A REVIEW OF THE THEORIES AND EMPIRICAL STUDIES ON THE DEMAND FOR WATER

by

HO-SUNG OH

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Water Resources Research Center
University of Hawaii
Honolulu, Hawaii

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INTRODUCTION

Although efforts to include market concepts in the study of water demand appear in the technical literature as early as 1926 (Metcalf, 1926), it was not until 1959 that some of the more difficult conceptual issues relating to economic demand versus physical requirement were separated (Ciriacy-Wantrup, 1959). Since then, various efforts have been made both by water engineers and economists to further clarify these issues in both theoretical and empirical terms. This paper presents a review of some developments and suggests improvements in several areas.

THEORETICAL ASPECTS OF DEMAND FOR WATER

Concepts of Physical Requirement and Economic Demand

Demand for water is studied to provide the necessary information for making policy decisions on water pricing, allocation, and systems design. In the field of water resources planning, studies on water demand in the strict economic sense have not been given much attention until in relatively recent years. Traditionally *demand* for water, in the more commonplace usage of the term, and water *requirement* were regarded as one and the same concept. Most water policy decisions have been made on the basis of the requirements approach and this concept is still widely used by water resource agencies today.

The concept of water *requirements* is purely a physical-engineering concept. It refers to how much water is needed to produce a unit of product and is usually determined by past trends of uses. An underlying assumption of this concept is that there is a fixed relationship between the output of a unit of product and the quantity of water as a factor input in its production. Similarly, water requirement for domestic use has been determined by the past records of water consumption divided by the population served, namely, per capita consumption. When the problem is forecasting future domestic requirements for water, the estimates of future water uses are determined statistically by extrapolating past trends of per capita water consumption into the projected population. To forecast future agricultural uses, the amount of water physically needed to irrigate an acre of specific crops is multiplied by projected acres. The word *requirement* is often used interchangeably with *use, need, consumption,* and *demand.*

Economic demand concepts are based on the functional relationships between factors such as price, income, and physical quantities consumed, whereas, the requirement concept lacks such functional relationships. A consumer buys a commodity to satisfy his wants. A consumer's individual demand function gives the quantity of a commodity that he will buy a function of many factors such as the commodity prices, income, and so forth. Theoretically, his demand function can be derived from his utility function and budget constraint assuming that he maximizes his utility under the *ceteris paribus* (other things being equal) condition. The consumer reaches his optimal demand when he equates the ratio of marginal utilities of the commodities and their price ratio. The market demand for a specific commodity is simply the horizontal summation of individual demand (see Appendix, Part I).

A producer's input demand is different from a consumer's demand. The producer buys an input to produce a certain product which he wants to sell. The producer's input demand is derived from the underlying demand for the commodity which he produces. His input demand function can be derived from his production function, assuming he maximizes profit under the *ceteris paribus* condition. Thus input demands are derived demands and a rational producer's input demands are identical with the value of the marginal product of the inputs. The market input demand functions are the horizontal summation of each individual producer's demand function in its most simplistic form (see Appendix, Part II).

Generally, a consumer's demand for a commodity is a function of the price of the commodity, prices of substitutes, income, and other socio-economic variables. A producer's input demand is a function of price of the final product, price of the input, prices of substitutes, and the overall level of economic activity of the society. Thus economic demand depends upon various factors which affect demand behavior. To project future demand level of a commodity, all the factors related to the demand behavior must be considered simultaneously and, hence, is much more complicated than the requirement approach. The demand approach allows alternative choices among the controlling factors while the requirement approach does not.

Advantages and Disadvantages of Each Approach

In spite of significant differences between the economic demand approach and the requirement approach, the studies and applications of economic demand have long been relatively neglected in the water resources field. Some major reasons for favoring the requirements approach over the demand approach have been recently put forth as follows: (a) the demand for water relative to the available supply has been small, (b) most people have an erroneous impression that water is free, (c) most water development projects have been financed by public funds, (d) usually engineers who are engaged in water resources planning have little training in economics, (e) there has been relatively little conflict among different water users as well as in water uses, (f) necessary data have not been readily available, and (g) most of engineers who are trained as professionals are unaccustomed to thinking in terms of the impact of alternative policy decisions (Sewell, *et al.*, 1968).

The requirement approach, however, has a big operational advantage. It is easy to use and gives clear cut results. In the past, this approach was regarded as a relatively adequate method in planning and managing water resources even though it has many theoretical defects. Even today most water resources agencies are adopting this approach not only because it is easy to handle but because the economic demand approaches are still in an experimental stage. In fact, the requirement approach has not failed in terms of providing relatively sufficient water supply, as long as (a) the demand for water is small in relation to its availability (where the availability is defined in terms of cost), (b) there are few conflicts in the different uses, and (c) there are easily available funds to develop more water projects. The requirement approach has been adequate in the sense that it probably does not lead to a greatly inefficient or wasteful investment in water resource development.

However, a potentially serious problem may exist in the demand and supply balance as the demand for water increases in relation to supply and as conflicts among the different possible ways of utilizing the resources arise. Also, as demands from other sectors of a society's economy press upon available capital and other resources, the requirement approach becomes more and more inadequate for resources planning and management. The requirement approach tends to result in over-investment through over-building of water supply systems (Hirshleifer, *et al.*, 1969). In addition to this, a *critical* stage may come when the projection of linear growth exceeds the amount of water then available, since the resource is finite (in terms of cost) and the requirement projection, which is largely linear, cannot go on indefinitely. It is no wonder that projected water use based on the requirement approach shows a severe future water shortage in most cases. Required water inputs are, in fact, highly variable in response to the availability and the price of water and the technology of water application. The fundamental difficulty of the requirement approach, however, is that by concentrating on projection of past trends, the attention is drawn away from other variables. There is a strong inclination to ignore further improvements which would reduce waste or leakage of water. Besides, changes in pricing schedules may be omitted from consideration and opportunities to revise the water using equipment or revise water laws over time through building regulations may be neglected (White, 1969).

In addition to these defects, the requirements approach in ground water using areas may be particularly misleading, since past increases in water use may be largely based upon improvements in pumping technology and relative price decreases of inputs such as power rather than net increase in demand. This has been the case for 17 western states (Ciriacy-Wantrup, 1961).

Practical Limitations of the Demand Approach

As mentioned earlier, the fundamental reason for studying the demands for water, including their projections, is to serve as a basis for better policy decisions. If this is to be taken seriously, a separation of the demand and requirements concepts becomes necessary. In empirical investigations, variables pertaining to demand must be differentiated from those relevant to supply. Because the requirements approach seldom separates demand and supply aspects, there is a general tendency to confuse issues that concern pricing to affect water demand vs pricing to cover costs of supplying water. Also the opportunities for policy decisions to reflect the likelihood of changing technology over time are limited by the critical assumption of fixed water use relationships which underlie the requirements approach.

However, the separation of demand and supply in water economics is by no means a simple matter conceptually or empirically.

Agriculture is an area where complications set in especially where water is largely self-supplied. In such a case, no market for water exists and once investments are made to develop and distribute water through diversion canals and ditch systems under force of gravity, the variable costs of producing water become very small. The investment on water is essentially a sunk cost. Meaningful demand function for one input requires that either the prices or the quantities of complementary and competing inputs also be taken into account. In the case of groundwater production for irrigation, the power input is capable of being used for other purposes beside pumping. The technology of applying water as an input is closely related to the technology of applying other inputs such as fertilizer. Under these circumstances, changes in prices and quantities of other inputs affect supply and demand of water at the same time. Decisions concerning the production and consumption of water are made by the same individual or the same group and they are not expressed technically as the decisions of firms in a water market.

Institutional factors such as water rights, water laws, and public decisions on water supply significantly affect the demand and supply of water (Ciriacy-Wantrup, 1961).

Despite these difficulties efforts have been made to apply economic tools to estimate the demand for irrigation water. Ruttan (1965), for instance, attempted to reconcile these difficulties by using a regional equilibrium model based upon a production function and a marginal-value product function but nevertheless the difficulties still remain.

Generally, the problem of separating demand and supply is less complicated in cases where the water is not self-supplied. In this regard, urban uses which are supplied by local water agencies pose less difficulties for demand analysis than self-supplied industries. Although it may not be possible to eliminate all difficulties completely, the accuracy may be greatly aided by carefully disaggregating total water use according to sub-categories of more specific uses on a more or less homogeneous area by area basis.

Water Use Classification and Their Relevance for Water Demand Studies

Traditionally, the uses of water have been classified according to the purposes for which water is used, such as municipal, agricultural, and industrial demands. Each of these aggregated uses can be disaggregated further. For example, municipal use can be sub-grouped into specific uses as residential, commercial, public, and industrial. Most water demand and forecasting studies are related to these particular water uses. Care must be taken, however, in forecasting overall demands from forecasts for individual and particular purposes. The net amount of water required in a region or area is not often equal to the sum of each sector's demands. This is because (a) not all water in various uses is consumed, (b) some water uses occur simultaneously with others, and (c) in many cases, the same water can be used several times.

Another way of classifying water uses is by separating them into withdrawal and on-site uses. Withdrawal uses are those in which water is taken from an original water course such as a stream, lake, or ground-water basin. The amount of water withdrawn is measured at the point of diversion or at the point of intake of the user. On-site uses are those based on the use of water where it occurs, for example, for navigation and for maintaining wild life habitats. On-site uses include flow uses which are those uses for which flow in the natural water course is a necessity. Such uses include electric generation and waste dilution. This kind of water use classification presents an entirely different set of conceptual and empirical issues for water demand studies.

Determinants of Water Demand

The determinants of water demand behavior are also very complicated. Unlike many other economic goods, living things need some minimum amount of water for their survival regardless of its scarcity, price, etc. After a certain degree of satisfaction, additional water is not needed even though it is free. In other words, the marginal utility of water is extremely high at the starting point but decreases rapidly and then reaches the point of negative utility. The range between the two extreme points is relatively short and this is where economic demand analysis has its relevancy. For many purposes, there are no substitutes for water, but a given amount of water can often be reused several times with proper care and adjustment.

Roughly, there are three broad categories of general water demand determinants -- economic, environmental, and technical. The economic determinants of water demand for individuals and other entities consist of such variables as the price of water, price of competing and substitute goods and services, product price level, general price levels, incomes, and habit patterns and for the total economy, the population. The environmental determinants include such factors as soil characteristics, topography, vegetation, climate, and density of population (land area). The technical determinants include the quality characteristics of water and the physical and marginal productivity of water (Bain, *et al.*, 1966). However, at the theoretical level, the determinants of water demands vary with specific uses and from region to region. Moreover, such determinants are significantly affected by institutional factors.

In the technical literature, domestic or residential water uses are frequently referred to in terms of the total water supplied by municipal water authorities. This is misleading, since municiple supplies may also serve industrial, public, and commercial demands which are quite different from domestic demands. Therefore, in the case of urban demand for water, a corresponding classification to specific uses may be established and the determinants of each use category can be investigated theoretically and statistically. A brief discussion of some of the salient points follow.

FINAL DEMANDS

Residential Demand. Residential demand is essentially a final demand for water to satisfy various consumers' needs and desires. These include home uses of water for drinking, cooking, sanitary facilities, bathing, washing and cleaning, watering of lawns and gardens, swimming pools, some type of air-conditioning, and so on. The determinants of this demand may be income of users, price of water, weather conditions, population, acreage of lawn and gardens, and various housing characteristics.

Public Demand. Public demand is not a demand by a purchaser but a diversion of self-supplied water by the municipality to various public uses such as for parks, street cleaning, fire department, schools, and other municipal purposes. Principal determinants would include such factors as the proportion of the city area devoted to public parks and recreation purposes, temperature, and precipitation. The price of water would seem to have little effect on this public demand unless in times of critical water shortages.

DERIVED DEMANDS

Commercial Demand. Commercial demand is a derived demand, determined principally in a city or suburban area by per capita income of the city and the extent to which the city produces commercial goods and services for its own use and for exports as compared to imports it purchases from outside. Precipitation and population density would not appear to have a significant influence on commercial demand, but temperature may be a factor insofar as it influences the rate of use of air-conditioning facilities in commercial establishments. The effects of water price on such demand has not been studied very much, but it would appear that commercial water demand is unlikely to respond much to price changes where water costs are a small portion of the total costs of the commercial enterprise.

Industrial Demand. Industrial demand for water supplied by municipalities varies considerably from region to region according to the degree of industrialization. The determinants of demand depend largely upon the industrial processes involved, the design of the plants, water-using technology, operation period, and outputs. Also, it is expected that the price of water may influence total demand significantly over time, especially for high water use industries.

In brief then, since the four major components of total urban demand are not equally responsive to each of the several potential major determinants of demand, considerable care must be taken to isolate and quantify their separate effects wherever possible.

SUMMARIES OF EMPIRICAL STUDIES

In this section, ten empirical studies on demand for municipal water are summarized in chronological order.[1]

1. J. Charles Headly. 1963. *The relation of family income and use of water for residential and commercial purposes in the San Francisco-Oakland metropolitan area.*

The objective of the study was to define the determinants of economic demand for water used for residential and commercial purposes and to estimate the parameters associated with these determinants as a basis for future projections. Fourteen cities in the San Francisco-Oakland Metropolitan Area were selected to collect time series and cross-sectional sample data. A time series model (1950-1959) was used to describe the unique features of each city studied and a cross-section model (1950-1959) was used to describe the demand relationships shared in common by the cities studied. In the cross-section analysis, population, precipitation, temperature, and price variables were treated as constants so that the study was allowed to be focused on the relation of family and water use.

Examined variables were water purchased, X_0 - gallons per day and exponential functions were used. The best fitting functions were as follows:

$$X_0 = -18.77 + 1.27 X_1 \qquad (R^2 = .80)$$
$$X_0 = .493 X_1^{1.87} \qquad (R^2 = .69)$$

The equations resulted in rather high income elasticities of 1.24 and 1.87. In the time-series analysis, the regression coefficient and the determinant of coefficient value were very poor, but income elasticity of 0.4 seemed to be more reasonable. Headly concluded that there is a positive relationship between family income and residential water purchase and income elasticities derived from time-series analysis seem to be more useful for planning purposes.

2. Manuel Gottlieb. 1963. *Urban domestic demand for water: a Kansas case study.*

This study formulated effects of income and price on domestic demand for water which was an aggregate of industrial, commerical, and public uses supplied by municipal water systems in the state of Kansas as a whole. Cross-sectional data of 1952 and 1957 were utilized. Quantities of water consumed, income and prices were the only variables investigated. Estimating functions were in logarithmic form:

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[1] To the writer's knowledge 15 empirical studies have been completed in this field since 1959. However it has not been possible to include 5 of these studies because they were not available for review at the time of this writing.

$$\log Y = \log a + b \log X + c \log Z$$

where, Y = consumption (in million gallons per year)
X = average household income (in dollars)
Z = price (in cents per million gallon)

In 1952, the income elasticity was 0.45 and the price elasticity was -1.23 and in 1957 the income elasticity was 0.58 and the price elasticity was -0.65. Actual equations did not appear in the study but R^2 values were .67 in 1952 and .69 in 1957. A conclusion was that "price increase tends temporarily to depress per capita consumption of water."

3. Charles W. Howe and F.P. Linaweaver, Jr. 1967. *The impact of price on residential water demand and its relation to system design and price structure.*

Models of water demand and relevant parameters were formulated from cross-sectional data of 39 areas scattered all over the U.S. The study, conducted between 1961 to 1966, differentiated not only between domestic (inside) and sprinkling uses but also among metered, flat-rate, septic tank, and apartment areas. The generalized structure of the domestic demand function is given as follows:

$$q_{a,d} = f(v, a, d_p, k, p_w)$$

where, $q_{a,d}$ = average annual quantity demanded for domestic purposes (in gallons per dwelling unit per day)
v = market value of the dwelling unit (in thousand dollars)
d_p = number of persons per dwelling unit
a = age of dwelling unit (in years)
k = average water pressure (in psi)
p_w = the sum of water and sewer charges that vary with water use (evaluated at the block rate applicable to the average domestic use in each study area)

From this generalized function, more specific linear and multiplicative functions were fitted.
The best fitting equations are:

Metered with public sewer

$$q_{a,d} = 206 + 3.47v - 1.30p_w \quad (R = 0.847)$$

Flat rate and apartment with public sewer

$$q_{a,d} = 28.9 + 4.39v + 33.6d_p \quad (R = 0.946)$$

Metered with septic tank

$$q_{a,d} = 30.2 + 39.5d_p$$

For the case of sprinkling demand, the generalized function is given as follows:

$$q_{s,s} = f(b, q_{max,s}, w_s, w_{max}, r_s, p_s)$$

where, $q_{s,s}$ = average summer sprinkling demand (in gallons per dwelling unit per day)
b = irrigable area per dwelling unit
$q_{max,s}$ = maximum day sprinkling demands (in gallons per dwelling unit per day)

w_s = summer potential evaporatranspiration (in inches)

w_{max} = maximum day potential evapotranspiration (in inches)

r_s = summer precipitation (in inches)

p_s = marginal commodity charge applicable to average summer total rates of use

A logarithmic function was first used then transformed into a linear function.

The best fitting equations are:

Metered and public sewer

$$q_{s,s} = 1.09 + 207(w_s - 0.6r_s) - 1.12P_s + .662v \quad (R = 0.854)$$

Flat rate with public sewer

$$q_{s,s} = 2.00 + 0.783v \quad (R = 0.797)$$

Major findings for the domestic demand were:

1. The demand behavior is best represented by separate linear equations
2. The price elasticity for metered public sewer areas is approximately -0.23
3. The income elasticity, as measured by the surrogate of property value, is approximately 0.35 for all public sewer areas
4. Population density in terms of the number of persons per dwelling unit strongly affects domestic demand in flat-rate and septic tank areas and it appears to be the only significant determinant in the latter areas
5. The frequency of billing and the regional price index appear to have no significant impact on demand or upon price elasticities.

Major conclusions for sprinkling demands were:

1. Sprinkling demands exhibit significantly greater price elasticity than domestic demands
2. Sprinkling demands exhibit substantially higher income elasticities than do domestic demands ranging from about 0.4 for metered western areas to about 1.5 in metered eastern areas
3. The price elasticity for dry western areas is approximately -0.7 (inelastic), whereas the elasticity for humid eastern areas is approximately -1.6 (elastic)
4. The major factors affecting sprinkling demand in flat-rate areas is the property value surrogated for income
5. Frequency of billing and rational price index have no significant impact upon demand or upon price elasticities,
6. In arid areas, maximum day magnitudes of demand do not respond significantly to price changes, but in humid areas they respond to price changes.

4. B. Delworth Gardner and Seth H. Schick. 1964. *Factors affecting consumption of urban household water in Northern Utah.*

This study was conducted in 1962 to determine factors affecting urban household water uses in Northern Utah. The analysis attempted to relate cross-sectional variations of water demands in six northern counties to various factors. Most of the urban families in the counties were supplied by 43 municipal water agencies.

Because detailed data for industrial, commercial, and public uses were not available, the total consumption was treated as residential water uses and other unclassified demands were assumed to be less than 10 percent. Therefore, the total amount supplied was divided by the population served to give per capita consumption of water per day. Examined variables were per capita consumption of water per day (Y), average price (X_1), per capita lot area (X_4), percent of homes with complete plumbing units (X_5), average monthly precipitation (X_6), and average maximum monthly temperature (X_7).

The basic regression formula was the linear function:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + B_7X_7 + e$$

The estimated linear equation derived from the analysis was:

$$Y = 879.93 - 1042.65X_1 - .1852X_2 + .33X_3 + .357X_4 + 849.03X_5 + 301.58X_6 + 2.23X_7 \qquad (R^2 = .55)$$

All the calculated coefficients had the expected algebraic signs except B_2 (income) and B_6 (precipitation). At 5 percent probability level with 35 degrees of freedom, plumbing, price, and lot size were significant. Then only with price and lot size as variables, a linear equation was fitted again. The result was:

$$Y = 302.29 - 1182.49X_1 + .0229X_4$$

The R^2 value improved somewhat and two variables were highly significant. When this function was fitted into logarithmic form, the R^2 value increased to .83. The price elasticity turned out to be -.77.

5. Ronald M. North. 1967. *Consumer responses to prices of residential water.*

Field studies of households using water services were conducted in Georgia in 1965 and 1966. Cross-sectional data were collected from a stratified, random sampling of households in each of fourteen municipal water districts. Data on household characteristics were obtained from households with a combination of mail questionnaires and personal interviews. Collected data were family size, number of bathrooms, dishwashers, washers, sprinklers and pools, lawn area, market value of residence, annual income, price of water, and annual water use. These variables were fitted into linear functions.

Better statistical results were obtained when market value of residence was used as a surrogate for family income level. The good fitting equation for estimating residential use of water within the city of Athens was:

$$Q = -15.415 + 9.2X_1 + 7.27X_2 + 0.86X_6 + 2.13X_7 \qquad (R^2 = .54)$$

where,
X_1 = number of family
X_2 = number of baths
X_6 = lawn area
X_7 = market value of residence

When price and income variables were analyzed to determine their relationship holding constant other variables such as population, weather, bathrooms, *etc.*, the equation showed the best fit with an R^2 value of 0.69 with a significance at 0.01 level:

$$Q = 66.08 - 53.103X_9 + 8.370X_8$$

where, X_8 = income
X_9 = price

Income elasticity was 0.83 and price elasticity -0.67.

6. F.P. Linaweaver, Jr., John C. Geyer, and Jerome B. Wolff. 1967. *A study of residential water use.*

During the years of 1961 to 1966, Linaweaver, Geyer, and Wolff conducted a residential water-use study to determine the water-use patterns and demand rates imposed on water systems and determine the major factors influencing residential water use. Master meters, punched-tape recorder systems, and other experimental instruments were installed to sample residential house and lawn areas in 41 study areas which were carefully classified by climatic characteristics and by metered as well as nonmetered areas. Metered areas were further classified into areas having public sewers and areas utilizing individual septic tanks for sewage disposal. The installation of experimental equipment in the houses studied produced valuable information on maximum daily demand and peak hourly demand problems which are lacking in other studies.

The authors found that water demands vary over a wide range throughout the country from season to season and from area to area. Most of the difference between summer and winter use in residential areas is attributed to lawn irrigation. On a winter day, there are typically two peaks in water use, one in the morning and one in the early evening. On a summer day, a much higher peak occurs at about noon and often an even greater peak occurs during the evening hours. The lower water use in apartment areas compared with residential areas reflects the relatively small lawn areas adjacent to apartment buildings. In areas with metered public water and sewer systems, the higher water use in the West results from the lack of natural precipitation during the summer season. In areas with septic tanks, the annual water use was lower than that for areas with public sewers. Water use in flat-rate areas is more than twice as great as that in block-rate areas. The mean of annual use of the study areas was 398 gallons per day per dwelling unit. Maximum daily demand averaged 259 percent of the annual use with a range from 157 to 541 percent. Peak hourly demand averaged 638 percent of the annual use with a range from 247 to 1,650 percent.

To determine the factors affecting water demands, the demands were separated into domestic demand and sprinkling demand and regressional hypothesis tests were conducted. The principal factors influencing total annual water use in any residential area are the total number of homes, economic level of the consumer, climate, cost of water, and whether or not the consumers are metered or are billed on a flat rate basis. Population density turned out not to be an important variable. Climate is one of the major factors affecting sprinkling demand. Others are irrigatable area, daily evaporation rate, and price of water. Water pressure has little effect on actual domestic and sprinkling uses: it has some effect on leakage. Estimation of income and price elasticities were not made in this study.

7. Thomas R. Burke. 1970. *A municipal water demand model for the conterminous United States.*

This study represents an effort at developing an econometric model of municipal water requirements which incorporates variables reflecting the various factors affecting water demand, using only readily available, published data. The model was used to determine the water requirements of 488 cities grouped into 19 geographic regions and separate regression functions were fitted to the cities within each of the 19 regions. Cross-section data of some 18 variables were examined for this study.

The list of variables are as follows:

1. estimated population served (in millions)
2. value added by manufacture (in million dollars)
3. land area (in square miles)
4. population (per square mile)
5. aggregate income (in millions)
6. number of families
7. precipitation (inches per year)
8. median family income
9. family income under $3,000 (percent)
10. family income over $10,000 (percent)
11. housing units
12. owner occupied housing units (percent)
13. median value of housing units (dollars)
14. manufacturers-total employees (annual average)
15. manufacturers-production workers (annual average)
16. number of retail establishments
17. water pumpage (in gallons)

Log-linear functions were utilized to fit the variables. Among the 19 fitted aggregate state demand models, New York and California's are as follow:

$$\text{New York:}\quad D = 6.8 + 0.2\log X_1 + 0.7\log X_6 - 2.6X_7 \quad (R^2 = 0.85)$$

$$\text{California:}\quad D = 2.6 + 0.7\log X_1 + 0.1\log X_2 + 0.18\log X_{16} \quad (R^2 = 0.86)$$

In New York, important variables are estimated population served (X_1), number of families (X_6), and precipitation (X_7); while in California, they are estimated population served (X_1), value added by manufacture (X_2), and number of retail establishments (X_{16}). In a strict sense, the demand model developed here is a water requirement model since no consideration is given in the analysis to the effect of price on the quantity of water demanded.

8. Stephen J. Turnovsky. 1969. *The demand for water: some empirical evidence on consumers response to a commodity uncertain in supply.*

Turnovsky developed a demand model by linking the formal theory of consumer behavior and the empirical estimation of the determinants of water demands by using econometric methods to determine whether theoretically desired conclusions were supported by the facts of the real world. In particular, this study formulated some demand models in situations where water supplies are known to be stochastic. The model was applied to data from a sampling of Massachusetts towns. Two cross-sections were estimated, one for 1962 and the other for 1965 which were two drought years. The basic models employed were:

(a) Domestic demand

$$x_i^* = a_0 + a_1\sigma_i^2 + a_2p_i + a_3h_i + a_4P_i$$

(b) Industrial demand

$$x_i^* = b_0 + b_1\sigma_i + b_2p_i + b_3IP_i$$

where,

x_i^* = planned per capita consumption in town i (in gallons per day)

σ_i^2 = variance of supply in town i (in gallons per day squared)

p_i = average price of water in town i (in cents per 1,000 gallons)

h_i = index of per capita housing space given by average number of rooms per dwelling unit and median number of occupants per dwelling unit in town i

P_i = percentage of population under 18 in town i

IP_i = index of per capita industrial production in town i

The income variable was substituted for index of per capita housing space because households tend to use as much water as is dictated by their needs and much of their water demand is a kind of derived demand purchased to be used with water-using appliances. Since the number of such appliances (number of bathrooms, washing machines, lawn sprinklers, *etc.*) is clearly related to the amount of real estate used by the consumer, it was felt that consumer water demand will be more closely related to some measure of real estate than to the income flow.

Two examples of best fitting equations are:

Domestic 1965:

$$x_i^* = -138.8 + 0.26\sigma_i^2 - 1.25p_i + 0.08h_i + 0.3P_i \quad (R^2 = 82)$$

Industrial 1965:

$$x_i^* = 58.3 + 0.62\sigma_i^2 - 1.23p_i + 0.02IP_i \quad (R^2 = 87)$$

R^2 values were generally satisfactory, considering that cross-sectional data were being fitted and that it is not easy to relate domestic water demand to pure economic factors. Industrial demand equations performed better on statistical criteria, reflecting that industrial demand does indeed respond more to economic factors. All of the above constant terms were significant. In the domestic demand model, the average price elasticity was -0.3, while housing space eslaticity was greater than unity (1.2). In industrial demand functions, the price elasticity was -0.5 which is greater than that for domestic. The results indicated that firms are more responsive than households to both price and uncertainty factors.

9. Ausberto Guilbe. 1969. *Quantitative analysis of residential water-use patterns.*

With the objective of developing a practical residential water demand function in a Puerto Ricoan community, a total of 327 cross-sectional sample surveys were conducted to get pertinent data on socio-economic factors which are known to influence the water usage for urban residences, old towns, and public apartment-type dwelling classifications. Variables such as number of bedrooms, number of inhabitants per dwelling unit, bathroom facilities, lawn and garden, number of automobiles, swimming pools, and laundering facilities were surveyed via questionnaires. Data on property assessed value and bi-monthly water meter readings for the dwelling units were obtained from the Puerto Rico Bureau of Property Assessment and the Puerto Rico Aqueduct and Sewer Authority.

Exponential functions were constructed for both water use in gallons per capita per day and per day dwelling unit for each dwelling classification. However, domestic and sprinkling water uses were not separated in the study and the price variable was not examined. Analysis revealed that the property assessment value is not only the best proxy of the property value but also the best indicator of various water using facilities such as number of bathrooms, pools, and washers, except the case of public apartment-type dwellings. The basic function used in the study was an exponential function,

$$W = ae^{kg}$$

where, W = water use in gallons per capita daily or per capita per dwelling unit

a = constant

e^k = base of natural logarithms system; 2.718---

g = assessed property value

The fitted function for per capita water use for urbanized dwellings was

$$W = 33.9e^{0.05g}$$

To test the fitted variables, the analysis of variance method was adopted and all estimated parameters were acceptable at 1 percent significance level.

Residential water use has been found to be influenced by factors such as the number and kinds of home water using fixtures, lawn or garden areas, automobile washing requirement, and income level. Property value was closely associated with these factors. To make a simplified functional relationship, the property valuation was used as an indirect indicator of the individual factors related to residential water use for development of the model. However, for public apartment-type dwellings, property value was not adequate as a basis to explain and predict water demand. Instead, the number of bedrooms was found to be more suitable.

10. Steve H. Hanke. 1970. *Demand for water under dynamic conditions.*

Effects of the changes in water price structure on water demands are presented in this study. Time-series data on quantities of water demanded and average prices paid by each sample household between 1956 and 1968 were fitted to a linear regression model. The study area, Boulder, Colorado, changed its water price structure from a flat-rate price to a metered one in 1961. Basic functions for flat-rate periods and metered periods were:

$$q_t = a_1 + b_1 Q_t \qquad \text{(flat rate)}$$

$$q_t = a_1 + b_2 Q_t \qquad \text{(metered)}$$

where, q_t = quantity demanded

b_1 = flat rate price

b_2 = metered price

Q_t = ideal sprinkking consumption

No other variables were examined except the above ones and no other domestic demand functions were presented in the study. His findings indicated that sprinkling demands not only were reduced after installation of meters, but continued to decline every year and domestic demands were reduced by 36 percent after the meter installation and stabilized at this lower level thereafter.

EVALUATION AND SUGGESTIONS FOR IMPROVEMENT

The empirical studies on demand for water reviewed are mostly concerned with finding the determinants of water demand by statistical methods. There are many practical pitfalls to securing satisfactory results by these methods. The task of finding a demand-price-income relationship is made difficult for most cities because the published data do not state separate quantities of water demanded for the four main types of urban water use. Residential, commercial, industrial, and public demands are usually lumped into a single aggregate. Aggregate urban demand per capita is thus obtained in most cases under the title of residential demand.

The summaries of the reviewed empirical studies are tabulated and presented in Table 1.

For the most part the studies attempt to estimate aggregate demands with limited data collected from various communities with different water price and income levels. This data is mainly to reveal the response of urban water demand to either changes or differences in the prices charged for water. But the responsiveness of water demand to changes or variations in prices is predictably different for each of the four major component demands contained in the aggregate: moreover, within a city, different types of water users do not necessarily pay the same price per unit of water. Considering the fact that prices for water are traditionally administered under the purview of public utility commissions and the characteristics of water demand vary significantly from community to community, it is not surprising that the results obtained from these studies are not all very impressive. The relevance of such studies for policy decisions at the local water agency level still remains questionable. If the demand for urban water were to be done at an intra-community level for each homogeneous major water using group, the possibilities of obtaining more reliable results may be increased.

Most of the studies are based on cross-sectional data and only a few studies utilize both time-series and cross-sectional data. This is probably due to the lack of available historical data. The net results of the cross-sectional studies appear to be not only underestimations of the effects of such variables as temperature, precipitation, and population change, but also an overestimation of the effect of price and income variables. These problems are compounded by the existence of multicollinearity and poor values for the coefficient of the determinants. There is some evidence that the aggregation of variables is an effort to avoid the problem of multicollinearity. This may be a reason for the most significant variables frequently being price, income, and lot size. Some of these problems may be partially avoided by the use of time-series data for a sufficiently long time period, but then the corresponding problem of auto-correlation enters. It appears that improvements may be brought about by refinements in the quality of data and the introduction of new variables.

For the most part, the empirical studies did not analyze annual, seasonal, daily, and hourly variations and frequencies of such extreme

TABLE 1. SUMMARY OF EMPIRICAL RESULTS IN RECENT WATER DEMAND STUDIES.

NAME	FIELD OF STUDY	STUDY AREA	TYPE OF DATA	INVESTIGATED VARIABLES	TYPE OF MODELS	SIGNIFICANT VARIABLES	PRICE ELASTICITY	INCOME ELASTICITY	R^2 OF BEST FITTING EQS.
HEADLY	RESIDENTIAL COMMERCIAL	14 CITIES IN SAN FRANCISCO-OAKLAND AREA	TIME SERIES CROSS SECTIONAL	INCOME	LINEAR, EXPONENTIAL	INCOME	N.A.	1.24 (CROSS) .4 (TIME)	.80 (LINEAR) .69 (EXP.)
GOTTLEIB	AGGREGATED URBAN DEMAND FOR WATER	STATE OF KANSAS	CROSS SECTIONAL	INCOME, PRICE OF WATER	EXPONENTIAL	INCOME, PRICE	-1.23 - .65	.45 .58	.67 .72
HOWE AND LINAWEAVER	RESIDENTIAL	39 AREAS ALL OVER THE U.S.	N.A.	MARKET VALUE OF DWELLING UNIT, PRICE, PERSONS, AGE OF DWELLING UNIT, WATER PRESSURE, REGIONAL PRICE INDEX, IRRIGABLE AREA, EVAPORATION, PRECIPITATION	LINEAR, EXPONENTIAL	MARKET VALUE OF DWELLING, PERSONS, PRICE, NO. OF PERSONS PER DWELLING UNIT	- .23 (DOMESTIC) - .7 (SPRINK. W) -1.6 (" E)	.35 (DOMESTIC) .43 (SPRINK. W) 1.4 (" E)	.70 (DOMESTIC) .72 (SPRINKLER)
GARDNER AND SCHICK	AGGREGATED URBAN DEMAND	6 COUNTIES IN UTAH	CROSS SECTIONAL	PRICE, INCOME, VALUE OF HOMES, LOT AREA, PRECIPITATION, TEMPERATURE, PLUMBING UNIT	LINEAR	PRICE, LOT SIZE, PLUMBING UNITS	- .77	N.A.	.55
NORTH	RESIDENTIAL	14 DISTRICTS OF GEORGIA STATE	CROSS SECTIONAL	FAMILY SIZE, BATHROOMS, DISHWASHERS, WASHERS, SPRINKLERS, POOLS, LAWN AREA, VALUE OF RESIDENCE, INCOME, PRICE	LINEAR	INCOME, PRICE	- .67	.83	.67
LINAWEAVER, GEYER, AND WOLFF	RESIDENTIAL	41 AREAS ALL OVER THE U.S.	-----	-----	LINEAR EXPONENTIAL FACTOR ANALYSIS	DOMESTIC = NO. OF HOMES, INCOME, CLIMATE PRICE SPRINKLING = PRECIPITATION, IRRIGABLE AREA, PRICE, EVAPORATION	N.A.	N.A.	-----
BURKE	AGGREGATED URBAN DEMAND	488 CITIES ALL OVER THE U.S.	CROSS SECTIONAL	POPULATION, VALUE ADDED BY MANUFACTURE, LAND AREA, INCOME, PRECIPITATION, HOUSING UNITS, EMPLOYMENT, NO. OF RETAIL ESTABLISHMENTS	EXPONENTIAL	NEW = POPULATION, NO. OF FAMILIES, PRECIPITATION CALIFORNIA = POPULATION, VALUE ADDED BY MANUFACTURE, RETAIL ESTABLISHMENTS	N.A.	N.A.	.85 (N.Y.) .86 (CALIF.)
TURNOVSKY	RESIDENTIAL INDUSTRIAL	UNKNOWN NO. OF TOWNS IN MASSACHUSETTS	CROSS SECTIONAL	VARIANCE OF WATER SUPPLY, PRICE, INDEX OF PER CAPITA HOUSING SPACE, PERCENTAGE OF POPULATION UNDER 18, INDEX OF INDUSTRIAL PRODUCTION	LINEAR	DOMESTIC = INDEX OF HOUSING, SPACE, PRICE, POPULATION UNDER 18; INDUSTRIAL = VARIANCE OF SUPPLY, PRICE, INDEX OF MANUFAC. PRODUCTION	- .3 (DOMES.) - .5 (INDUS.)	1.2 (DOMES.)	.82 (DOMES.) .86 (INDUS.)
GUILBE	RESIDENTIAL	A COMMUNITY IN PUERTO RICO	CROSS SECTIONAL	BEDROOMS, NO. OF FAMILIES, LAWN AND GARDEN AREA, NO. OF WATER USING APPLICANCES, PROPERTY ASSESSED VALUE	EXPONENTIAL ANOVA	PROPERTY VALUE (URBANIZATION) NO. OF BEDROOMS (PUBLIC DWELLING)	N.A.	N.A.	N.A.
HANKE	RESIDENTIAL	BOULDER, COLO.	TIME SERIES	FLAT-RATE PRICE, METERED PRICE	LINEAR	PRICE	N.A.	N.A.	N.A.

demand changes of water demands which are very important in water policy decisions. Only the study by Linaweaver, Geyer, and Howe shows any real consideration for maximum daily demand and peak hourly demand. The reason for neglecting these demand variations is again probably due to the lack of readily available data. Lineaweaver, *et al.*, used various experimental devices to monitor the water-use variations for considerable periods. For a meaningful water demand study, it is necessary to include such analyses on demand variations even at costs of money and time.

None of the empirical studies reviewed make any effort to explain logically why they change from linear to logarithmic functions or from logarithmic to linear functions. Such changes raise a significant question if there is no apparent reason other than the improvement of the regression fit by the change. In the view of the algebraic characteristics of the functions and of the natural characteristics of each water demand behavior, an appropriate function must be chosen logically. The dependent variables of the demand functions are expressed in terms of either average daily per capita consumption or per capita consumption per household unit in most cases. In a few instances these variables are defined in terms of either an aggregate community consumption per day or aggregate demands for specific uses per day. The differences in the definition of the dependent variables result not only in different values for the regression coefficients but also different interpretations even when the same basic data are used. The basis for defining these variables must be carefully determined in order to yield the best results consistent with the purpose of the study.

A final significant shortcoming stems from the fact that little effort was made to clearly separate out the theoretical and the empirical conflicts between the economic demand and requirements approaches. In many respects, these studies are simply regression procedures devoid of substantial economic evaluations. How to overcome both the practical and conceptual problems of explaining water demand behavior in the economic sense is one of the more important issues to be resolved in the water resources field. This issue should be clearly spelled out before actual empirical studies and other efforts to improve on methodologies are undertaken. It is hardly surprising that the empirical studies have not turned out to be any more successful than they are when the issue is unsolved. The difficulties of economic demand may be alleviated to some extent by separating the aggregate demand into more detailed demand according to specific uses on a relatively homogeneous regional basis. Historical observation of the variation in the demands in the view of institutional change may help to minimize the difficulties further. Also it is suggested that assumptions be articulated, although this may not be a perfect means of eliminating them. At the least, a serious consideration of this and earlier suggestions can be expected to lead to further improvements in the results obtained from future empirical studies in water demand.

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APPENDIX

PART I. DERIVATION OF DEMAND FUNCTION

CONSUMER'S INDIVIDUAL DEMAND FUNCTION

A consumer's individual demand function gives the quantity of a commodity that he will buy as a function of many factors such as commodity prices, income, taste, and so forth. Theoretically, the demand function can be derived from the consumer's utility function assuming he maximizes his utility with given income, prices of other commodities, taste, and other factors which affect the consumer's demand behavior.

Consider a simple case in which the consumer's purchases are limited to two commodities. His ordinal utility function is

$$U = f(q_1, q_2) \tag{1}$$

where q_1 and q_2 are the quantities of the two commodities Q_1 and Q_2.

Assume the consumer's budget constraint:

$$y^\circ \geq p_1q_1 + p_2q_2 \tag{2}$$

where y° is given income and p_1, p_2 are prices of commodities Q_1, Q_2, respectively.

In order to maximize the utility function subject to the budget constraint, the consumer must find a combination of commodity that satisfies the equation (2) and maximize the utility function (1). These conditions can be obtained by using the technique of Lagrange multipliers. From the function (1) and (2):

$$V = f(q_1, q_2) + \lambda(y^\circ - p_1q_1 - p_2q_2) \tag{3}$$

where λ is the Lagrange multiplier and V is a function of q_1, q_2 and λ satisfying the two conditions.

To maximize V, calculate the partial derivatives of V with respect to three variables and let them equal zero.

$$\frac{\partial V}{\partial q_1} = q_2 + p_1\lambda = 0$$

$$\frac{\partial V}{\partial q_2} = q_1 + p_2\lambda = 0$$

$$\frac{\partial V}{\partial \lambda} = y^\circ - p_1q_1 - p_2q_2 = 0$$

The demand functions can be obtained by solving this system for the unknowns

q_1 and q_2.

$$q_1 = \frac{y^\circ}{2p_1}$$

$$q_2 = \frac{y^\circ}{2p_2}$$

Given the consumer's income and prices of commodities, the quantities demanded by him can be determined easily from above functions.

CONSUMER'S MARKET DEMAND FUNCTION

In general, the consumer's ordinary demand function for Q is written as:

$$q_1 = f\ (p_1 p_2,\ y\ \text{-----})$$

The market demand for a specific commodity is simply the horizontal summation of the individual demands of each consumer.

PRICE AND INCOME ELASTICITIES OF DEMAND

The price elasticity of demand for Q_1 is defined as the proportionate rate of change of q_1 divided by the proportionate rate of change of its own price with p_2 and y° constant.

$$\varepsilon = \frac{dq_1}{dp_1}\ \frac{p_1}{q_1}$$

An income elasticity of demand is defined as the proportionate change in the purchase of a commodity relative to the proportionate change in income with price constant.

$$\eta = \frac{dq_1}{dy}\ \frac{y}{q_1}$$

Two basic factors affecting price elasticity are availability of substitute goods and the number of uses to which a good may be put. The more and better the substitute for a specific good, the greater its price elasticity will tend to be. Goods with few and poor substitutes - salt and wheat, for example - will always tend to have low price elasticities. Similarly, the greater the number of possible uses of a commodity, the greater its price elasticity will be. Thus a commodity such as wool--which can be used in producing clothing, carpeting upholstery, draperies, and so on--will tend to have a higher price elasticity. On the other hand, income elasticities of "luxury" goods tend to have higher values, while "necessity" items tend to have lower elasticities. But the definitions of "luxuries" and "necessities" are so dubious that they may not be applied uniformly.

PRODUCER'S INDIVIDUAL INPUT DEMAND FUNCTIONS

The producer's input demands are derived from underlying demand for the commodity which he produces. Therefore input demand functions can be derived from the firm's production function. The basic assumption is profit maximization. Consider a production function.

$$q = Ax_1^{\alpha}x_2^{\beta} \tag{4}$$

where q is the quantity of the commodity produced, α, β, and A are constants. x_1 and x_2 are the quantities of inputs X_1 and X_2, and with $\alpha, \beta > 0$, $\alpha + \beta < 1$.

Profit function is given by

$$\pi = pg - c \tag{5}$$

where π is profit
c is total cost
p is price of the final product

Total cost function

$$c = r_1x_1 + r_2x_2 + b \tag{6}$$

where r_1, r_2 are the prices of the variable inputs X_1 and X_2, and b is the cost of the fixed input.

From the above functions:

$$\pi = pAx_1^{\alpha}\, x_2^{\beta} - r_1x_1 - r_2x_2 - b \tag{7}$$

Take partial derivatives with respect to x and x , and let them equal zero:

$$\frac{\partial\pi}{\partial x_1} = p\alpha Ax_1^{\alpha-1}\, x_2^{\beta} - r_1 = 0$$

$$\frac{\partial\pi}{\mu x_2} = p\beta Ax_1^{\alpha}\, x_2^{\beta-1} - r_2 = 0$$

When x and x of these equations are solved, the corresponding input demand functions can be derived:

$$x_1 = \left(\frac{\alpha}{r_1}\right)^{(1-\beta)/k}\left(\frac{\beta}{r_2}\right)^{\beta/k}\left(Ap\right)^{1/k}$$

$$\bar{x}_2 = \left(\frac{\alpha}{r_1}\right)^{\alpha/k} \left(\frac{\beta}{r_2}\right)^{(1-\alpha)/k} \left(Ap\right)^{1/k} \tag{8}$$

where $k = 1 - \alpha - \beta$

The demand for each input will decrease as r_1 or r_2 increases, and increase as p increases. In a perfect competition market, the demand curve for the output of an individual entrepreneur appears as a horizontal line at the level of the market price given by p = constant. If the firm's total revenue is

$$R = pq$$

the marginal revenue is the rate at which the total revenue increases as a result of a small increase in sale. That is,

$$\frac{dR}{dp} = p$$

since p is constant. The marginal revenue curve faced by the individual firm is identical with its input demand curve. Therefore, a rational entrepreneur's optimum input combination satisfies the condition that the price of each input equals the value of its MP.

PRODUCER'S MARKET INPUT DEMAND FUNCTIONS

A producer's individual input demand functions for the one-output-two-input case can be generalized as follow:

$$D_{i_1} = D_{i_1}(r_1, r_2, p)$$

$$D_{i_2} = D_{i_2}(r_1, r_2, p)$$

where D_{ij} is the ith firm's demand for the jth input.

Assuming that all other prices are constant and neglecting the input subscripts, the ith firm's demand function for a particular input is:

$$D_i = D_i(r)$$

where r is the price of input.

The aggregate market demand function is obtained by summing the individual demand functions. If there are m firms demanding the input:

$$D = \sum_{i=1}^{m} D_i(r) = D(r)$$

However, derivation of an individual firm's demand curve and aggregated market demand function for a productive service is not a simple matter if the price of the input factor is allowed to change. The reason is that the various inputs are interdependent in the production process. Hence, a change in the price of one input leads to changes in the rate of utilization of others through substitution, production, and revenue effects. In the case of market demand, the process of addition of individual firm's demand curve is considerably more complicated because when all firms expand or contract simultaneously, the market price of the commodity changes.

Theoretically, consumers' demand functions for the consumers goods and firms' demand functions for inputs can be derived from utility functions and production functions, respectively. However it is a formidable and impractical job to construct each individual's utility functions and each firm's production functions to derive a good's market demand function. The best alternative is to utilize statistical methods with the information of existing or surveyed data relevant to demand behavior.

PART II. SUPPLY FUNCTION OF A MONOPOLIST

An ordinary monopolist whose aim is profit maximization will maximize profit by producing and marketing that output for which marginal cost equals marginal revenue. However, a public utility monopolist, such as a municipal water supply agency, whose aim is not profit maximization acts differently from an ordinary monopolist. Nonprofit maximizing public monopolist's supply condition depends upon a given market demand function (average revenue) and his marginal cost situation rather than marginal cost and marginal revenue. Therefore, his supply is a function of marginal cost and demand. Consequently, his marginal cost curve may be considered as his supply curve both in short-run and long-run cases.

PART III. PRICING OF PUBLIC UTILITIES: MARGINAL COST PRICING VERSUS AVERAGE COST PRICING

Prices for public utility products are charged for two basic reasons when the primary aim of the firm (assume a monopoly) is not profit maximization. One is financial. Enough money must be raised to cover the cost incurred in the production of the goods or services. The other reason is economic efficiency. The quantity of goods people buy depends on prices if other factors are given. If the price is set up to be higher than the equilibrium point between demand and supply curves (or average revenue and marginal cost curves) the quantity demanded will be reduced so that fuller economic utilization of the plant will be prevented. If the price is set lower than the equilibrium point, the quantity demanded will tend to expand beyond the point of economic feasibility since the marginal cost is higher than the average revenue.

It is an economic equilibrium point to produce just up to the point that consumers are willing to pay for the additional unit produced where the marginal cost curve meets the demand curve. These two conditions are satisfied simultaneously in a theoretical long-run pure competition market shown in Figure A-1. At the equilibrium point of the long-run pure competition market, the price is equal to the marginal cost and average cost. However, things are not so simple in the real world of public utility business.

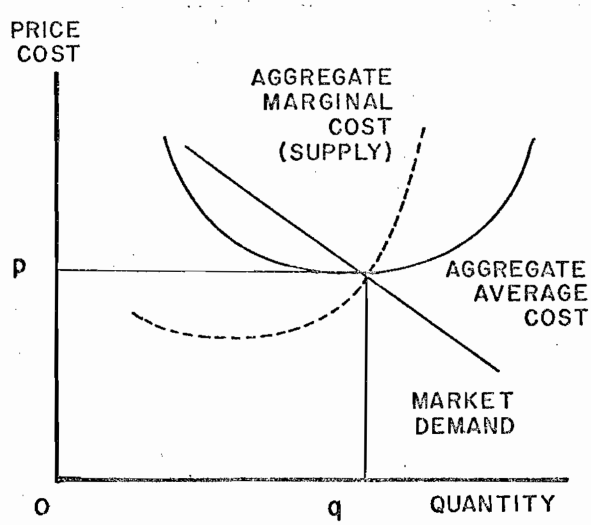

FIGURE A-1. EQUILIBRIUM PRICING.

A municipal water business, for example, is a typical monopoly in that profit maximization is not the aim of the business. Two short-run monopoly market conditions are assumed where the monopolist's scale of production is large of the total demand is relatively small.

First, consider a case in which the scale of plant is almost as large as the total market demand as shown in Figure A-2. Then the optimum quantity production is oq determined by the intersection of demand and supply curves. A monopolist can charge op_1 price per unit of products which is the marginal cost pricing. This op_1 price satisfies the economic condition that the marginal demand cost is exactly the same as the level of the price which consumers are willing to pay for an additional unit of product. With marginal cost pricing, the monopolist not only can redeem the cost incurred, but also enjoy $(p_1 - p_2)q$ amount of profit which may be invested for an additional unit of plant to meet expected future increase in demand.

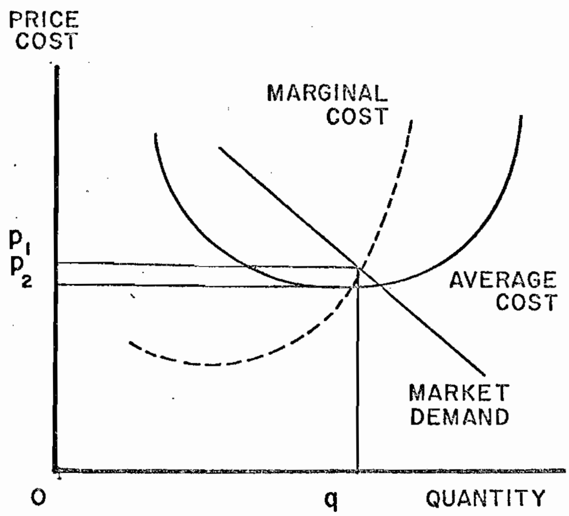

FIGURE A-2. MARGINAL COST AND AVERAGE COST PRICING WHEN DEMAND IS LARGE.

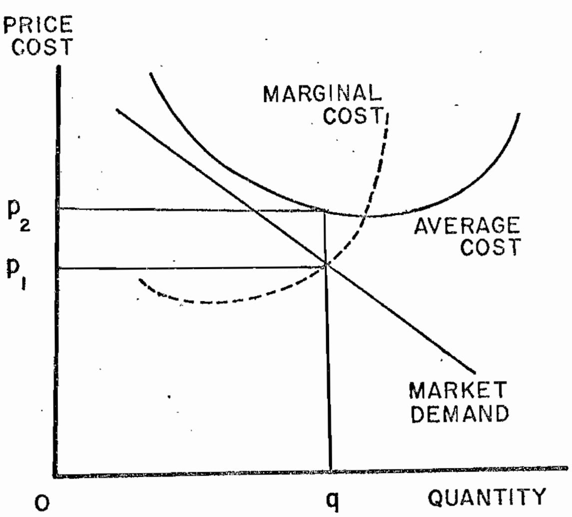

FIGURE A-3. MARGINAL COST PRICING AND AVERAGE COST PRICING WHEN THE DEMAND IS SMALL.

The alternative pricing technique is to charge op_2 level of price which is the average cost pricing. With the average cost pricing, the monopolist can satisfy only the financial requirement by covering the costs incurred in production.

Secondly, consider the other case in which the demand is relatively smaller than the scale of the existing plant (or the cost of development is very high), as shown in Figure A-3. The optimum production level is determined at the oq level. In this case, the marginal cost pricing op_1 satisfies only the economic condition. With an op_1 price, the monopolist will not be able to cover the costs incurred in production and will suffer from $(p_2 - p_1)q$ amount of loss. To avoid this loss and fulfill the financial requirement, the price would have to be set at op by average cost pricing. However, the total demand may be reduced preventing fuller economic use of the plant due to the higher charge than the consumer is willing to pay.

Generalizing these two cases, under conditions of increasing average costs, the marginal cost pricing technique more than satisfies the financial requirement. Under conditions of decreasing average cost, there is a dilemma. Marginal cost pricing does not raise enough revenue, and average cost pricing restricts full economic use of the plant. Some compromise between the conflicting requirements is required. Alternative approaches are available for reconciling these conflicts. One possibility is to employ price discrimination to capture some of consumers' surplus. The second approach is to find an outside benefactor willing to subsidize the project by the amount of loss. In water resources planning, the benefactor is usually the federal, state, or local government. The third approach is to levy a tax or some lump sum fee on those using output while maintaining marginal cost pricing.