some households had no indoor plumbing, a situation not found often today--especially in the urban area studied. In fact Conley cites a study by Gardner and Schnick which found the per capita median income not only insignificant but having the "wrong" sign.[4] This is consistent with my findings of this study of the Boston Metropolitan Area. The area income was insignificant and the sign was unstable for the 1975 regression while positive for the 1960 and 1970 variables. Attempts to isolate the income effect by staging the regression were unsuccessful.

In the Johns Hopkins study Linaweaver, Geyer and Wolff [26] found that, in addition to the number of homes, residential water use was influenced by the economic level of the consumer, the climate, and whether the area was metered. They found that outdoor water use had an elasticity of -1.12, while inside domestic demand was -.4. [19] Population density was found to be a major factor in areas with either fixed rates or septic tanks. The income effect that was found could just reflect the density factor which determines the amount of outdoor watering that is done.

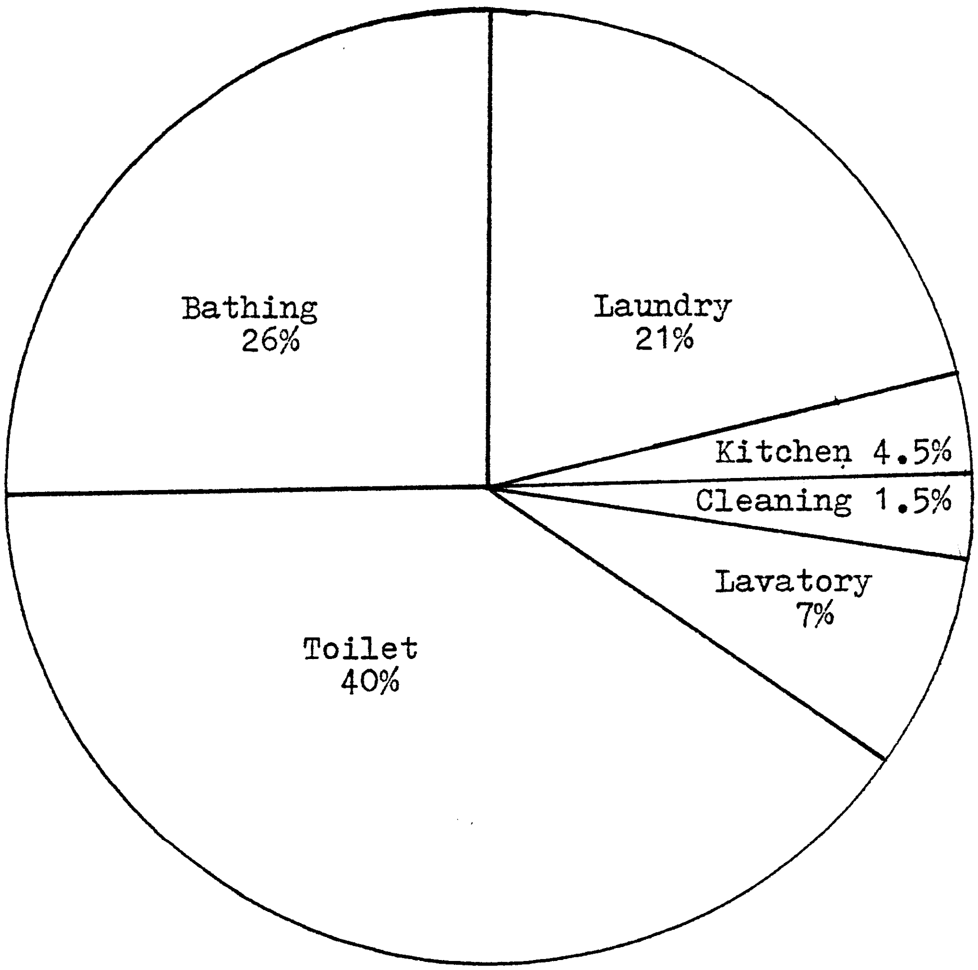
The traditional view of prices' impact on residential consumption is that prices have no effect. [23] Grima found a widespread prejudice among water utility management that the way residential water is priced does not affect the level of water use. [10] The water officials interviewed in the Boston area felt that this was true. This view is based on experience when water rates were low, or when the change in consumption following the installation of meters appeared only transient, with a return to former levels. Using a time series analysis of Boulder, Colorado, Hanke demonstrates that the installation of meters actually results in a long term reduction in water use; if the meters had not been installed the consumption would have risen to an even higher level. Hanke found that domestic, in-house demands were initially reduced by 36 percent upon meter installation, and stabilized at lower than unmetered levels. His study indicates that water users do not return to their old use patterns after meters are installed; the result is a "permanent and significant improvement in water use efficiency." [13] This is certainly true in Beverly and Salem which installed meters in 1920 and did not reach the usage of the early twenties again until the 1960's. [20]

While the introduction of meters may result in a large-scale, one-time change in consumption, smaller decreases in demand are possible. The fallacy that demand for residential water is inelastic with respect to price is based on the premise that it is a single good. [10] Water should be viewed as at least two goods, the essential water and other water; essential water is inelastic with respect to price and other water is elastic. The Johns Hopkins study, with different elasticites for indoor and outdoor residential use, is consistent with this view.

Even domestic, or indoor, use as broken down in Figure 3-A, has some flexibility. Under current use patterns toilet flushing is the single major domestic use, and it is probably the easiest use to reduce. Inexpensive toilet dams which can be installed by the consumer can reduce the amount of water flushed away by 30 percent.[8] New toilets are designed to use 3.5 gallons a flush compared to the earlier models which used 6 gallons. Over time, as old units are replaced, demand due to toilet flushing can be expected to decrease 40 %. A Boston firm, Energy and Resource Conservation Systems, Inc., or ECOS, estimates that typical household water consumption can be reduced 50 percent.[8] This is in the area of use which is considered the most inelastic.

Perhaps greater reductions are possible in outdoor residential use, which was shown to be much more elastic in the Johns Hopkins study. The magnitude of outdoor demand is difficult to quantify as it is highly variable. In a study of the Merrimack River area the Army Corps of Engineers found that the presence of a swimming pool used by a four member family could add 22.5 gpcd to the average annual demand. Carwashing uses 60 to 80 gallons each time the car

FIGURE 3-A
RESIDENTIAL, INDOOR WATER USE



is washed while lawn watering uses roughly three times this amount. [31] How often a person washes the car or waters the lawn is highly variable, depending on personal tastes as much as the weather, and the presence of water charges does influence the amount of water used outside the home. Linaweaver found that lawn watering was twice as high in areas with fixed rates as it was in comparable areas with metered water. [26]

Industrial Demand The next largest user of publicly supplied water, accounting for roughly a fifth of total per capita consumption in Massachusetts (see Table 3-A), is industry. However, this does not nearly reflect the total industrial demand. In the period from the mid 1960's to the '70's, public water systems supplied only about 12 percent of the fresh water used by industries. Of this public supply approximately four-fifths went to heavy users such as food processors, paper and chemical producers, petroleum refiners and manufacturers of transportation equipment.[9]

It is not possible to characterize the industrial demand by the type of industry except in the most general terms. Plants in the same industry can have different water needs due to variations in process technology, plant size and location, and the age of the plant. The industrial demand curve will not be continuous, as there are major water saving devices available which involve large capital outlays but result in substantial reductions in water use once built.

Conley did a study of industry in southern California in which he derived an industrial price elasticity of -.4.[4] This is fairly inelastic, probably reflecting the low price, and hence low budget share, of water.

While the budget share of water is still small, the costs of disposing of that water are beginning to climb as a result of sewer discharge costs associated with the Clean Water Act, PL 92-500.[31] This act places stringent requirements on the amount of pollutants allowed in waste water. By July of 1983 all plants must apply the best available technology that is economically achievable. Since the cost of treatment per unit of pollutant is less the more concentrated the waste, it is expected that this act will be the major impetus for the reduction of industrial water demand.[49]

Commercial Demand The major component of commercial water demand is for use as the cooling agent in air conditioning. Greenberg and Hordon's survey of Milwaukee, Chicago and Kansas City found that the demands of air conditioning make up twelve to forty-three percent of the total water consumed in those cities.[9] Demand could be greatly reduced by the use of air cooled systems, but in the past this has been an engineering decision made at the time of building construction rather than one influenced by current water rates.[4]

Public Demand Public demand is water used for fire fighting, street cleaning, water line flushing, consumption in unmetered public building, and loss in leakage. It is this last area which is the biggest and most variable component of public use. In Boston in 1978, approximately 20 to 30 percent of the water put into the system was unaccounted for. [35] Within the MDC system almost all leakage in excess of 3000 gallons per mile of main per day is presently salvageable at current water rates. [49] If this were done the demand system-wide could be reduced as much as 76 mgd.

Boston Metropolitan Area Demand

The greatest demand for water is where the population is densest, the Boston Metropolitan Area. The questions facing water supply planners are, how this demand will change in the future and what can be done to influence this consumption. If growth is concentrated in urban areas, as suggested by state policy makers in "Towards a Growth Policy in Massachusetts" [31], the demand for water will be greatest in those areas already facing supply deficits.

Another factor in future demand aside from distribution of growth, is the rate of population increase. A study of eastern Massachusetts water demand done by the Army Corps of Engineers used the OBERS population projections, but since then the newer Series E and D projections have been developed and forecast growth at half the original rate.

This has a profound effect on predictions of water demand for the area. Looking at the same area but using different population projections, anticipated supply deficits in the year 1990 range from 70 mgd in the state's water supply statement to 193 mgd in a study done by the Metropolitan Area Planning Council. [31]

A third important aspect of increased water demand is the growing per capita demand. Estimates of this are as varied as total population projections. The Corps puts the growth as high as 1.2 gpcd per year while the resource planner at the New England River Basins sees a decline in the rate of annual increase to .8 gpcd. [24]

Industrial growth will also affect the metropolitan area water needs. The level of use is expected to be a fairly stable proportion of local consumption over time. This reflects a moderate growth in industries coupled with a slow-down in the growth of heavy users, as well as the more efficient use of water brought about by the discharge fees associated with the Clean Water Act. [31]

Metropolitan District Commission The MDC has used in its demand projections a 1.1 percent per year increase in the per capita consumption, based on the SENE report. [37] This, along with population growth, expansion of the number of communities served, and increases in residential, commercial and industrial water use will worsen the current average annual overdraft of 7 mgd. Consumption in excess of the safe yield has not been a problem because of above-average precipitation. [30] However, at the higher present levels of consumption a drought such as the one of 1961 to 1965 would cause a drop in Quabbin Reservoir's capacity to 31 percent. Quabbin is the major source of supply for the MDC system.

Not only will the growing population and individual use within the system increase the demand, but the continued contamination of municipal wells and limited supply expansion possibilities for towns not in the system will put pressure on the MDC to expand its service to most of the metropolitan area. Furthermore, outside the Boston Metropolitan Area Worcester can withdraw MDC water on an emergency basis, and Amherst has requested such powers to help the town meet severe seasonal shortages brought on by the rapid growth of the University of Massachusetts campus located in the town. [30]

Leakage is another factor in demand within the MDC system. It has been estimated that as much as 70 million gallons a day are unaccounted for. [30] It is difficult to tell how much is leakage. Even if the loss were all leakage, there is little the MDC could do as it has no authority over local distribution systems. However, as the price of MDC water goes up it will become economically feasible to repair more leaks. At current prices all leakage in excess of 3000 gallons per mile of main per day is economically salvagable. [49]

Demand projections have taken into account rising commercial, industrial and residential use but have ignored other effects on demand. In order to develop a system which might give more refined projections, and indicate ways to influence demand, a regression analysis of water demand factors was done of the Boston Metropolitan Area.

Boston Metropolitan Area Water Demand Regression Study
Typically, demand projections take into account the factors which increase demand but tend to ignore the factors which would inhibit consumption, such as the virtually untapped potential of pricing policy. To explore how pricing might be used to encourage water use conservation, the study looked at total consumption on a town to town basis as a function of water rates, per capita income, total employment, age distribution, population, and age of the housing stock.

Of the 78 towns and cities in the metropolitan area, the 57 which had public water supply systems and kept data on rates and consumption were used in three cross-sectional regression studies. A cross-sectional study was done for all the towns which recorded data for the years 1960, 1970 and 1975. More extensive work was done with the latest time period. For a detailed description of the variables used and the methods of regression analysis, see the appendix.

The resulting regression equations took the form
Consumption = Constant + Rate + Income + Total Employment +

TABLE 3-B
REGRESSION EQUATIONS

Equation 1 1975 Consumption

$$Y = \underset{1.66}{903262} - \underset{-2.29}{6154.4}(X_1) - \underset{-.19}{11.8}(X_2) + \underset{8.94}{44.4}(X_3) - \underset{-2.20}{27422}(X_4) + \underset{9.56}{32.7}(X_5)$$

$R^2 = .96$

Where Y is the total town consumption in thousands of gallons

X_1 is the marginal rate in cents per 100 cubic feet charged the average residential customer

X_2 is the per capita income for the year 1974

X_3 is the total employment by place of work

X_4 is the percent of the population aged 0 to 14 years

X_5 is the population

Equation 2 Log of the 1975 Consumption

$$Y = \underset{1.96}{7.23} - \underset{-2.53}{.19}(X_1) - \underset{-1.11}{.18}(X_2) + \underset{2.60}{.14}(X_3) - \underset{-3.22}{.55}(X_4) + \underset{10.92}{.92}(X_5)$$

$R^2 = .96$

Where Y is the log of the total water consumed in 1975

X_1 is the log of the price charged for water

X_2 is the log of the 1974 per capita income

X_3 is the log of total employment

X_4 is the log of the population aged 0 to 14

X_5 is the log of the 1975 population

TABLE 3-B Continued

Equation 3 1975 Consumption with the STOCK Variable

$$Y = \underset{-1.78}{-1483350} - \underset{-2.36}{5711.4}(X_1) + \underset{1.67}{112.7}(X_2) + \underset{10.52}{50.2}(X_3) + \underset{1.25}{22720.1}(X_4)$$

$$+ \underset{9.61}{30.3}(X_5) + \underset{3.53}{13377.4}(X_6)$$

$R^2 = .97$

Where Y is the total town consumption in thousand gallons

X_1 is the marginal rate in cents per 100 cubic feet charged the average residential customer

X_2 is the per capita income for the year 1974

X_3 is the total employment by place of work

X_4 is the percent of the population aged 0 to 14 years

X_5 is the population

X_6 is the percent of year round housing units built 1939 or earlier

Equation 4 Log of the 1975 Consumption with STOCK Variable

$$Y = \underset{1.02}{2.4} - \underset{-3.07}{.21}(X_1) + \underset{.50}{.08}(X_2) + \underset{4.04}{.22}(X_3) - \underset{-.012}{.003}(X_4) + \underset{9.94}{.82}(X_5)$$

$$+ \underset{3.28}{.34}(X_6)$$

$R^2 = .97$

Where Y is the log of total town consumption

X_1 is the log of the price chared for water

X_2 is the log of the 1974 per capita income

X_3 is the log of total employment

X_4 is the log of the population aged 0 to 14

X_5 is the log of the 1975 population

X_6 is the log of the year round housing units built 1939 or earlier as a percent of total units

TABLE 3-B Continued

Equation 5   1970 Consumption

$$Y = \underset{.47}{184959} - \underset{-2.03}{10254.7}(X_1) + \underset{.59}{29.5}(X_2) + \underset{1.37}{13.5}(X_3) + \underset{.24}{1653.1}(X_4) + \underset{10.30}{39.2}(X_5)$$

$R^2 = .95$

Where Y is the total town consumption in thousands of gallons

X_1 is the marginal rate in cents per 100 cubic feet charged the average residential customer

X_2 is the per capita income for the year 1969

X_3 is the total employment by place of work

X_4 is the percent of the population aged 0 to 14 years

X_5 is the population

Equation 6   1960 Consumption

$$Y = \underset{-.17}{-141203} - \underset{-.89}{6433.3}(X_1) + \underset{.42}{97.6}(X_2) + \underset{7.57}{48.1}(X_3) - \underset{-.05}{1137.7}(X_4) + \underset{6.90}{29.5}(X_5)$$

$R^2 = 1.0$

Where Y is the total town consumption in thousans of gallons

X_1 if the marginal rate in cents per 100 cubic feet charged the average residentail customer

X_2 is the median family income in 1960 divided by the number of families

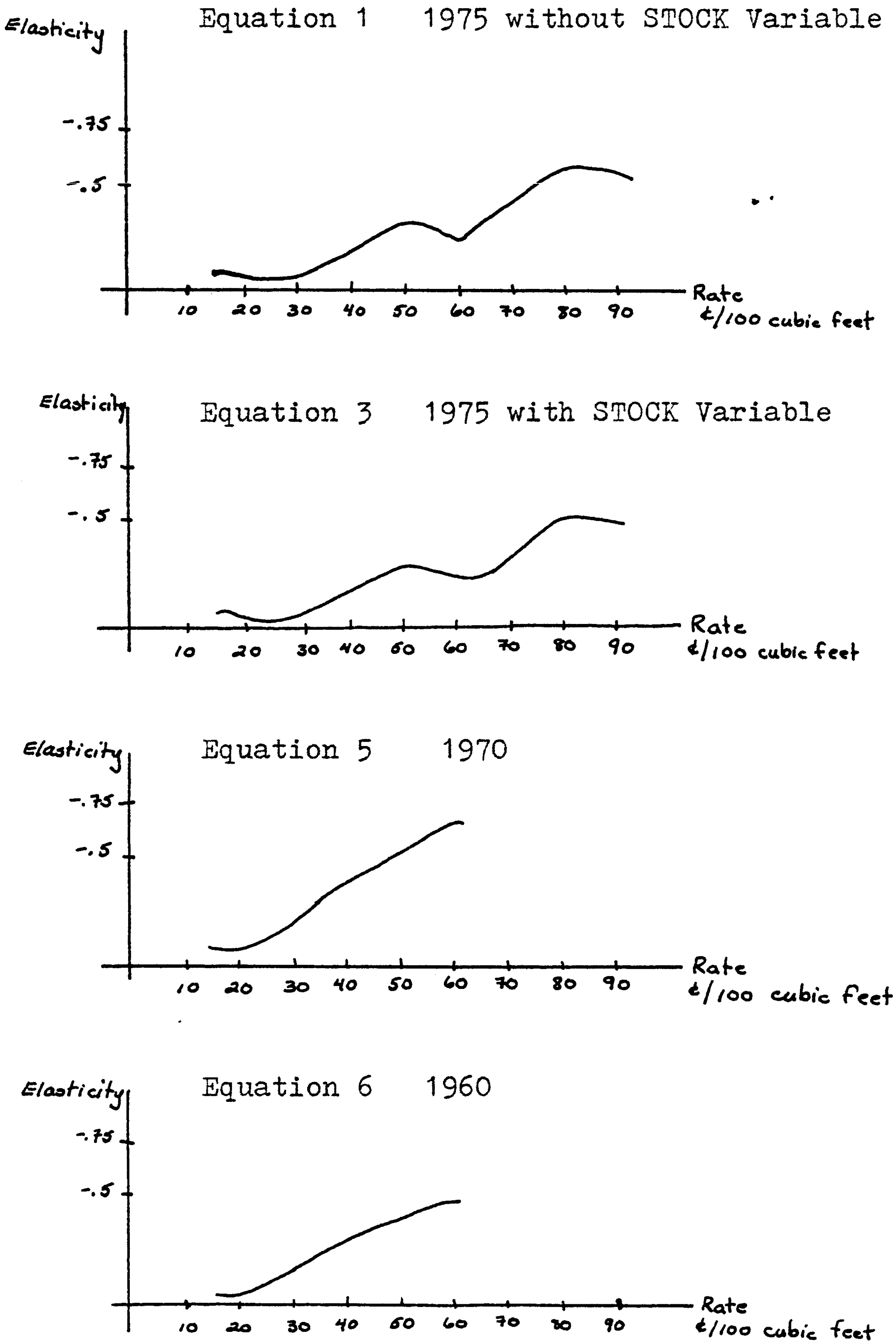
X_3 is the total employment for the year 1963

X_4 is the percent of the population aged 0 to 14 years

X_5 is the population

Age Distribution of Residents + Total Population. The coefficients for the various regression equations are presented in Table 3-B. These equations show that, as expected, population and total employment are the most important factors in determining water consumption in a municipality. For 1975 data the rate elasticity is -.2, meaning that doubling the price of water will decrease consumption by 20 percent. The lack of significance for the rate variable in the 1960 equation may be due to the lack of spread in the data point for this period. However, rate has the same magnitude of coefficient as in the 1975 regression. This does not appear to be a major point of leverage for reducing demand, but it is more significant when one looks at the elasticites over a range of prices. See Figure 3-B for graphs of rate elasticities over price ranges. As expected, the rate is more elastic at higher prices. Not only do elasticities increase over the range of prices, which is consistent with an earlier study of MDC communities [49], but they can be expected to increase over time as consumers have more time to experiment with ways to reduce consumption. [15] The rates used in the regression were the marginal cost as perceived by the average residential consumer. In 1975 no town had water pricing which charged increasing marginal rates, so that the effect of pricing on demand could be greatly enhanced by the restructuring of rate schedules.

FIGURE 3-B
RATE ELASTICITIES



The linear equations did not show significant income effect unless the age of the housing stock was introduced. This is contrary to many of the earlier studies which found income to be an important factor in determining demand, and this contradiction is not easily explained.

The AGE variable is also affected by the introduction of the STOCK variable. This may be due to the large number of young children in suburbs which have grown more recently and therefore have newer systems with fewer leaks.

The regressions for 1970 and 1960 also had significant employment and population variables. The lower value of the coefficients is in keeping with the lower per capita water consumption for these periods.

The elasticity of the population is significant for water supply planning. The log equation which contains the STOCK variable shows that by doubling the population the consumption will increase 80 percent. This means that the straight line projections favored by the water managers [30] will over-estimate the amount of future demand. This may mean that the projected deficits will not be as great as has been anticipated and would be more easily brought in line with supply by decreasing demand through the manipulation of prices, reducing the need for supply augmentation.

In summary, demand in the metropolitan area needs to be better quantified before it is used as the justification for large scale expansion. The combined effects of leakage detection and repair programs, the institution of a rate structure with increasing marginal costs, and public education about conservation may dramatically cut the future demands.

Pricing

Water resource management has traditionally concentrated on supply issues. The use of measures such as pricing to influence demand has been largely ignored. The pricing mechanism has been viewed as a way to raise revenues, not to allocate a resource. Yet the study done by the U.S. National Water Commission states: "While other means might be employed to motivate better use of existing and future supplies of water...nothing is as comprehensive and as effective as the pricing mechanism." The Commission felt that an economicallly sound rate structure could "conserve water supplies, retard premature investment in water development projects, reduce financial burdens now borne by those who do not benefit from the services, and allocate water more efficiently among competing users." [47]

One of the major reasons that pricing has not been used as a tool for resource management is the perception that water is somehow different from other goods. [4] Vickrey has found that the dominant attitude is that people ought to have some specified supply of water, almost regardless of cost, and that the system should be designed to supply this. [48] This sentiment for unlimited public access to water is one of the arguments used for public intervention in the water business. Others advanced include the lack of divisibility of the output and benefits, such as flood control or water recreation; the economies of scale which may dictate a project so large that a competitive market can not exist; and the physical interdependence of elements of the production function which may result in external economies and diseconomies. [45] For whatever the reasons, public intervention in the water supply and management field is here to stay. In Massachusetts there are private water supply companies but they are subject to state and local regulations concerning quality and rates.

Once water supply is a government function the prices are not set by the pulls of supply and demand, but are the policies of the water system managers. These policies reflect the managers' perceptions of what water ought to cost. Traditionally this has been based on revenue considerations of the municipal system and not on consumption allocation. [4] Pricing is almost an afterthought. The concern is with the supply of the water. The demand, which could be influenced by the price, is simply taken as a given.

This attitude is beginning to change. The state Water Supply Policy Statement says that programs such as conservation-oriented pricing should be implemented and vigorously pursued. [31] Numerous theories have been advanced as to how such a pricing policy should be structured. The common themes in most of these are that the price should be related to the cost of supplying the water and that the beneficiaries of a supply project should bear the costs of the project. In the past state and federal agencies have developed sources and then turned the supplies over to utilities at a price less than the cost.[9] This has lead to inflated demand and overinvestment in water resources. The rationale behind this was that the subsidy would promote development of an area and that the ripple effects of such development would benefit all the area residents. This reasoning is still reflected in Massachusett's water policy which stresses the importance of water as the only resource the state may have to offer future businesses.[31] However, according to a study done by Rivkin/Carson, Inc. this is fallacious reasoning; it found that fundamental economic and location factors determine whether a community will grow or decline and that the availability of water-related facilities and services plays a minor role. Investment in water seems to be in response to development, not to attract it.[41] It is more likely that the social welfare will be served by pricing water at a rate which reflects its costs rather than in trying to price it to subsidize certain groups. Subsidies are more appropriately done through the tax and income support mechanisms. (A more complete discussion of the issue follows.)

Rate Structures

Most utilities have priced water at the average cost, although theoretically marginal cost pricing would be more efficient. However, there are various market characteristics which make marginal pricing less than optimal. In the presence of economies of scale, which are common in large scale water projects, pricing at the marginal cost would lead to a deficit. Such pricing would require extensive amounts of information which are currently unavailable and, even if it could be collected, would cost too much. Also, marginal cost pricing will not lead to efficient allocation of resources if there are other areas of the economy out of adjustment; but, although marginal cost pricing can not, and probably should not, be achieved, there are elements of it that should be retained. The consumers should pay for the benefits they receive, and those who receive different levels of benefits should pay different rates. This means that a pricing system should be able to respond to changes in costs with changes in prices.

In the past communities in Massachusetts have had times of drought and times of water excess with little change in the price of water. Now the metropolitan area faces a demand which exceeds the supply. The options are to increase the supply or to decrease the demand. This is just the situation discussed by Vickrey. He suggests a system of prices tied into the reservoir level and the interest rate. If the water in the reservoir is overflowing the marginal costs are roughly zero and the price should be too. If the reservoir is neither full nor empty the price should rise at the rate of interest. Once the reservoir is empty the price should be set to limit the consumption to the inflow. [42]

The amount of information necessary to run such a pricing structure is beyond the capacity and interest of most local water departments. However, certain elements of it are applicable. Look at a system which is faced with a supply shortage. Usually the system is expanded and there is a large increase in the amount of water available. The costs of the new supply are used to justify a rate increase. Using Vickrey's model the timing of the rate and supply increases should be reversed. As the supply is depleted the rates should increase to curtail demand. The price should continue to rise until it becomes economical to invest in a larger system, or until the total benefit from the added capacity is greater than its cost. The expansion of the system should result in a lowering of the price of water to encourage full utilization of the new supply.

This system can be further fine-tuned by having a two-part pricing scheme as suggested by Davis and Hanke[6] as well as the National Water Commission.[41] There should be a base fee which covers the fixed costs and an incremental rate which covers the cost of the service.

The service costs vary over distance and time. Pricings which take these factors into consideration are zonal and peak-load. There are few examples of this type of of pricing in practise, although peak-load pricing is being tried by the electrical utilities. Peak-load pricing is a rate structure which charges more for use during the time the greatest demands are placed on the system, such as during a dry, hot summer when both water and electricity use are highest. The case for peak-load pricing of water is strong. A study by Marshall Gysi found that meeting the last 12 percent of a community's summer demands almost doubled the required capital cost of a supply system and cut the marginal community benefits in half. [11] Peak-load pricing can also address the daily variations in water use. Generally utilities operate at a level well below capacity. Demand approaches capacity only a few hours a day for a few days a year. [14] Since maximum daily demand is one of the important factors in the design of a water system, the more the demand can be leveled out the less capacity a system need be designed for. [26] Under the guise of equity, water systems have tended to charge all the customers according to the same rate schedule. There may be differentiation by class of user, such as residential or commercial, but not by zone or peak-load.

Another way the electrical utilities have dealt with the peak-load problem is to have a load shedding program. If a large scale user opts to be in the load shedding program it will receive lower rates in return for agreeing to reduce its total use by a specified amount on an hour's notice. This allows the utility to cut down on total system demands as needed. Load shedding would not work for residential water users because of the logistics of notifying customers of the need to reduce use but it may be adaptable to large industrial water users. It would require modification of meters and probably some capital investment by the industries to increase water storage and recycling capacity.

A rate system based on zonal charges would take into account the conveyance costs. In a system of multiple wells the price of piping the water can exceed the cost of sinking the well. [31] Geography also affects the cost. When there is a rise in elevation, a costly pumping station is required. Many advocate that this cost be borne by those at the higher elevation rather than by all in the system.

It has been the practise among water managers to use one rate structure for all users regardless of the costs they impose on the system. In the past the most frequently used rate structure was one which levied a decreasing per unit charge as the total use increased. This resulted in a de facto subsidy of industry by residential users. The residential users paid the highest per unit rate while industry paid the lowest. In interviews of local water officials this type of structure was justified on the grounds that it would encourage industrial location and expansion and therefore would improve the economic and employment base of the town. Yet this type of subsidy can end up costing everyone more in the long run. The industrial demand is artificially inflated by the low rate which results in water departments expanding supplies in response to the inflated demand. As one water supply is depleted more expensive water sources must be used so the price of water goes up for all customers. If all users were to pay the approximate costs of their demand the demand would be lower and the need to turn to expensive water sources would be unnecessary. In addition it is the large scale users who have the greatest potential for recycling and other forms of conservation.[5] They are also more responsive to price increases. Conley found industry to have a rate elasticity of -.4[4] while residential rate elasticity is only -.2. The more inelastic a use is the more distributional effects an increase in the price will have.

There are various types of rate structures now in use, including block rates, flat rates and fixed rates. A block rate is one where price varies according to the total amount used; it can increase or decrease with use. A flat rate keeps the per unit charge constant, no matter what the total consumption. When a set fee is assessed for a given time period, regardless of use, it is a fixed rate. This is generally used in municipalities which have no meters, or when only a small portion of the consumers have meters.

To illustrate the rate structures assume a consumer uses 6,000 cubic feet of water per year. In a town which has a flat rate of 40 cents per 100 cubic feet the bill would be $24.00 (.4x60=24), with a marginal rate of 40 cents. In a town with a descending block rate of 50 cents per 100 cubic feet up to 5,000 cubic feet and 30 cents per 100 cubic feet after that, the bill for the same use would be $28.00 (.5x50 + .3x10 = 28) and the marginal rate is 30 cents. Given an ascending block rate of 20 cents per 100 cubic feet for the first 1,000 cubic feet and 45 cents for any use in excess of 1,000 cubic feet the bill would be $24.50 (.2x10 + .45x50 = 24.5), the marginal rate is 45 cents. In a towns with a fixed rate the consumer would pay that rate no matter what level of use and the marginal cost would be zero.

Local Issues

In Massachusetts the demand continues to grow while the supply remains the same or decreases due to well contamination. The Metropolitan District Commission, which supplies water to 75 percent of the metropolitan population, is currently exceeding its safe yield capacity by an average of 7 million gallons a day (mgd). [35] Safe yield is the amount which can be depended upon during a dry period. There are two projects under study which could increase the supply, but neither could be in operation in less than five years. Pressure is being put on the local entities to do something about the imbalance between supply and demand.

At this point it is possible for a change in pricing to aid in correcting the imbalance; pricing can help to ration demand while at the same time it can bring forth supply. By raising the price of water, supply sources that were uneconomical to develop may now become feasible. However, it is more likely that initially demand will be decreased as the price goes up. Gysi believes that short term conservation can be achieved through flexible pricing that rises with increasing scarcity. [11] Eventually the revenue from the rate increases will justify the establishment of new supplies.

How much a rate increase will affect demand depends on the type of rate structure and the elasticity of water consumption. The metropolitan area was found to have an elasticity of -.2 at the mean rate of 60 cents per hundred cubic feet. This is fairly inelastic but it could be used to ration demand. For example, by doubling the price of water the consumption would decrease twenty percent. Such a move would bring consumption in the MDC water district in line with the supply which is being overdrawn by approximately two percent of the daily safe yield.

A drastic rate hike may seem inequitable, as it would represent a bigger budget share for a low income consumer than it would for someone with a high income; the larger the portion of a budget which is devoted to an expenditure, the greater the income effect of a price change will be and hence, the greater the change in demand for that commodity. [16] This would lead to a situation where poorer consumers are asked to share a relatively greater burden of conservation. This need not be so. The portion of household budgets allocated to the purchase may be so small that the effect will not be great for any party. [10] Conley found this to be true in California [4] while in Massachusetts in 1975, the fees for water made up less than one percent of the average person's budget, assuming the mean rate of 60 cents per hundred cubic feet. The National Water Commission found that it was "not at all clear that incremental cost-based pricing results in a relative burden on low-income families." [47]

The relation between income and water consumption is not clear. Economic theory predicts that as income increases so will the consumption of most goods. Earlier studies of water use found this to be true. For instance, the Larson and Hudson study of 1951 found an apparent relationship between income and use but this included households which had no indoor plumbing. [23] Greenberg and Hordon's study attributes much of the 60 percent increase in per capita consumption over the last century to the ability to buy such water using appliances as washing machines and garbage disposals. [9] However not all studies found a positive relationship between income and consumption. Gardner and Schnick did a study of Utah in which they found the effect of income insignificant and having a negative relationship to consumption.[4] This is consistant with my findings of a study of the Boston metropolitan area's water consumption in the years 1960, 1970 and 1975. The income effect was insignificant and the sign was unstable for the regression done on the 1975 data.

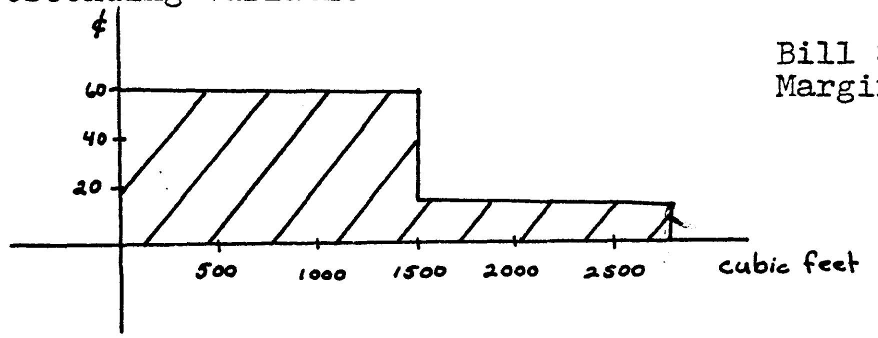
The rate may be structured so that the marginal price faced by the consumer is high although the total budget share may not be greatly altered by a decision to consume more water. Figure 4-A shows four rate structures which would result in water bills ranging from $10.50 to $10.92 for a quarterly consumption of 2,800 cubic feet. For a given family the budget share would be roughly the same under all the rate structures while the marginal cost would vary from zero with the fixed rate to 70 cents for the ascending rate.

According to economic theory a consumer makes a decision based on the margin. The question the consumer asks is, "Is that additional unit of water worth the price charged for that additional unit?". The greater the cost of the additional or marginal unit the more likely the answer will be "no". Thus an ascending block rate may decrease consumption with little change in the budget share expended for water when compared to a descending block or flat rate. A consumer faces a decreasing marginal utility from increasing water consumption. A descending rate structure may

FIGURE 4-A

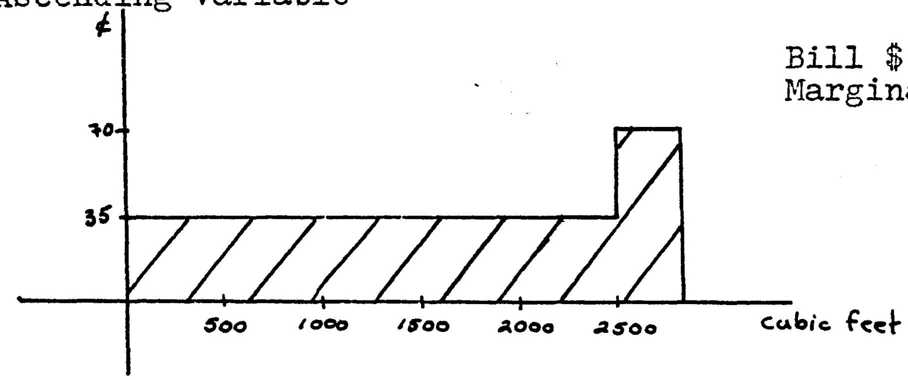
RATE STRUCTURES AND SAMPLE BILLS

Descending Variable



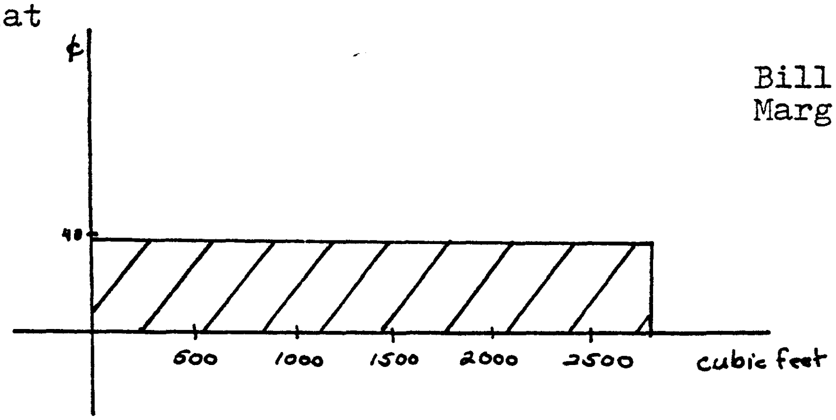
Bill $10.60
Marginal Price $.15

Ascending Variable



Bill $10.85
Marginal Price $.70

Flat



Bill $10.92
Marginal Price $.39

Fixed

Bill $10.50
Marginal Price 0

coincide with this decreasing utility, making a consumer use more water than if the rate were flat or ascending. It may be argued that the marginal price is not important to the average consumer and that what matters is the total bill. If this is true is it possible to devise an equitable pricing structure which encourages conservation without burdening the lower income consumers? Marginal cost pricing can influence the consumer whose only concern is the total bill by making the consumer aware of how a change in consumption will change the bill. This is possible by having a high marginal cost for any use above a predetermined level. This level might correspond to the average winter domestic use which reflects only inside use without the highly elastic outdoor use. [26] If the marginal cost were high the bill would vary from billing period to billing period. Even if the percent changes were not great the bill would never be the same from period to period. The consumer who only looks at the total bil would still realize that use was affecting the price paid. The more frequent the billing period the more obvious would be the relation between use and the price paid. Suppose in the ascending rate structure presented in Figure 4-A the rate increased to $1.50 per hundred cubic feet for any use over 2,800 cubic feet so the bill was $10.85 The next quarter use rose to 3,000 cubic feet; the bill rose to $13.85. A seven percent increase in use resulted in a 28 percent increase in the total bill. While this is still a small portion of a person's income it is a very noticeable change in the water bill.

A flat rate has some of the features of an ascending rate, as the price paid per unit of utility **will increase** after a level of necessity has been reached. The question of defining a necessary amount of water per consumer is a difficult one. In the literature there is agreement that some basic level of water is needed for survival, but what that level is has not been determined. There is also the question of needs above an absolute physiological level, including cooking, bathing, and general domestic use.

Traditionally the sentiment among water supply planners has been that people should be able to have whatever amount of water they want. This is reflected in the constant increase in water supply systems and the growing per capita demand for water. In Massachusetts the daily per capita demand for water is expected to increase .8 gallons a year, down from one gallon per capita annual increase. [24] This, along with decreasing block rates, has lead to an over-inflated sense of demand and premature expansion of systems.

Pricing can deflate the demand and result in a more efficient allocation of resources, both natural and economic, within a society. In a trial application of peak pricing in Washington, D.C., Hanke found that it was possible to appreciably change the existing water supply picture and that the peak "requirements" for summertime use might be greatly reduced if users paid the real costs of their demand. [16] He suggests a price structure with winter rates based on operating costs while the summer rate covers both the operating and capital costs. The National Water Commission also advocates a two part rate. It suggests a fixed fee covering the revenue deficit brought about by marginal pricing in the face of economies of scale, and a second part based on the incremental cost of the services provided. [47] These incremental charges would vary by class of user. Both of these rate structures attempt to provide a key element of an equitable pricing system which is that those who put increased demands on a system, and hence raise the costs, should bear the burden of the increased costs. This same principle is the basis for peak-load and zonal pricing and ascending block rates.

Decreasing block rates may be contributing to Massachusetts's current supply deficit by encouraging over-consumption of water. However, over the fifteen years covered by the sample, the rate structures of the metropolitan area towns have shifted away from the descending block rate in favor of flat rates. In the years since 1975 four towns have adopted ascending block rates. (see Table 4-A) This may reflect a growing awareness of the place pricing can play in the management of demand, although one would expect

TABLE 4-A

RATE STRUCTURE OF THE SAMPLE TOWNS

	1960		1970		1975		1979	
	#	%	#	%	#	%	#	%
Descending Variable	16	39	18	38	13	23	7	13
Flat	25	61	28	60	42	74	41	77
Ascending Variable	0	0	0	0	1	1	4	8
Other	0	0	1	2	1	1	1	2
Total*	31	100	47	100	57	100	53	100

*percents may not total 100% due to rounding those towns trying to ration water through the pricing mechanism would have higher marginal prices. This is not the case. There is no correlation between the type of rate structure and the price charged. Of the towns whose prices are above the mean, 32 percent have descending block rates, while 31 percent of the towns with rates below the mean use this same rate structure.

The price charged generally is based on the average cost of the water supplied. Of the 19 non-MDC towns surveyed seven are self-sufficient departments, eight try to cover costs and four do not cover costs and are subsidized by the town. To determine the price, most take the total water consumed and divide it by the cost of supplying that water. Towns cited the Alpha Act or that they were an "Enterprise" department as the reason that they were required to cover costs. A system which has to cover costs but may not run a surplus can not use marginal pricing because total revenue may be less than total cost when the marginal cost is less than the average cost. This occurs when a system has economies of scale and is operating at less than capacity. A surplus could occur when the marginal cost is increasing. In either case the system is likely to be viewed by consumers as poorly run. When there is a loss the department will be accused of inefficiency, while it might be charged with gouging when it runs a surplus.

The politics of pricing have always been more important than the economic aspects. System managers have been concerned with the revenue aspects of pricing but not the allocation aspects.[4] The laws which govern pricing are concerned with the bottom line, not with how it is achieved. The state's biggest water supplier, the MDC, is restricted by law to run a system which roughly covers its costs from year to year without making a profit, or running a deficit. The rate, which is currently $240 per million gallons, is set by the commission which bases it on the total expenses and the use. The rate can not change in increments less than five dollars. The legislature has given the system the power to issue water system improvement bonds which it can sell to cover capital expenditures but may not be used to run the system. The total expenses include operating expenses and debt service.

It is not clear that the MDC is limited to average cost pricing. Chapter 1039 of the Acts of 1973 states that the rate must be set each year by increasing or decreasing the rate per million gallons to the nearest multiple of five dollars. All towns must be charged the same rate unless a special bill is passed by the legislature. (This has been done for several communities in the western part of the state which receive MDC water.) The difficulties of using anything other than the average cost for a price while maintaining some sort of equity and staying within the confines of the law are viewed as overwhelming by MDC officials interviewed by phone. They see the responsibility for allocation to individual consumers as being the proper domain of local communities.

It is only recently that the MDC has considered issues such as conservation and demand allocation through pricing. The MDC's original mandate was to supply water to the participating towns in whatever quantities demanded. There were no provisions for it to do anything else. However, there are now pressures on the MDC to deal with the issues of demand rather than just responding to them by increasing supply. A conservation policy is being developed which is seen as "an important element in an overall water resource management program." [35] Until this policy is implemented the MDC is not accepting new members unless so required by the legislature.

Throughout the pricing decision by local authorities runs the conflict between wanting to supply water at a very low price due to its essential nature and the general view of public entitlement and the desire to keep taxes and municipal expenditures at a minimum. To subsidize water rates means that the money has to come out of taxes. In one case a local official felt the reverse was true; the water rates were being used to subsidize the tax rate. The general public view seems to be to keep the water rates low. In the late '70's Boston almost doubled the water rates and then proceeded to continue to raise the rates until

1979 when they were down to $7.55 per thousand cubic feet, still more than double the 1970 rate. The public outcry was tremendous and the price of water became an issue in the 1979 city council elections. The public reaction was probably responsible for the decrease in the '79 rates.

The question that politicians must deal with in the setting of water prices is whether water prices should be subsidized or should the consumer pay the costs of their demands? This is not an all or nothing situation as it is possible to derive a system which allows a reasonable level of consumption at a low rate and charges a high marginal rate for use in excess. There are other resources which are essential to survival, such as fuel and food, for which the consumer receives no subsidy at the production level, but for which there are programs of income support such as food stamps and fuel rebates. Is there any reason for water being treated any differently? Would income subsidies be more appropriate and less distorting to the interactions of supply and demand? The answers to these questions must be determined by the state which has the capacity to supplement income but the policy implementation will rest largely with local water departments.

Elements of a Pricing Structure

The municipalities within the metropolitan area face, at best, a short run water shortage. Supply is relatively fixed and demand continues to grow due to both population growth and increased per capita demand. These towns need a conservation-oriented pricing structure that will decrease demand for water in the short run and contribute to efficient use of water resources over the long run. The elements of such a price structure should be based on the premise that the price to a consumer reflects the costs that that increased demand places on the system. More specifically:

1) The price should vary over time. Peak-load prices which charge more for increased water use in the summer would help to level out the demand and would reduce the capacity need within the system. The increased demand in domestic water in the summer is a reflection of outside use which is the most elastic element of domestic use [26] and therefore would be responsive to increased rates.

2) The price should not vary over distance from the source. This contradicts most conservation pricing theory but it is in keeping with the state land use policy which encourages development in urban areas and the containment of dispersed development. [31] Pricing which encourages consumption near the reservoirs in central and western Massachusetts could also lead to degradation of the watershed area needed to maintain the supply.

3) The price should encourage recycling by large scale users. Conrad suggests a differential pricing system based

on an industry's technical ability to adopt water conservation measures.[5]

4) An ascending block rate should be adopted to discourage excessive use. The initial rate increments would be small so that expenditures on basic water needs would represent a low budget share, even for low income families, while the marginal cost for use above this basic level would be high.

5) The price should reflect the availability of additional supply. The scarcer additional water is the higher the price would be. As demand approached system capacity the price would rise sharply to keep demand within the supply capacity. Once a new supply project is completed the price would be lowered to encourage utilization of the system.

6) Price should be the same for all like consumers.

Reference List

1] J. S. Anderson and K. S. Watson.
Patterns of household usage.
Journal of the American Water Works Association 59(10): 1228-1237, 1967.

2] Michael Brewer.
Economies of public water pricing: The California case.
In Stephen C. Smith and Emery N. Castle, Economics and Public Policy in Water Resource Development, pages 222-243. Iowa State University Press, 1964.

3] William H. Bruvold.
Consumer response to urban drought in central California.
National Technical Information Service, report PB-286-625, January 1979.

4] Bryan C. Conley.
Price elasticity of the demand for water in southern California.
Annals of Regional Science 1(1):180-189, 1967.

5] Jon M. Conrad.
Water resource investments under alternative pricing policies.
Paper presented before the Workshop on Water Supply, Tufts University, April 1977.

6] Robert K. Davis and Steve H. Hanke.
Pricing and efficiency in water resource management.
National Technical Information Service, report PB-209-083, December 1971.

7] Dorothy F. Dunn and Thurston E. Larson.
Relationship of domestic water use to assessed valuation, with selected demographic and socio-economic variable.
Journal of the American Water Works Association 55(4): 441-449, 1963.

8] Energy and Resource Conservation Systems, Inc., Boston, MA., also known as ECOS.
How to save water (and fuel and money) in the home, 1977.

9] Michael Greenberg and Robert M. Hordon.
Water Supply Planning: A Case Study and Systems Analysis.
Center for Urban Policy Research. Rutgers University, 1976.

10] Angelo P. Grima.
Residential Water Demand: Alternative Choices for Management.
University of Toronto Press, 1972.

11] Marshall Gysi.
The effect of price on long run water supply benefits and costs.
Water Resources Bulletin 7(3):521-528, June 1971.

12] Robert E. Hall.
TSP: Time Series Processor.
Harvard Institute of Economic Research, Technical Paper Number 12, April, 1975.

13] Steve H. Hanke
Demand for water under dynamic conditions.
Water Resources Research 6(5):1253-1261, 1970.

14] Steve H. Hanke.
Pricing urban water.
In Selma J. Mushkin, editor, Public Prices for Public Products, pages 283-307. The Urban Institute, Washington, D.C., 1972.

15] Steve H. Hanke.
Some behavioral characteristics associated with residential water price changes.
Water Resources Research 6(5):1383-1386, 1970.

16] Steve H. Hanke and Robert K. Davis.
Demand management through responsive pricing.
Journal of the American Water Works Association 63(9): 555-560, 1971.

17] Steve H. Hanke and J. Ernest Flack.
Effects of metering urban water.
Journal of the American Water Works Association 60(12): 1359-1366, 1968.

18] Jack Hirshleifer, James C. DeHaven, and Jerome W. Milliman.
Water Supply: Economics, Technology and Policy.
University of Chicago Press, 1963.

19] Charles W. Howe and F. P[ierce] Linaweaver, Jr.
The impact of price on residential water demand and its relation to system design and price structure.
Water Resources Research 3(1):13-32, 1967.

20] Thomas Knowlton.
Water conservation is a part of good water works practice.
Journal of the New England Water Works Association 93(2):188-195, 1979.

21] Victor Koelzer and Alexander B. Bigler.
Policies and Organizations for Urban Water Management, pages 189-200.
Water Resources Publications, Fort Collins, Colorado. 1975.

22] John V. Krutilla.
Is public intervention in water resources development conducive to economic efficiency?
Natural Resources Journal 6(1):60-75, 1966.

23] Bernt O. Larson and H. E. Hudson, Jr.
Residential water use and family income.
Journal of the American Water Works Association 43(8):603-610, 1951.

24] Stephen P. Lathrop, senior resource planner, New England River Basins Commission.
14 November 1979, interview about the future water supply in the Boston metropolitan area.

25] F. Pierce Linaweaver, Jr. and John C. Geyer.
Use of peak demands in determination of residential rate.
Journal of the American Water Works Association 56(4):403-410, 1964.

26] F. P[ierce] Linaweaver, Jr., John C. Geyer, and Jerome B. Wolff.
Summary report on the residential water use research project.
Journal of the American Water Works Association 59(3): 267-282, 1967.

27] Helen Linsky, MDC Consultant.
19 November 1979, telephone interview about the MDC's supply picture and water conservation program.

28] Edna Loehman and Andrew Whinston.
A new theory of pricing and decision making for public investment.
Bell Journal of Economics 2(2):606-625, 1971.

29] Edwin Mansfield.
Microeconomics: Theory and Applications, pages 92-99.
W. W. Norton and Company, third edition 1979.

30] Commonwealth of Massachusetts.
Report of the special commission relative to determining the adequacy of water supply in the Commonwealth.
House number 5596, January 1979.

31] Commonwealth of Massachusetts. Executive Office of Environmental Affairs.
Massachusetts Water Supply Policy Statement, May 1978.
Known as the gray book.

32] Massachusetts Institute of Technology.
CMS at IPS: A Primer.
Memo VM-1 revision 1. April, 1979.

33] Metropolitan Area Planning Council, Boston, MA.
208 River Basin Studies
Ipswich River Basin, August 1977.
Lower Charles River Basin, November 1977.
North and South River Basin, 1977.
North Coastal River Basin, August 1977.
Upper Charles River Basin, September 1977.
Suasco River Basin, September 1977.
Weymouth River Basin, July 1977.

34] Metropolitan Area Planning Council.
<u>State of the Region</u>, 1977.

35] Metropolitan District Commission. Boston, MA.
Water Conservation report.
Published as a continuing series of topics beginning in June 1979.

36] Jerome W. Milliman.
New price policies for municipal water service.
<u>Journal of the American Water Works Association</u> 56(2):125-131, 1964.

37] New England River Basins Commission.
Report of the Southern New England Study.
Regional and planning area reports, December, 1975.
Known as the SENE Report.

38] Walter Nicholson.
<u>Microeconomic Theory: Basic Principles and Extensions</u>, pages 128-142.
Dryden Press, second edition, 1978.

39] Ralph Porges.
Factors influencing per capita water consumption.
<u>Water and Sewage Works</u> 104(May 1957):199-204.

40] Potlure Rao and Roger LeRoy Miller.
<u>Applied Econometrics</u>.
Wadsworth Publishing Company, Inc., Belmont, California. 1971.

41] RivKin/Carson, Inc.
Population growth in communities in relation to water resources policy.
National Technical Information Service, report PB-205-248, October 1971.

42] Robert J. Rosenthal.
The poisoning of our water supplies.
<u>The Boston Globe</u>, page 1+, 9 September 1979.

43] Robert J. Rosenthal.
Wastes--Permanent Danger?
The Boston Globe, page 1+, 10 September 1979.

44] Robert J. Rosenthal.
State water cleanup? No funds, little staff.
The Boston Globe, page 1+ 11 September 1979.

45] E. Roy Tinney.
Water as a consumer commodity.
Journal of Soil and Water Conservation 26(3):103-107, 1971.

46] United States Department of the Interior.
Cost analysis of ground water supplies in the North Atlantic region.
Cited in Commonwealth of Massachusetts Executive Office of Environmental Affairs, _Massachusetts Water Supply Policy Statement_, page 141.

47] United States National Water Commission.
Water Policies for the Future.
Government Printing Office, 1973.

48] William Vickrey.
Responsive pricing of public utility service.
Bell Journal of Economics 2(1):337-346, 1971.

49] Water Resources Research Center, University of Massachusetts, 1975.
Water Usage Study in Communities Served by the Metropolitan District Commission.
Chapter 13, Water Conservation.

APPENDIX

Methods

The goal of this thesis was to look at the relation between the price and the consumption of water. It was hoped that an elasticity could be derived which could be exploited to encourage water use conservation. To do this I wanted a sample population which varied in some demographic features as well as in prices paid for water.

The Boston Metropolitan Area was chosen as the data base, for ease of data collection. There are 78 cities and towns in the area. I immediately dropped from the sample all towns with a population less than 10,000 in 1975. Most of these towns rely on private wells for water supply. Some towns simply did not have the information I needed and so were dropped. There are three pairs of towns which share water systems and keep records system-wide rather than by municipality, even if the two towns charge different rates. These pairs of towns were dropped. Lynnfield has two systems within the town which charge different rates, as well as a portion of town supplied by individual wells and so was dropped. A few towns are unmetered, charge a fixed rate or have a minimum rate which covers almost all residential use and so is like a fixed rate. Since the residential consumers would act as though there were no charge for water or the marginal cost of water were zero, these towns were dropped from the sample. Walpole was the only town dropped because of its data. The water consumption was so high that I assumed that the figures were wrong or at least so unique as to warrant being removed from the sample. It is possible that the consumption is altered by the presence of two state prisons and a state hospital. For an annotated list of the municipalities dropped from the sample see Table A. This left 57 towns in the sample. See Table B for the complete sample.

At first I thought I would do a large-based cross-sectional study using current data and a smaller time series study. I was going to use all 57 towns for the cross-sectional study. The time series study would use as a sample those towns which had experienced population growth of less than thirty percent between 1960 and 1975. By eliminating towns which have had extensive growth I hoped to avoid the supply cost effects. In the end I did only cross-sectional studies for the three different periods. I found that the variation in rates was not enhanced by using data from different years.

I made an initial phone survey of local water officials, covering the following questions: 1)What is the current rate structure? 2)Does the water department cover its costs? 3)How long has the current rate been in effect? 4)Have there been any recent changes, or are any anticipated, in rate, usage or supply? 5)What percent of the town is metered? 6)How often are residential customers billed? 7)If there have been any changes in the rate do you have a sense of a change in consumption? 8)Are there any other towns in the same water district?

TABLE A

BOSTON METROPOLITAN TOWNS NOT IN SAMPLE

Town	Reason for Deletion
Ashland	Population under 10,000
Dedham	Joint system with Westwood
Dover	Population under 10,000
Hamilton	Population under 10,000
Hingham	Joint system with Hull, different rates
Holbrook	Joint system with Randolph, different rates
Hull	Joint system with Hingham
Lynnfield	Two systems, one private and one public, within the town as well as private wells
Marshfield	Unmetered
Middleton	Population under 10,000
Millis	Fixed rate so no price effect
Norfolk	Population under 10,000
Norwell	Population under 10,000
Pembroke	Employment data not available
Randloph	Joint system with Holbrook
Sherborn	Population under 10,000
Topsfield	Population under 10,000
Walpole	Unbelievable data, probably due to the presence of two prisons and a state hospital
Weston	Consumption data not available
Westwood	Joint system with Dedham
Winthrop	Minimum before a charge per cubic foot is assessed is so high that people consume as if it is a fixed rate

TABLE B

TOWNS USED IN REGRESSION EQUATIONS

Town	1975	1970	1960	Sample Number
Arlington	x	x	x	1
Bedford	x			2
Belmont	x	x	x	3
Beverley	x	x	x	4
Boston	x*	x	x	5
Braintree	x	x	x	6
Brookline	x	x	x	7
Burlington	x			8
Cambridge	x		x	9
Canton	x			10
Chelsea	x	x	x	11
Cohasset	x			12
Concord	x	x	x	13
Danvers	x	x		14
Duxbury	x			15
Everett	x	x	x	16
Framingham	x			17
Hanover	x			18
Lexington	x	x	x	19
Lincoln	x	x		20
Lynn	x		x	21
Malden	x	x	x	22
Manchester	x			23
Marblehead	x	x	x	24
Medfield	x			26
Medford	x	x	x	27
Melrose	x	x	x	28
Milton	x	x	x	29
Nahant	x	x		30
Natick	x	x	x	31
Needham	x	x	x	32

Table B Continued

Newton	x	x	x	33
North Reading	x			34
Norwood	x	x	x	35
Peabody	x			36
Quincy	x	x	x	38
Reading	x	x		39
Revere	x	x	x	40
Rockland	x	x		41
Salem	x	x		42
Saugus	x	x	x	43
Scituate	x			44
Sharon	x			45
Somerville	x	x	x	46
Stoneham	x	x	x	47
Sudbury	x			48
Swampscott	x	x	x	49
Wakefield	x	x	x	50
Waltham	x		x	52
Watertown	x	x	x	53
Wayland	x	x	x	54
Wellesley	x	x	x	55
Wenham	x	x		56
Weymouth	x	x	x	58
Wilmington	x			59
Winchester	x	x	x	60
Woburn	x	x	x	62

*Equations were run using Boston and deleting it in 1975

Because of the difficulty in getting demographic data for 1979, I then decided to look at the years 1960, 1970 and 1975. I called all the towns and got rate and consumption data for these years for time series towns and for 1975 for the cross-section towns. Not all the towns have information going back as far as 1960, so I got what I could.

The regression format can only use one number for each variable so I had to establish a system for deciding which rate to use. Therefore I tried to find the marginal cost faced by the average residential consumer. I asked the water department which rate the average customer paid. If this information was unavailable I took the population of the town and divided it by the numer of families to get an average family size. I then multiplied this by per capita domestic water use as given in MAPC's <u>State of the Region</u> [34] and took the rate which applies to this level of consumption. The per capita use was given as a range of gallons per capita per day. I assumed a fairly even level of consumption so that if a water department billed quarterly I would assume a quarterly use 91.5 (or 365/4) times the daily use.

I am primarily interested in the relation between price and consumption, but I also had to include in the regression equations the other factors which bear on consumption. I gathered data on population, income, employment, industrial composition, age composition, density, family size, town growth and age of the housing stock. For a complete list of variable used in all the regressions see Table C.

Population was included to help equalize the comparisons between municipalities and I expected a large positive relationship. Income is a determining factor in most consumption and had been cited in an early study by Larson and Hudson as having a positive, significant relationship with residential use. [23] In regression equations for 1970 and 1975 I used the per capita income for the years 1969 and 1974. There was no per capita income data available for 1960 so I took the median family income in 1960 and divided it by the family size to get a more roughly equivalent income figure although I never directly compared the 1960 figures with the later periods.

Since I could only get aggregate consumption data I felt there should be a component which might pick up different commercial uses of water. The MAPC puts out figures which give the number of employees by place of work broken down by the degree of water use in the manufacturing firms. [33] The firms are classified as "very wet," "wet" and "dry" depending on the amount of water used in production. These categories turned out to be uninformative and the total employment figures seemed to be the key in the regression equation. I expected the level of employment in manufacturing and especially in the water intensive firms to have a positive relation with the consumption.

TABLE C
REGRESSION VARIABLES

Variable Name	Definition
AGE60, 70, 75	Percentof the population aged 0 to 14 years
CAPEMP	Total employment, by place of work, divided by the town population (per capita employment)
CAPOT	Total employment minus employment in wet and very wet manufacturing firms divided by the town employment [TOTEMP - (DRY+EMPOT)]/POP75
CAPWET	Employment in wet and very wet manufacturing firms divided by the population
CCAP60, 70, 75	Per capita consumption for the years 1960, 1970, 1975
CONS60, 70,75	Total water consumed in thousand of gallons for the years 1960, 1970, 1975
DENS70	Population per urban acre
DRY	Employment in dry manufacturing firms, as defined by the MAPC
DRYCAP	Per capita dry employment
EMP63	Total employment for the year 1963
EMPCAP	Employment other than wet and very wet manufacturing divided by the population
EMPOT	Non-manufacturing employment
FAM	Number of families in 1970
Growth	Population in 1910 divided by 1970 population
INC60	Median family income in1960
INC70, 75	Per capita income for the years 1969 and 1974
LAGE	Log of population aged 0 to 14 (AGE)
LCCAP	Log of per capita consumption (CCAP75)
LCEMP	Log of per capita employment (EMPCAP)
LCONS75	Log of total water consumed in 1975 (CONS75)
LEMP	Log of total employment (TOTEMP)
LGROW	Log of the growth in population from 1910 to 1975 (GROWTH)

Table C Continued

LINC75	Log of 1974 per capita income (INC75)
LPOP75	Log of the 1975 population (POP75)
LRATE	Log of the price charged for water (RATE75)
LSTOCK	Log of the percent of year round housing units built 1939 or earlier (STOCK)
MANUF	Total manufacturing employment
MCON75	Consumption when available, otherwise modified pumpage figures
MON60	Median family income in 1960 divided by the number of families
OLD	Population over 14 years of age
OTEMP	All employment other than that in wet and very wet manufacturing firms
Pop10,60,70,75	Population for the years 1910, 1960, 1970, and 1975
PUMP	A dummy variable equal to zero when the CONS75 variable is the total gallons of water pumped into a water system and equal to one when it is the estimation of water consumed
RATE60,70,75	The marginal rate in cents per 100 cubic feet charged the average residential customer
SIZFAM	Average family size, obtained by dividing the population by the number of families
STOCK	Percent of year round housing units built 1939 or earlier
TOTEMP	Total employment by place of work
URBAC	Urban acres
VWCAP	Per capita employment in the very wet manufacturing firms
VWET	Employment in the very wet manufacturing firms, as defined by MAPC
WET	Employment in wet manufacturing firms, as defined by MAPC
WETCAP	Per capita employment in wet manufacturing firms

Table C Continued

WETS	Employment in wet and very wet manufacturing firms
YOUNG	Population aged 0 to 14 years.

The breakdown by wet and dry employment was only available for 1975 but I used the percentages as constant for the three periods for which I ran regression. I asked the local officials about changes in major water users during the time studied and knew there were no dramatic changes. Also, the woman at MAPC who had done the original work on the classification felt that the relative percentages were fairly constant over the period.

The age composition of the town was given as the percent population zero to fourteen years of age. This breakdown was used as it was the only figure available for the three years studied. This percentage of population was used in the equations along with the total population. I also tried running some regressions using the number over fourteen rather than the total population. This segmented population did not offer any new insights and was later omitted. I expected age to have an effect but was not sure if a larger young population would increase or decrease consumption, as it would indicate larger family size and I anticipated certain fixed water uses in any household unit. For instance it takes a fixed amount to water a lawn no matter how many are in the house. At the same time I felt that young children would have a higher per capita use.

There were problems in getting the towns' water consumption data. No town keeps an accurate record of consumption broken down by user categories such as "residential," "commercial" and "industrial", although a few can give what they feel to be a good estimate. Some sources identified the figures as billable consumption, while others only had figures on the amount of water pumped in the system. For the towns which only had pumpage figures I asked for an estimate of the amount consumed. This would exclude water used in fire fighting, line flushing and losses due to leaks. Because of the variation in these figures I tried to derive a variable which I called "modified consumption" or MCON. For this I used the figure given as consumption, and if that was not available I subtracted the estimated water loss from the pumpage figure. If no estimate was available I took 90 percent of the figure given. This reflects a very optimistic view of the condition of the water supply systems. This variable did not produce a better regression than the use of the figures as given (CONS) so I dropped it.

Another way to control for having pumpage rather than consumption figures is to introduce a variable which might serve as an indication of leaks in the system. This should be highly correlated with the age of the water supply system. Boston, which has the oldest system in the United State, has until recently lost 50 percent of the water introduced into its system. [42] To capture this I used the variable STOCK which was the percent of year round housing units built in 1939 or earlier. This should be positively correlated with consumption.

I also tried to get at the age of the system by looking at the ratio of 1910 population to the 1970 population. A town with a low ratio should have a relatively new system, fewer leaks and therefore a lower consumption than its older counterpart. Neither of these variables would be suitable if towns had regular repair programs, but it is only recently that water has been priced at a level that makes it at all economically feasible to pay for maintainence rather than for more water. In the spring of 1978 towns within the MDC began a program of ongoing leakage testing. [35] Previously leakage testing had been expensive and difficult. However, the recent development of electro-acoustical methods has made testing cheaper and and easier. The MDC had purchased new equipment and is conducting a regularly scheduled leak detection program.

Density was tried as a variable. I felt that high density areas would use less water per capita as there would be less outside water use which is the most elastic residential use according to the studies done at Johns Hopkins. [26]

I began running regression equations for all three time periods and looked at the relation between consumption, rate, income, age composition, density, population and employment broken down by level of water consumption. I soon decided to concentrate on the cross-section series for 1975; after I had worked through that, I would consider the same equations using 1970 and 1960 data. It did not look as though much would be gained by doing a time series regression, as the 1975 data on rates had a range of fifteen cents to 90 cents per 100 cubic feet. The data for 1960 and 1970 would not broaden the range, although it would shift the average rate rate down. In 1960 there were 39 observations with an average rate of 28 cents. In 1970 there were 42 observations with an average of 34 cents while in 1975 there were 59 observations with a 49 cent average rate.

After the initial run I dropped Walpole because the data values were beyond reason. Walople may have been influenced by the presence of three state institutions.

The first regression used the following equation: CONS75 = C + RATE75 + INC75 + DRY + WET + VWET + EMPOT + AGE75 + DENS70 + POP75. (see Table C) Population and non-manufacturing employment were significant. The manufacturing employment broken down by degree of water use was insignificant with all t-statistics less than 1. Other equations were run using the per capita figures for the data and trying the modified consumption figures.

For the next run I dropped the modified consumption variable which had lowered the R^2 and had not changed the significance of any of the variables. I also combined the employment data into one variable--the total employment, and introduced the dummy variable PUMP. PUMP was an attempt to improve the consumption variable, which was consumption for some towns and pumpage for others. PUMP was used in the per capita equations. I also tried breaking down employment. This did nothing to improve the equations. The water-intensive employment gave no statistical significance and produced a negative sign. The other employment continued to be very significant.

The PUMP dummy did nothing for the equation and was dropped from further consideration, as was the variable which measured population per urban acre. At this point the income variable had not improved in significance and had an unanticipated negative sign.

The next set of equations was run with a new variable STOCK which was the percent of year round housing units built in 1939 or earlier. The introduction of the STOCK variable raised the significance of the other variables except the percent of the population fourteen and under (AGE75) and reversed the sign on the income variable. The income variable was sensitive to any changes and the sign tended to flop back and forth.

Because of the decrease in the significance of AGE75 I tried breaking down the population into two groupings--those fourteen and under, and those over fourteen. This replaced the total population and the percent fourteen and under. The change in definition did not change the basic relation between the variables and was dropped.

I also ran the variable GROWTH which was the ratio of the 1910 population to the 1970 population. This produced a slightly lower R^2 than when using STOCK and decreased the significance of some of the variables.

The logs of the variables as well as the per capits figures were used with the various equations.

In the end I felt that the best regression equations explaining consumption were as follows:

Equation 1

	T-Statistic	
CONS75 = 903262	1.66042	
-6.154.41(RATE75)	-2.29242	
-11.8348(INC75)	- .185166	R^2 = .9625
44.3633(TOTEMP)	8.94045	
-27422.0(AGE75)	-2.19526	
32.7060(POP75)	9.55785	

Equation 2

	T-Statistic	
LCONS75 = 7.22648	1.95974	
-.186983(RATE75)	-2.52668	
-.178011(LINC75)	-1.11404	R^2 = .9611
.138357(LEMP)	2.60437	
-.554806(LAGE75)	-3.21525	
.919075(LPOP75)	10.9155	

Equation 3

	T-Statistic	
CONS75 = -1483350	-1.77673	
-5711.41(RATE75)	-2.35590	
112.696(INC75)	1.66802	R^2 = .9674
50.1516(TOTEMP)	10.5242	
22720.1(AGE75)	1.25387	
30.3423(POP75)	9.60932	
13377.4(STOCK)	3.53290	

Equation 4

LCONS75 =	2.37177	1.021010	
	-.208564(LRATE)	-3.06745	
	.083671(LINC75)	.502744	
	.220524(LEMP)	4.03569	R^2 = .9681
	-.002815(LAGE75)	-.012213	
	.821136(LPOP75)	9.94473	
	.336809(LSTOCK)	3.28471	

Equation 5

CONS70 =	184959	.467257	
	-10254.7(RATE70)	-2.03358	
	29.4614(INC70)	.594776	R^2 = .94546
	13.4531(TOTEMP)	1.36983	
	1653.09(AGE70)	.238172	
	39.1629(POP70)	10.2980	

Equation 6

CONS60 =	-141203	-.169026	
	-6433.32(RATE60)	-.885454	
	97.5628(MON60)	.418051	R^2 = .9973
	48.1456(EMP63)	7.573160	
	-1137.70(AGE60)	-.051571	
	29.5388(POP60)	6.90284	

The last two equations were run to insure that the data for 1960 and 1970 did not bear any surprises. Employment and population continued to be the significant factors. Income lacked significance as did rate in the regression for 1960. However, rate had the same magnitude coefficient as in the 1975 regression. The lack of significance may be due to the lack of spread in the data points for rate in 1960

In brief the conclusion drawn from the regression equations are that the rate elasticity is -.2, there is no income effect and population and total employment are the most important factors in determining the water consumption in a municipality. In the 1975 regressions age is significant until stock is introduced. This is probably due to the presence of larger numbers of children in the suburbs which also have newer systems and less leakage. There is an income effect when stock is used.