AN ECONOMIC APPROACH TO WATER SUPPLY PLANNING IN SOUTHEASTERN VIRGINIA

by

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TABLE OF CONTENTS

Chapter 1

INTRODUCTION

Economics and Water Supply Planning

Municipal water supply planning has been a frequent subject of theoretical analyses by economists. It has been generally concluded in such analyses that water supply planning, as it is usually practiced, violates certain principles of economic efficiency.

The usual procedure of water supply planning involves the projection of water "requirements" on the basis of past trends in population growth and per capita water use. These requirements are then compared to the existing capacity of the water supply system in order to determine the need for future increases in the capacities of those systems. An effort is then made to determine the cost effective manner in which to meet those needs, given the various constraints which may exist regarding the use of various sources.

This basic approach has been criticized by economists on the grounds that the role of price in influencing the use of water is ignored. Economists maintain that, except in unusual cases, the variation of price in response to long-term changes in the demand for water, such as would accompany an increase in population, is a necessary condition for the achievement of efficiency.

There are many economic models of varying degrees of sophistication which address the issue of water supply planning. However, there have been few analyses which have applied the techniques of economic analysis to actual cases of water supply planning. The current water supply situation in southeastern Virginia offers an excellent opportunity for an in-depth application of economic theory and methods in an attempt to evaluate alternative courses of action and to develop an economically efficient response to that situation.

The Water Supply Situation in Southeastern Virginia

The population of the southside of Hampton Roads in Virginia (Figure 1.1), has increased substantially in the past ten years and is expected to continue to grow.[1] The increase in population has been accompanied by a significant rise in the level of water use in the area. Table 1.1 shows projected levels of population and municipal water use in the principal cities of the area.

The principal sources of publically supplied water in the cities of Portsmouth, Norfolk, Virginia Beach and Chesapeake are the water supply systems of Portsmouth and Norfolk. The Norfolk water system presently provides water to that city and also provides water in bulk to Virginia Beach and Chesapeake. The bulk purchases of water account for all of the publically provided water used in Virginia Beach and

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[1] Commonwealth of Virginia, Department of Planning and Budget, Economic Research Section, "Population Projections, Virginia Counties and Cities 1980-2000" (Richmond, Va., June 1977).

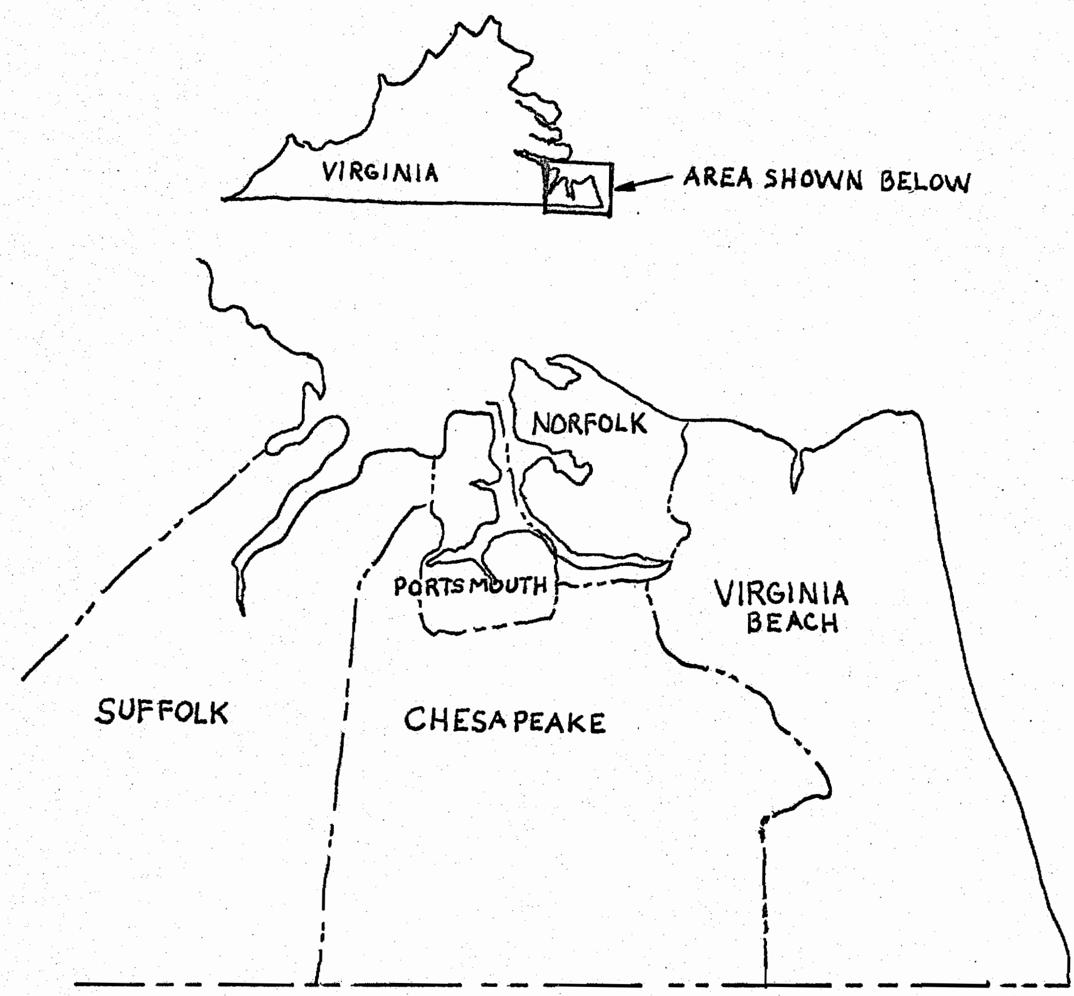

Figure 1.1 Southside Hampton Roads

TABLE 1.1

PROJECTED AVERAGE DAILY USE[a] AND POPULATIONS[b]

		1980	1990	2000	2010	2020	2030
Norfolk	MGD	46.6	49.8	52.7	55.1	56.8	58.3
	Pop.	(291,000)	(293,000)	(293,000)	(293,000)	(293,000)	(293,000)
Virginia Beach	MGD	22.1	33.7	44.4	53.6	63.7	74.3
	Pop.	(249,000)	(315,000)	(359,000)	(399,000)	(444,000)	(493,000)
Portsmouth	MGD	15.5	17.3	18.9	20.2	21.5	22.5
	Pop.	(115,000)	(119,000)	(122,000)	(124,000)	(127,000)	(129,000)
Chesapeake	MGD	8.7	12.7	16.7	20.7	24.7	28.7
	Pop.	(112,000)	(137,000)	(155,000)	(176,000)	(197,000)	(218,000)

[a]Source: Department of Public Utilities, City of Chesapeake; Department of the Army, Norfolk District, Corps of Engineers

[b]Source: Southeastern Virginia Planning District Commission

approximately two-thirds of such water used in Chesapeake.[2] The Portsmouth water system provides all water used in that city and provides, in bulk, approximately one-third of the water used in the public water system of Chesapeake.

If the substantial projected increases in water use in Virginia Beach were realized, the capacity of the present Norfolk water system would become inadequate within ten years. This would be the case even though water use in Norfolk is expected to remain relatively stable and Chesapeake plans to cease its purchases of water from Norfolk in that period.

Water use in Chesapeake is also expected to increase substantially in the future. While Chesapeake is in the process of developing its own water source, it is expected that additional sources will be required in approximately ten years.[3]

Water use in Portsmouth is expected to increase slowly due to limited growth in population. The capacity of the existing water system would be adequate to meet projected levels of water use in that city over the next 50 years.[4]

Responses to the Projected Shortages

The eventual need for additional sources of water to provide for the projected levels of use in Norfolk, Virginia Beach and Chesapeake

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[2] City of Norfolk, Department of Public Utilities.

[3] City of Chesapeake, Department of Public Utilities.

[4] City of Portsmouth, Department of Public Utilities.

(NVBC) has been a matter of concern for those officials having responsibility for water supply planning in the area. The Southeastern Virginia Planning District (SVPDC) in 1970 engaged an engineering consulting firm to analyze the water supply situation. The study by this firm recommended the development of the Blackwater River as a source of additional water.[5]

A regional water supply authority, the Southeastern Water Authority of Virginia (SWAV), was formed in 1973. This authority was comprised of all the member jurisdictions of the SVPDC and had as its sole purpose the coordination of efforts to seek a long-term solution to the projected water shortages. SWAV engaged the same consulting firm that had conducted the previous study for SVPDC to reassess the water supply situation and to recommend a solution to the area's water supply problem. An important reason for this second study was that the environmental impact of developing the Blackwater River appeared serious enough to present difficulties in obtaining the necessary permits. The second study recommended that the projected water needs of the area be met through the use of water from Lake Gaston.[6]

SWAV was disbanded in 1975 and its functions assumed by the Southeastern Public Service Authority (SEPSA). SEPSA sought the assistance of the U.S. Army Corps of Engineers (COE) in determining the appropriate

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[5]Henningson, Durham and Richardson for the Southeastern Virginia Planning District Commission, Potable Water Supply Feasibility Study (March 1972).

[6]Henningson, Durham and Richardson for the Southeastern Water Authority of Virginia, Water Sources for Southeastern Virginia (July 1975).

response to the perceived water supply problem. The COE was authorized by an act of Congress to conduct a federally funded study of the water supply situation in southeastern Virginia. SEPSA is currently awaiting the results of a comprehensive study of all water resources available for use in southeastern Virginia. The final report of that study is due in June 1978. An intermediate step in this analysis was the elimination of all but five potential sources of water. The final recommendation will call for the use of either the Blackwater River, Lake Gaston, the Roanoke River, the Chowan River, or the Appomattox River. The use of any of these sources would involve the transmission of raw water over relatively long distances. The proposed sources of withdrawal from both the Chowan and Roanoke Rivers would be in North Carolina. Each of the proposed sources would be ultimately capable of providing 70 million gallons per day (MGD) when developed as proposed by the COE.[7]

The Political Setting

Considerable attention has been paid recently to water supply planning, both in Virginia and at the national level. The interest in Virginia arises, primarily, from projected water shortages in Southeastern Virginia and in Northern Virginia. At the national level, several agencies of the executive branch have perceived the possibility for substantial improvements in the conduct of water supply planning through major changes in policy.

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[7] Department of the Army, Norfolk District, Corps of Engineers, "Announcement of the Third Public Meeting on Water Supply Study for Southside Hampton Roads, Virginia" (October 21, 1977).

The Virginia State Water Control Board (SWCB) has proposed that an interim solution to the projected water shortage in NVBC could be achieved through water conservation, i.e., reduced levels of water use.[8] The U.S. Environmental Protection Agency has proposed that it withold partial funding of sewage treatment plants unless municipalities enact water conservation ordinances. It was proposed that a goal of a 15% reduction in water use would be reasonable.[9] The Secretary of the Interior has been actively concerned with the question of water policy. He has also proposed regulations that would make partial federal funding of water resources projects, having water supply aspects, contingent upon steps aimed at reducing water use.[10] There has been little work done in determining the net effects of such policies upon the benefits derived from water use. It seems apparent that the impact of reductions in water use would vary among municipalities depending upon the particular set of circumstances involved.

Alternative Approaches to Water Supply Planning

Each of the previous studies have employed essentially the same approach. The projected levels of water use were examined relative to the capacities of the systems serving the area in order to determine

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[8]Water conservation was proposed by the SWCB in a presentation to SEPSA, September 28, 1977.

[9]Statement of T. Jorling, Assistant Director of EPA, before the Senate Subcommittee on Environmental Pollution, June 1977, Federal Register 4 (July 25, 1977): 37941-37954.

[10]Gaylord Shaw, "Water Policy Would Tie Waste to Loss of Federal Aid," Virginian-Pilot, May 19, 1977.

future shortfalls in the existing systems. These shortfalls were considered to be the water "requirements" of the area to be supplied by additional sources of water. Estimates of the costs of developing the various sources capable of supplying these requirements were then derived in order to determine the least cost means of doing so. This basic approach to water supply planning, meeting projected water needs through the development of cost effective sources, is the standard practice of agencies involved in water supply planning.

A substantially different approach to water supply planning is suggested by economic theory. Economic theory leads to an examination of the relationship between price and quantity of water consumed rather than the acceptance of a fixed water requirement. The determination of the appropriate response to the water supply situation would require an analysis of the costs and benefits of alternative courses of action. It would be necessary to determine the benefits associated with the levels of use other than those originally projected. The original projections of use can still be seen as valid, yet it is recognized that those projections represent estimates of future use given a certain level of price.

Previous Economic Analyses

The problem presented by water supply planning has been a frequent subject of economic analysis. The determination of the net benefits of supplying particular quantities of water in a certain manner involves straightforward cost-benefit analysis and has been conducted for many such situations. Hirschleifer et al. in their work explained the basic procedure of cost-benefit analysis.[11] The basic elements of such analyses are the use of the demand curve for water in the estimation of the benefits derived from water use and the discounting of benefits and costs in future time periods in order to express net benefits in present value terms.

The determination of the proper level of capacity and water use, given their costs and the benefits associated with water use, has been analyzed by Davis et al., Hirschleifer et al., and Coase.[12] They determined that in the case of static demand, the appropriate capacity of a water supply system would be that level at which the marginal value of water would be equated with the long-run marginal cost of its provision. The marginal costs of water supply would include the marginal costs of constructing the necessary facilities as well as the operation and maintenance costs.

A closely related issue involves the operation of existing facilities. Both Feldman and Hirschleifer have examined this issue and concluded that existing facilities should be operated at that level at which the marginal value of water is equated with the marginal costs of operating the facilities.[13]

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[11] Jack Hirschleifer et. al., Water Supply: Economics, Technology, and Policy (Chicago: University of Chicago Press, 1969).

[12] Robert K. Davis et al., Pricing and Efficiency in Water Resource Management (Springfield, Va.: National Technical Information Service, 1971), pp. 37-38; Hirschleifer, Water Supply; Ronald H. Coase, "The Marginal Cost Controversy: Some Further Comments," Economica 1 (May 1947): 150-153.

[13] Stephen L. Feldman, "On the Peak-Load Pricing of Urban Water Supply," Water Resources Research 11 (April 1975): p. 355; Jack Herschleifer, "Peak Loads and Efficient Pricing: Comment," Quarterly Journal of Economics 72 (August 1958) 451-462.

The problem of determining the appropriate timing of expansions in the capacity of water supply systems when demand is increasing over time has been examined by Williamson. His analysis considered discrete increases in capacity and concluded that expansion should take place when the annual benefits derived from the additional capacity exceeded the annual costs of the expansion. While this decision rule would indicate the appropriate time to invest in a particular set of facilities, the more general issue of determining the timing and size of expansions in capacity was not addressed.[14]

Riordan developed a model for the selection of optimally sized expansions in capacity and their implementation at appropriate times. This dynamic programming model involved the iterative comparison of the net benefits of different sets of facilities placed in operation at the proper times.[15]

The Approach of this Study

The analysis of this study will differ substantially from the preceeding analyses of water supply investment decisions. An important omission in previous analyses of water supply planning has been the failure to consider the effect that decisions made with regard to the water supply system can have upon the costs incurred in waste water treatment.

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[14] Oliver E. Williamson, "Peak Load Pricing and Optimal Capacity," American Economic Review 56 (September 1966): 810-827.

[15] Courtney Riordan, "General Multistage Marginal Cost Dynamic Programming Model for the Optimization of a Class of Investment-Pricing Decisions," Water Resources Research 7 (April 1971): p. 215.

An attempt to identify the proper response to the water supply situation when this influence is taken into account is complicated by the differing quantities of waste water produced by the same levels of different types of use. It is generally infeasible to price the different types of water on the basis of the quantities of waste water produced by them due to the high cost of installing meters to measure waste water flows.

This analysis will attempt to determine the appropriate use of alternative sets of water supply and waste water treatment facilities. The objective will be the achievement of economic efficiency given the costs and benefits associated with alternative responses to the water supply situation over time.

The detailed engineering data necessary to determine the most efficient manner in which to expand the water supply system were not available. That determination would have required estimates of the costs of water supply and waste water treatment facilities of every possible size. It was felt that the less ambitious objective of determining the appropriate use of those facilities, for which detailed cost information was available, will prove useful in its implications for this area and for water supply planning in general. This would be the case because the choice of the facilities to be employed has been effectively limited to those to be analyzed. There are also several important unexamined aspects of water supply planning which can be fruitfully approached on that basis.

Objectives

The objectives of this study are to evaluate the principal proposed approaches to the future conduct of the water supply function and to develop an economically efficient response to the water supply situation.

More specifically, the objectives of this study are:

1. To estimate the net benefits associated with supplying the projected levels of water use in Portsmouth, Norfolk, Virginia Beach and Chesapeake, through the use of the proposed alternative sets of water supply and waste water treatment facilities.

2. To estimate the net benefits associated with reductions in the projected levels of water use achieved by water use restrictions, by increased prices, and by the installation of water saving devices. In each case, the net benefits are to be estimated for each of the proposed sets of facilities.

3. To determine the most efficient manner in which to employ the existing and variously proposed water supply and waste water treatment facilities, given the demand relationships to be projected in this analysis. A principal element of this objective would be the scheduling of the different expansions in capacity.

Procedures

The analyses related to each of the above objectives required a determination of the relationship between the quantity of water supplied and the benefits derived in each of the cities during the coming years. The estimation of the benefits of water use relied upon the estimated demand curves for the different types of use. The demand curves were estimated on the basis of projected levels of use at existing prices and estimates of water use demand elasticities derived in previous studies.

It was also necessary to obtain estimates of the costs of operating the existing water supply and sewage treatment systems. The estimated costs of constructing, operating, and maintaining the facilities which could be employed in increasing the capacity of the above systems were also required. The estimation of the costs incurred in sewage treatment required a determination of the relationship between the level of water use and the quantity of waste water produced.

The evaluation of each of the alternative courses of action, including the optimal responses, was conducted by examining the benefits and costs associated with the use and provision of water in excess of projected 1980 use. For none of the alternatives would use in any year be less than projected 1980 use. The costs and benefits associated with projected 1980 use would be the same for each of the alternative courses of action. The estimated net benefits associated with use in excess of projected 1980 use could, therefore, be used to determine the difference in the <u>total</u> net benefits associated with the alternative courses of action.

The estimation of the net benefits of supplying the originally projected levels of use was conducted by, first, determining the benefits which would be derived in each year from the projected levels of use. The costs associated with the operation of the existing facilities and the construction and operation of the proposed facilities, in such a manner that the projected levels of use could be achieved, were then estimated for each year. A determination of these costs required that a schedule be developed for the expansions in the capacities of the water supply and sewage treatment systems. The annual benefits and costs were then discounted in order to determine the present value of net benefits in 1980.

The determination of the optimal courses of action, given the projected water demand curves and the costs associated with existing and proposed water supply and waste water treatment facilities, involved the derivation of schedules for investment in the additional facilities. The proper timing for investment in additional facilities was found by comparing the annual benefits which would result from the increases in capacity to the annual costs incurred in effecting the expansion in capacity. The optimal investment schedules were derived for each of the potential sources of additional water.

The net benefits associated with the optimal use of the different sets of facilities were found by first determining the benefits in each year resulting from the levels of water use dictated by the capacity of the water supply system or the sewage treatment system, whichever happened to be the effective constraint on the level of water use. The costs in each year associated with the operation of the existing facilities, and the construction and operation of the proposed facilities were then found. The annual benefits and costs were discounted in order to obtain the net benefit estimate in present value terms.[16]

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[16] The evaluation of the proposed responses and the determination of the optimal responses were conducted with the use of computer programs developed with the assistance of Robert B. Jensen.

Contents

The theoretical model necessary to conduct the analysis will be developed in Chapter 2. Chapter 3 will present the procedures employed in the estimation of future water demand curves. Chapter 4 will contain an evaluation of supplying the projected levels of water use. Chapter 4 will evaluate certain reductions from the projected levels of use. Chapter 5 will contain a determination of the optimal manner in which to employ existing and proposed water supply and waste water treatment facilities. Chapter 6 will present a comparison of the net benefits of the different responses examined in Chapters 4, 5, and 6. Chapter 6 will also discuss the implications of the study, with the objective of providing a basis for the more efficient conduct of the water supply function, both in the cities studied and in other areas experiencing similar problems.

Chapter 2

THEORY

Introduction

Economic models capable of providing a basis for the evaluation of alternative courses of action, as well as serving to suggest appropriate courses of action, will be developed in this chapter. While a variety of different models will be developed, there are two elements which are central to all of the models: the evaluation of the benefits derived by the use of water through estimates of willingness to pay (WTP) and the evaluation of the costs incurred in the supply of water and treatment of sewage through estimates of the opportunity costs of the resources expended.

The Benefits of Water Supply

An individual's WTP for a particular quantity of water is the maximum amount of money an individual would be willing to pay in order to consume that quantity rather than to do without it. Obviously, the total WTP for the levels of use normally encountered would be quite high, reflecting the lack of close substitutes for a commodity of vital importance. It is not necessary to estimate WTP for the entire quantity of water provided because the purpose of this analysis is to determine the merit of changes from the present levels of use. What is of concern, then, is the WTP for changes in the level of consumption within a range over which estimates can be made with greater confidence than for WTP for the entire quantity used.

The concept of WTP can be illustrated through the use of the indifference map of a typical individual as shown in Figure 2.1. Let point A in Figure 2.1 represent the individual's present level of consumption of water and of expenditure upon other goods, given the budget constraint v_3q_3. It may be assumed that for any initial combination of consumption of water and other goods that there is a continuous function passing through the point representing that level of consumption which defines a set of consumption points among which the individual is indifferent. Each point on such a function yields the same level of utility to the individual. The indifference curve of an individual, if known, could be examined in order to assess the value that the individual places upon a change in the quantity of water which he consumes. In the above figure, for instance, the individual initially at point A would be indifferent between remaining at point A and paying an amount of money equivalent to the distance between v_1 and v_2 in order to increase his consumption of water from q_1 to q_2. A payment of any amount greater than that would leave the individual worse off; a payment of any amount less than that would leave the individual better off than at point A. The difference, v_1 minus v_2, therefore, represents the individual's maximum willingness to pay for the change in the quantity of water consumed. It is an estimate of this WTP which will serve as a measure of the value of various quantities of water.

A function expressing the <u>slope</u> of the individual's initial indifference curve can also be used to determine the WTP for particular

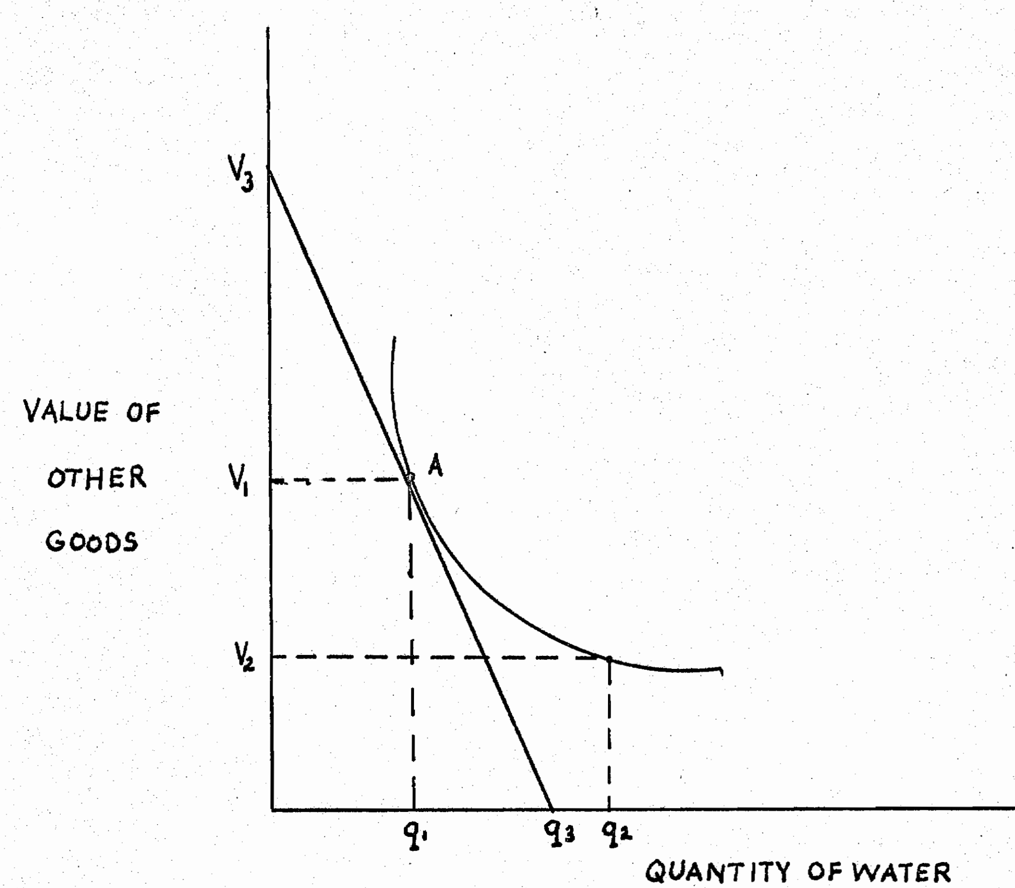

FIGURE 2.1 INDIFFERENCE CURVE

quantities of water. The slope of the indifference curve at any point represents the rate at which the individual is willing to give up money (consumption of other goods) in order to gain water and is referred to as the marginal rate of substitution or the marginal evaluation (MEV) of water. Elementary calculus tells one that the area under the marginal evaluation function between q_1 and q_2 would be equivalent to the WTP for that quantity. Therefore, the shaded area in Figure 2.2 is equivalent to v_1v_2 in Figure 2.1.

An MEV function compatible with the nature of the indifference curve shown in Figure 2.1 is shown in Figure 2.2. The area under this curve represents the WTP for the quantity of water between q_1 and q_2 because the MEV function indicates the value of each unit of water use between q_1 and q_2. This can be shown mathematically as follows.

Let q = quantity of water,

WTP = f(q) as shown in Figure 2.1, and

$$\text{MEV} = \frac{d(\text{WTP})}{dq} = f'(q).$$

By the rules of integration,

$$\int_{q_1}^{q_2} f'(q)dq = f(q_2) - f(q_1) .$$

Therefore, the definite integral of, or area under the Mev function, indicates the difference in the WTP for q_2 and q_1 and, thus, represents the WTP for the quantity of water between q_1 and q_2. If the individual's MEV function is available, it can be used to determine the WTP for quantities of water over which it is defined.

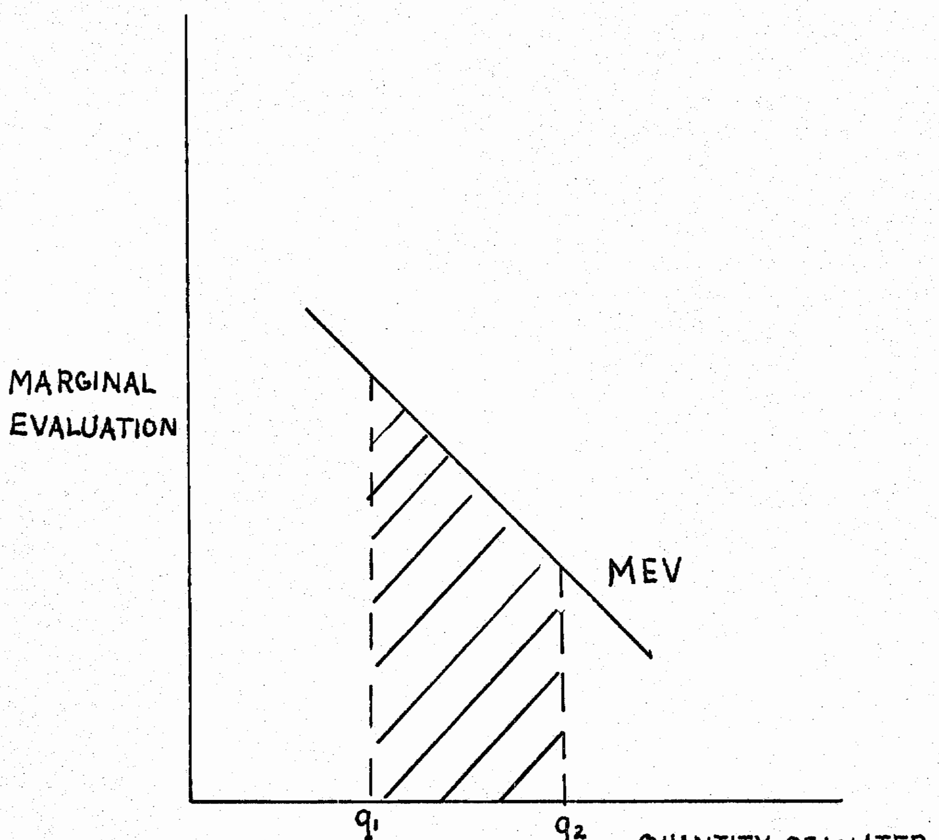

FIGURE 2.2 MARGINAL EVALUATION

It must be assumed that the individual makes informed and rational adjustments to the price of water and, therefore, chooses those levels of consumption at different prices which would maximize his level of utility, subject to his budget constraint. The rational individual will choose that level of consumption at which his MEV is equal to the marginal cost of water to him, i.e., its price. A failure to do so leaves the potential for an increased level of well-being through a change in the level of consumption.

There is, however, an additional condition which must be met if the individual's demand curve is to be considered equivalent to the MEV function from which WTP may be derived which involves the effect of changes in income upon the marginal evaluation of water. To examine this condition one must return to the individual's indifference curve. Figure 2.3 shows the individual's utility maximizing response to two different prices as determined by the nature of the individual's indifference curves.

Point A, in Figure 2.3, once again represents the individual's initial level of water use (q_a) and expenditure upon water at the price indicated by the slope of the line M_1P_1. If the price were to be lowered as indicated by the price line M_1P_2, the consumption of water would increase from q_a to q_c. The individual is assumed to be a utility maximizer and the MEVs at q_a and q_c, therefore, equal the prices faced at those quantities. The lowering of the price of water has permitted the individual to move to a preferred position. The movement from q_a to q_c can be seen to consisit of two elements. The movement from q_a to q_b can be attributed to the substitution effect and results

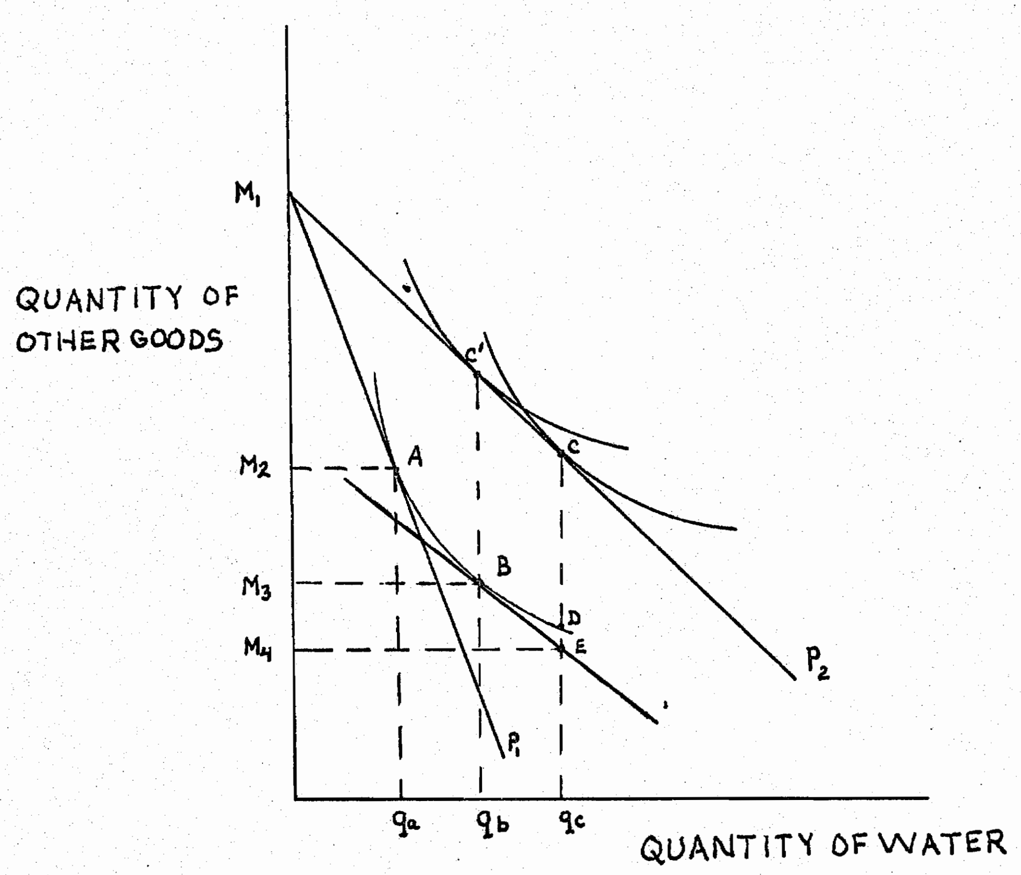

FIGURE 2.3 INDIVIDUAL PRICE RESPONSE

solely from the change in the price of water. Point B indicates the individual's response to the lower price if he were constrained to his initial level of utility. The movement from q_b to q_c can be attributed to the income effect and is due to the increased consumption of other goods and water made possible by the lowered price. The ability to consume increased quantities of money (other goods and services) and water will lead to such an income effect if the MEV of a given quantity of water increases with increases in the consumption of other goods.

The demand curve showing the level of consumption at each price will not be equivalent to the MEV function from which WTP may be derived if the MEV of a given quantity of water changes with the quantity of money expended upon water. This can be seen from an examination of Figure 2.3. As explained above, the WTP for the quantity of water between q_c and q_a is equal to M_2 minus M_3 and this WTP could be determined by integrating the MEV function derived from the indifference curve through point A over the relevant quantity. If the lowering of the price of water leads to consumption of q_c, then the demand curve will not be equivalent to the MEV function because the MEV at q_c will be different at point C than at point D even though the quantity of water remains constant at those points. If, as shown, the MEV at q_c is greater at point C than at point D, the use of the demand curve to derive WTP will lead to an overstatement of the WTP. The difference between the MEV function for water and the demand curve for water in the above situation is illustrated in Figure 2.4.

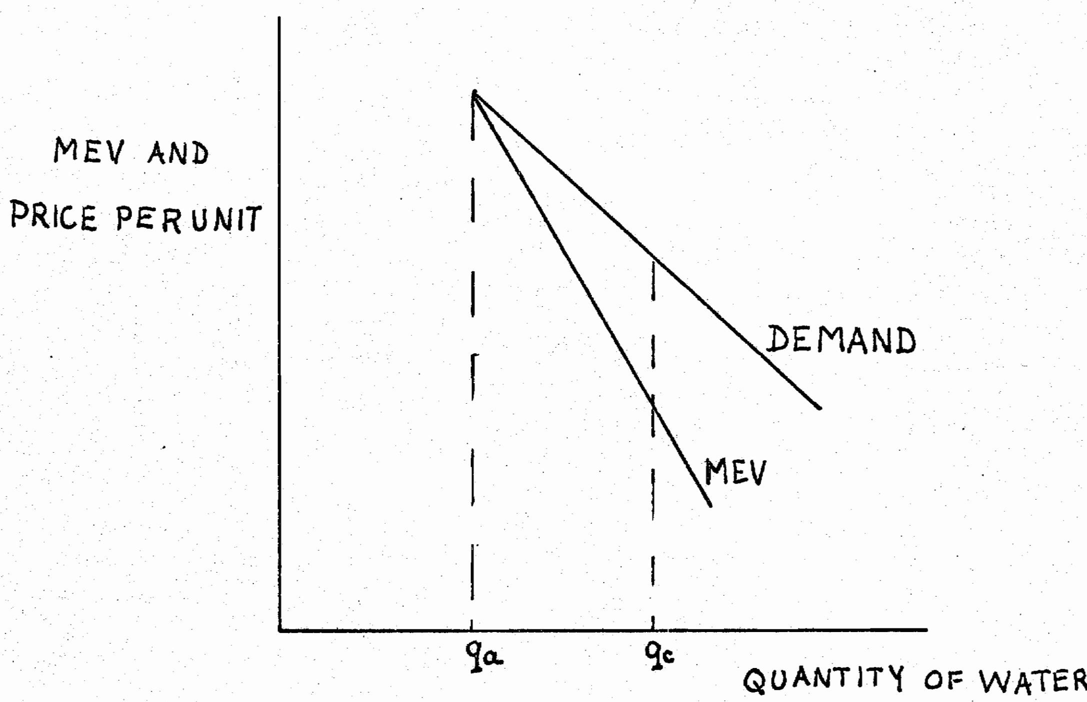

FIGURE 2.4 MARGINAL EVALUATION AND DEMAND

The MEV function will be below the demand curve between q_a and q_c and the use of the demand curve to estimate WTP will, therefore, lead to the overestimation of WTP. The demand curve and the MEV function will be equivalent if there is no change in the marginal evaluation of a given quantity of water with changes in expenditure upon that quantity. A case in which this is true is shown in Figure 2.3. If the individual's preferences were such that his consumption at the lower price would equal q_b at c', then the MEV at q_a would be the same at point B and point C. (It is assumed that consumption always occurs at a quantity at which the price of water is equivalent to its MEV.) If this is the case for all quantities between q_a and q_c, there will be a unique MEV over that range. The demand curve must be equivalent, in such cases, to the MEV function from which WTP can be derived.

It is unlikely that there would actually be a substantial divergence between the demand and the MEV curve. This is because the proportion of total income typically expended upon water is quite small. As a result, any change in the expenditures upon other goods due to a change in the price of water will be relatively small. Such small changes would not be expected to significantly affect the MEV of any particular quantity of water. It will, therefore, be assumed in the following analysis that an accurate measure of WTP can be derived through the integration of estimates of demand curves.[17]

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[17] Robert K. Davis and Steve H. Hanke, Pricing and Efficiency in Water Resource Management (Springfield, Va.: National Technical Information Service, 1971), pp. 37-44.

The above discussion has dealt with an individual's response to changes in price and the manner in which that response may be employed in assessing the value of certain quantities of water. Similar arguments hold in cases in which the water user is a commercial or industrial establishment. The total WTP of a group of water users for a particular quantity of water can be obtained by summing the individuals' WTP derived from their individual demand curves. Alternatively, the total WTP may be found by first aggregating the individuals' demand curves and then integrating the aggregated demand curve to determine WTP. The aggregate demand will indicate the level of consumption by all users associated with different prices and is the horizontal summation of the individual demand curves.[18]

The equivalence of the aggregate measures of WTP derived in these two ways is demonstrated in Figure 2.5. The D represents the horizontal of the individual demand curves, D_1 and D_2. The area under D between q_5 and q_6 can be shown to equal the sum of the areas under D_1 between q_1 and q_2, and under D_2 between q_3 and q_4. The sum of the areas under the price line p_1 between q_1 and q_2, and between q_3 and q_4, is equal to the area under p_1 between q_5 and q_6, because q_1 plus q_3 equals q_5, and q_2 plus q_4 equals q_6. The sum of the triangular areas under D_1 and D_2 and above p_1 is equal to the triangular area under D and above p_1. This can be seen by examining the integrals of D_1, D_2, and D (expressed as functions of price) from p_2 to p_1. By changing the axis

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[18] O. E. Williamson, "Peak Load Pricing and Optimal Capacity Under Indivisibility Constraint," American Economic Review, No. 56 (September 1966): 810-827.

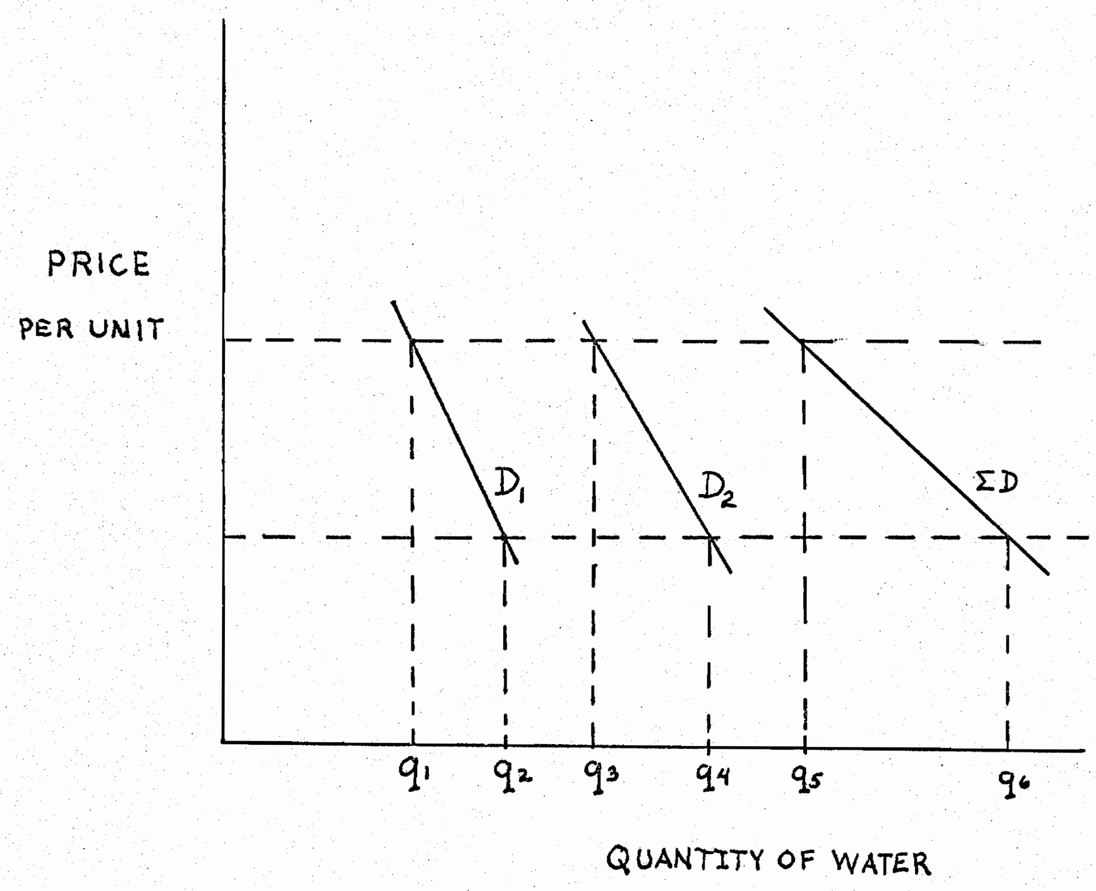

FIGURE 2.5 DERIVATION OF AGGREGATE WTP

of integration, the property of integration as a linear operator can be employed. Because D is the sum of D_1 and D_2, the integral of D must equal the sum of the integrals of D_1 and D_2. The unshaded rectangular areas between p_2 and p_1 comprising portions of those integrals must equal the rectangular area comprising a portion of the integral of D. Therefore, it can be seen that the use of the sum of the areas under the individual demand curves, as a measure of aggregate WTP, is equivalent to the use of the area under the aggregate demand curve.

The Costs of Water Supply

The costs of providing various quantities of water and of treating the resulting waste water, relative to the benefits derived, will determine the efficient use of existing and proposed water and sewage treatment facilities. An examination of costs relative to benefits is also necessary in order to evaluate different ways in which those facilities could be employed. The costs associated with the provision of water can be determined in a considerably more straightforward manner than the benefits. It may reasonably be assumed that the market value of the resources required to provide any quantity of water is equal to the true opportunity costs of those resources. This is the case because the markets for most of the resources employed in water supply are free of the influences which would lead to significant divergences between market value and opportunity cost. Also, because the communities by which the expenditures would be made are elements of the larger economy in which such divergences occur, their relevance to the decisions of the community are limited. If, for example, the resources employed in water supply were purchased outside the community and it were solely from the community's stand point that water supply decisions were to be made, any divergence between market value and true opportunity cost would become immaterial. The cost to the community could be measure by reference to the market value alone.

Types of Cost

The costs of water supply are of two basic types: those which vary with the capacity of the water supply system and those which vary with the quantity of water supplied by a particular set of facilities. A typical total cost curve indicating the relationship between the quantity of water supplied in a particular period and the costs incurred in that period is shown in Figure 2.6. This cost curve is relevant only to a particular set of facilities. To provide a quantity of water, q_1, it would be necessary to expend an amount, oa, upon facilities of capacity, q_2, and upon those operation and maintenance costs which would not vary with the quantity of water supplied by the facilities. In addition, an amount, ab, would be expended upon those operation and maintenance costs which would vary with the quantity of water supplied by the facilities. The slope of the line segment, ac, indicates the relationship between the quantity of water supplied and the level of such operations and maintenance costs. Any increase in quantity past q_2 would require expenditure upon additional facilities and their operation and maintenance. To provide q_3, for example, would require an expenditure of oa plus cd upon new facilities and invariant operation and maintenance costs, and an expenditure of ac plus de for those operation and maintenance costs

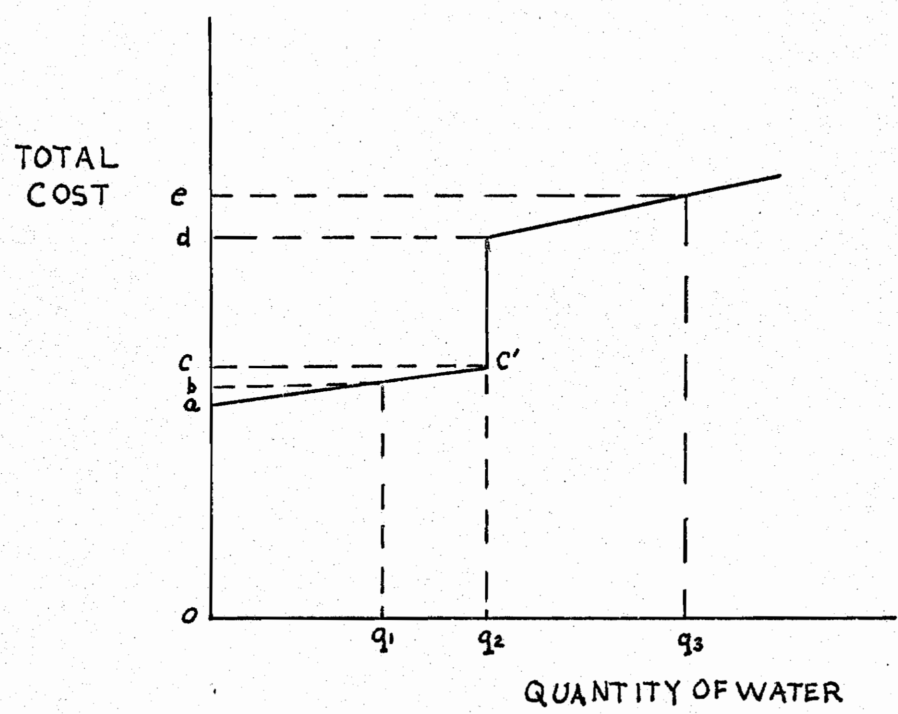

FIGURE 2.6 TOTAL COST OF WATER SUPPLY

which would vary with quantity.

There will be a different cost curve of the above sort associated with each of the different sets of facilities which could be employed to supply the relevant quantities of water. It is apparent that the minimum construction and fixed operation and maintenance costs for any particular quantity would be achieved by employing facilities having a capacity of exactly that quantity. If there were not diseconomics of scale relevant to the variable operation and maintenance costs, the minimum total costs associated with providing a particular quantity of water would also be achieved by employing facilities of that capacity. If the minimum costs of facilities of different capacities are known, as well as the operation and maintenance cost incurred in operating those facilities at capacity, it is possible to derive a cost curve indicating the minimum total cost of supplying any given quantity. Such a cost curve is, of course, quite different from the one presented earlier.

Determination of Optimal Capacity

Knowledge of the minimum cost of providing any quantity of water and of the WTP for certain quantities of water would provide the basis for the selection of the appropriate level of capacity if it is assumed that the WTP will remain constant over time. The appropriate level of capacity would be that at which the difference between WTP and total cost would be at a maximum. If the WTP and total cost curves were as shown in Figure 2.7, the optimal level of capacity and use would be q_m. This would be the quantity at which the MEV of water would be equivalent to the marginal cost of providing the water. The excess of WTP over total cost, or

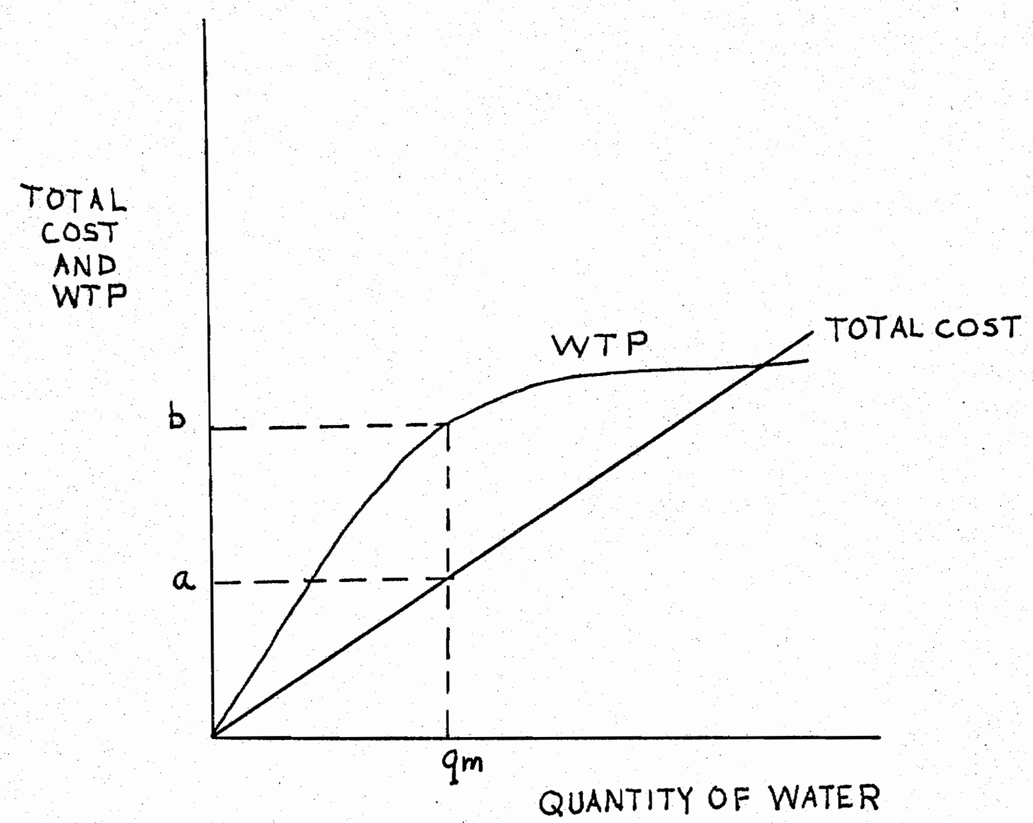

FIGURE 2.7 OPTIMAL LEVEL OF CAPACITY

net benefit derived, would be equal to ab. An alternative illustration of the optimal level of capacity and use can be made through the use of MEV and marginal cost curves as shown in Figure 2.7. The marginal conditions would hold and the net benefit would be equivalent to the area of the shaded traingle. This is so because the integral of the marginal cost function yields total cost just as the integral of the MEV curve yields WTP.

The optimal timing of investment in facilities and the efficient use of facilities in a case in which WTP would be increasing over time can be determined for any particular set of facilities as shown in Figure 2.9. The marginal cost curve shown, MC, is compatible with the total cost curve of Figure 2.6 and includes construction costs and both types of operation and maintenance costs. These costs may be included in a single marginal cost curve if it is assumed that the facilities would be operated at capacity. Implicit in this assumption is that the marginal variable operation and maintenance costs are less than the MEV at any quantity through q_2. The total cost of the operation of the facilities at q_1 and q_2 can be determined by integrating MC over the appropriate interval. Let D_1 represent an initial demand curve for water (assumed equivalent to the MEV curve from which WTP can be derived); the appropriate level of capacity would be q_1. An increase in capacity from q_1 to q_2, given D_1, would clearly lead to a decline in the net benefit derived from water supply. If WTP were to continue to increase, as indicated by the shift from D_1 to D_2, the price of water would need to rise in order to prevent shortages at capacity q_1. If WTP were to continue to increase, it would become desirable to invest in

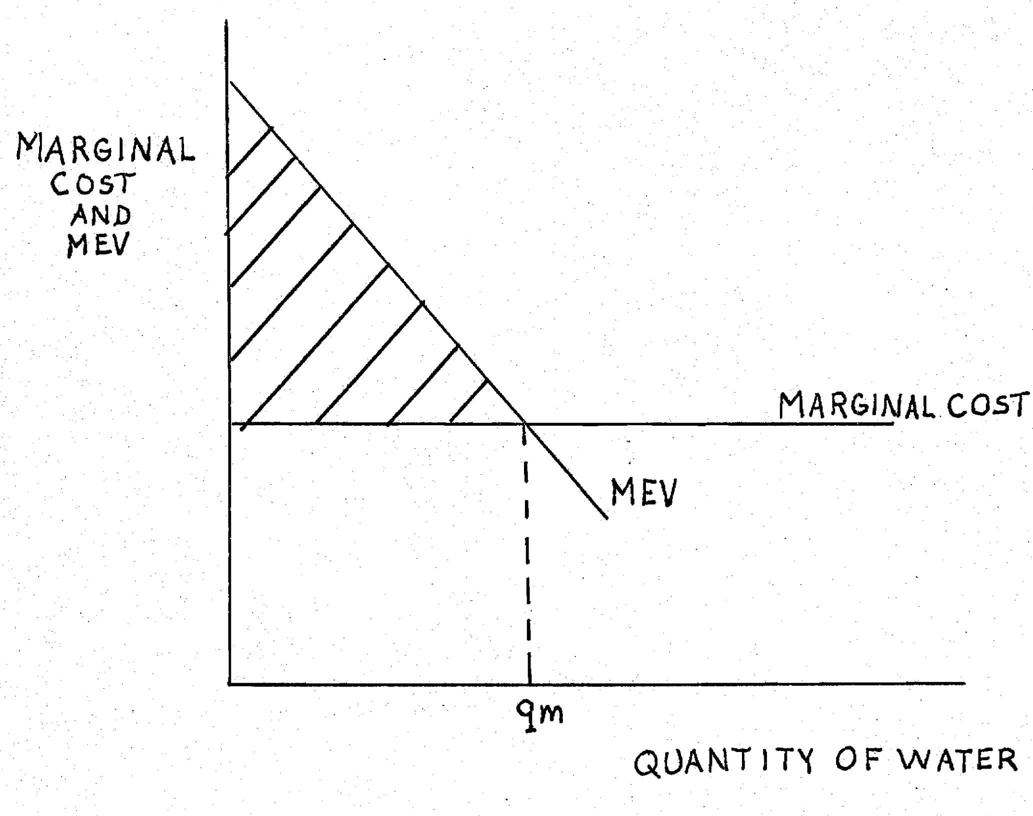

FIGURE 2.8 MARGINAL COST AND MEV

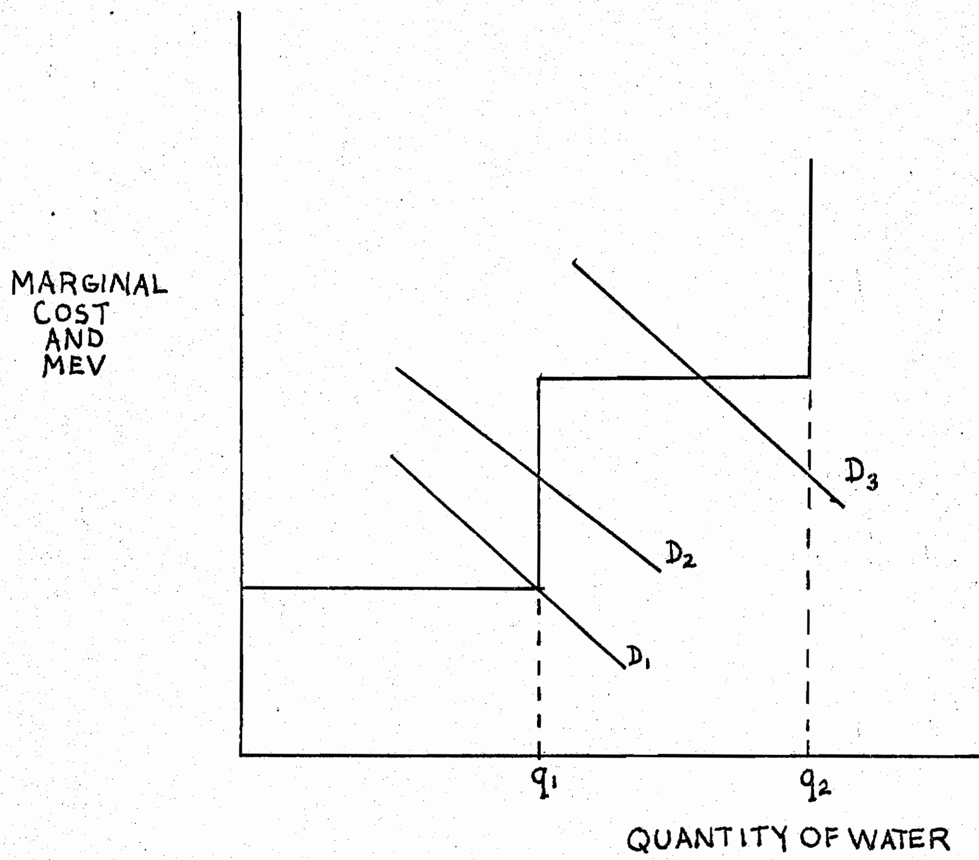

FIGURE 2.9 OPTIMAL TIMING OF INVESTMENT

additional capacity, q_2, at that time at which the WTP per period for the additional quantity of water would exceed the discounted cost per period of supplying it. This point would be reached when the area under the demand curve, e.g. D_3, between q_1 and q_2, exceeded the area under the MC curve over that interval. Mathematically, investment in the new facilities should take place when

$$\int_{q_1}^{q_2} f'(q)\, dq = \int_{q_1}^{q_2} g'(g)\, dq$$

where WTP = f(q) and Total Cost = g(q). This criterion provides the basis for determining the appropriate time at which to invest in a particular set of facilities.

The choice between different sets of facilities in situations of increasing WTP must rely upon a comparison of the present value of net benefits derived from properly implemented sets of facilities over the appropriate planning period. This analysis is relevant to a situation in which a "lumpy" decision must be made, i.e., capacity is either q_1 or q_2 and no level of capacity between those levels is considered, The use of the above investment criterion will necessarily lead to the maximization of the present value of net benefits of water supply from the facilities under consideration.

An example of the manner in which the comparison between two sets of facilities would be made is illustrated in Figure 2.10. In this example there are three periods within the planning period with successively higher levels of WTP for water as indicated by the three WTP curves.

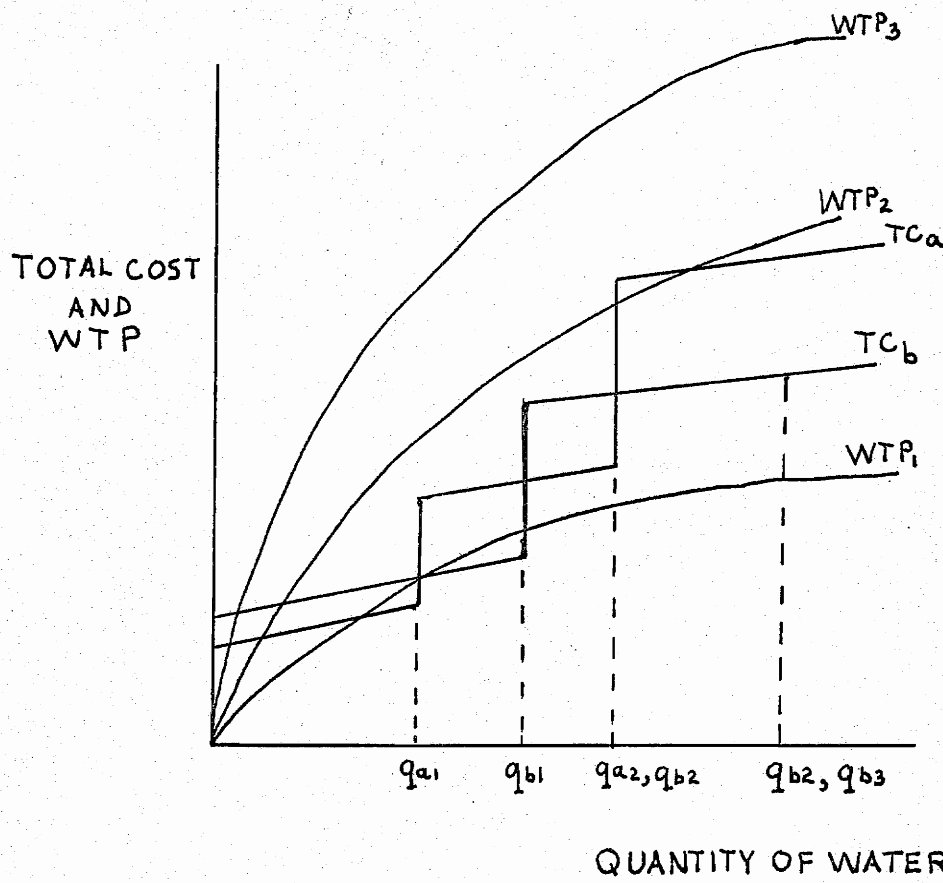

FIGURE 2.10 CHOICE BETWEEN SETS OF FACILITIES

The total costs of two different sets of water supply facilities are indicated by the curves TCa and TCb. Total costs are expressed as discounted costs per period in order that they would be directly comparable to the levels of WTP. The proper implementation of the sets of facilities associated with the cost curves can be determined by first ascertaining the quantity of water associated with the maximum net benefit in each period. Employing the earlier assumpiton about the relative magnitude of the costs which would vary with quantities supplied from a particular set of facilities, the optimal quantities will equal the capacities of the elements of the two sets of facilities. The optimal levels of supply in each period are indicated by the q_{ij}s, where the first subscript refers to the set of facilities and the second to the period in which that quantity of water is first supplied. The choice between these two sets of facilities can be made by summing the net benefit in each period for each set of facilities, then discounting future net benefit by an appropriate factor, and comparing the total net benefit of the two sets of facilities over the planning period.

Because there are actually an infinite number of such facilities, the determination of the single most efficient arrangement of facilities would require a dynamic programming approach in which certain limits were placed upon the number of possible sets to be considered. This would, of course, require a tremendous quantity of cost data and would, for the typical actual planning horizon of 50 years, require the use of iterative procedures capable of performing the large number of calculations necessary. This procedure has been attempted for specific cases, but the uniqueness of the nature of the cost functions to the particular situations to be considered precludes its general use as a tool in water supply planning.[3]

The Peak Load Problem

To this point, it has been assumed that WTP for a particular quantity of water per unit of time would be invariant within each period. The WTP for water generally changes over time within some period even though there may be no change in WTP among the periods. A common case is the difference in WTP for water during the warmer and cooler months of the year as reflected in higher use during the summer than the winter at the same price. The problem encountered with "peak" loads is illustrated in Figure 2.11 for a situation in which WTP varies within periods but remains constant among the periods. The selection of appropriate levels of capacity and use in such situations would depend upon the nature of the demand curves in the sub-periods and of the marginal cost curve. The MC curve shows the per unit costs (both facilities and operation and maintenance costs), associated with each quantity of water. The demands for water in the warmer half of the year and the cooler half of the year are indicated by D_s and D_w, respectively. The optimal capacity and use, if variable costs were insignificant (less than the MEVs), would be q_1; the quantity at which the vertical summation of demand in the sub-periods would be equal to LRMC. The vertical summation is appropriate because

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[3]Courtney Riordan, "Multistage Marginal Cost Model of Investment-Pricing Decisions: Application to Urban Water Supply Treatment Facilities," Water Resources Research, 7 (June 1973): 463-478.

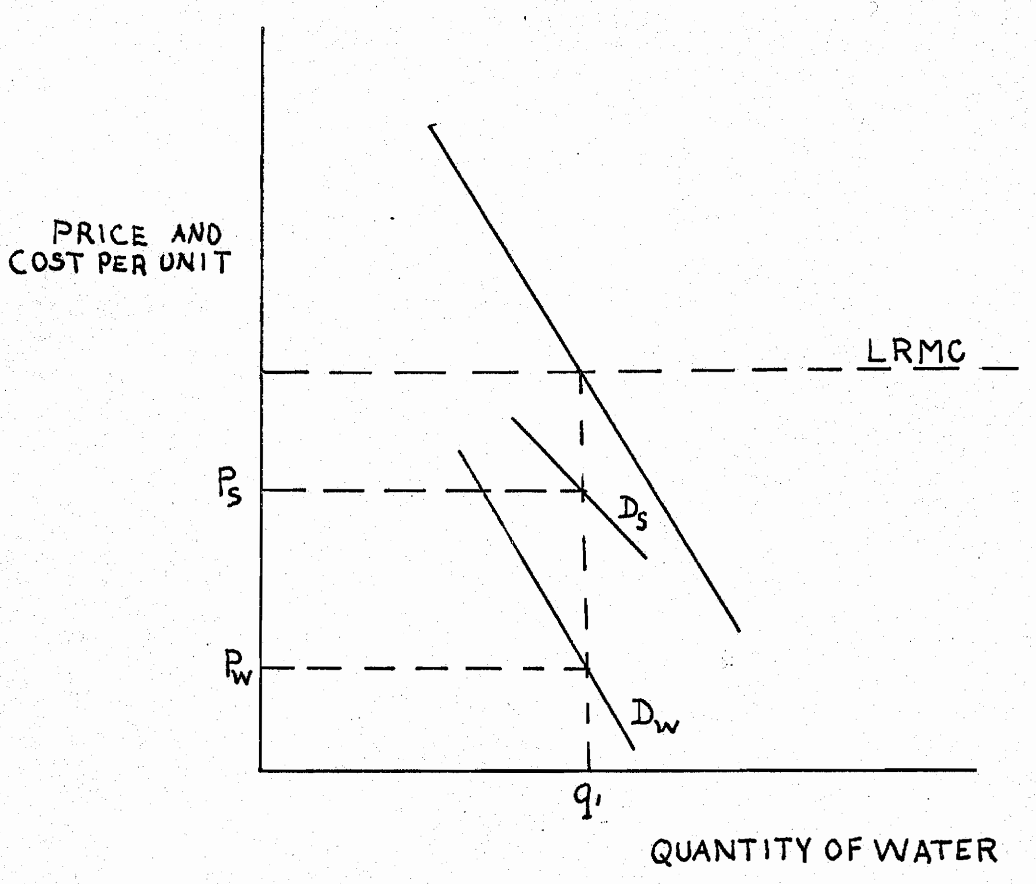

FIGURE 2.11 PEAK LOAD PRICING

the use of capacity in one sub-period does not diminish the level of capacity available in the other sub-period. The marginal evaluation of each unit of capacity, thus, equivalent to the sum of its marginal evaluations in each sub-period. Prices P_s and P_w would be necessary in the sub-periods to ration use, as the period having the higher demand would have the higher price.

The necessary conditions for the optimal level of capacity can be derived mathematically by maximizing the following objective function:

$$NB = f_w(q) + f_s(q) - g(q)$$

where

NB = net benefit

$f_w(q)$ = WTP in the cooler months

$f_s(q)$ = WTP in the warmer months

$g(q)$ = total cost

Setting the first derivative w.r.t. q equal to zero yeidls:

$$f_w' + f_s' = g'.$$

The sum of the marginal evaluations at the optimal quantity equals the marginal cost at that quantity.

Determination of Optimal Storage Levels

The preceding sections have been concerned with the determination of the proper sizing of water supply facilities in cases with fixed demands, and the proper timing of additions in capacity in cases with increasing demands. In both cases, it has been assumed that the availability of water from the source during any period equaled or exceeded the capacities of the facilities under consideration. Such analyses are applicable to some cases such as groundwater sources of potentially high flows and surface water sources with high minimum flows. Many surface water sources, however, have periods of low flows well below the levels of consumption that would occur even at very high prices. Such variability in the available water leads to the potential for increases in net benefits through the use of storage facilities.

The question of the appropriate capacities of storage facilities and of the other facilities, as well as the proper use of those facilities, can be addressed through modifications of the models presented above. It is necessary to derive the relationship between use during the low flow period and the size of, and expenditure upon, storage facilities. This can be determined by subtracting the flow during the period from the possible levels of use during that period to find the capacity of the storage facilities required for each possible level of use. If the relationship between storage capacity and cost were available, the relationship between use during the low period and expenditure upon storage facilities and operation and maintenance could be found. For levels of use below the low flows no storage would be required. Figure 2.12 illustrates the selection of the optimal level of capacity in a situation in which storage would be required for use during the low flow period above q_n, and in which demand in the two sub-periods would remain unchanged over time.

The D_w and D_s curves represent demand in the high flow and low use, and low flow and high use sub-periods, respectively. Once again, the D curve indicates the vertical summation of these curves and the

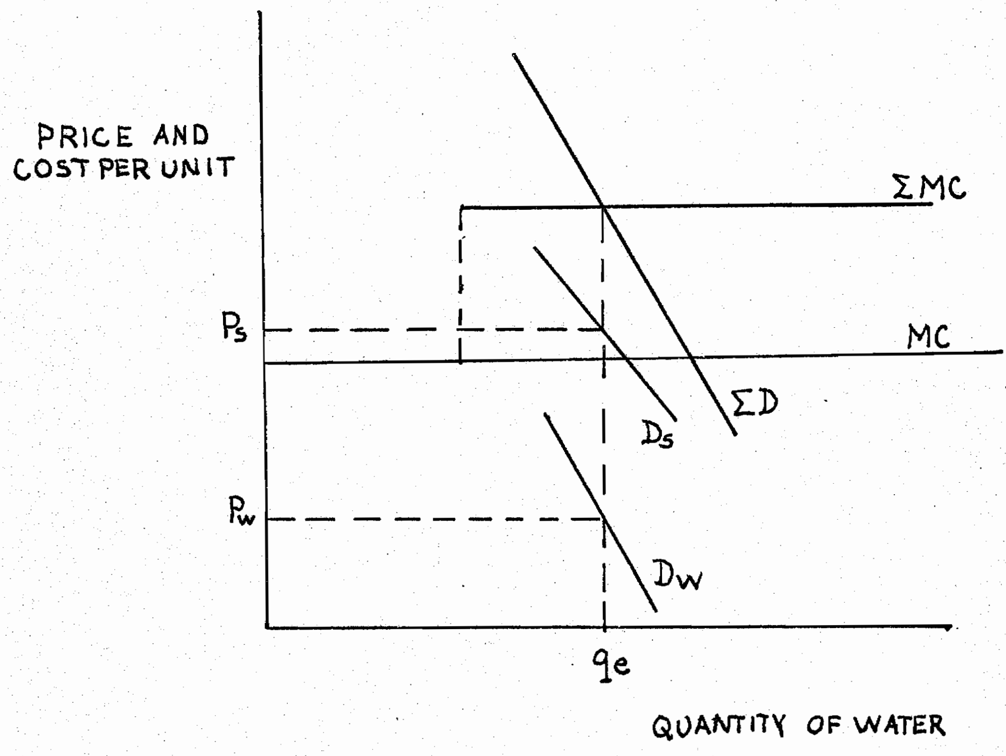

FIGURE 2.12 PEAK LOADS AND STORAGE

MC curve indicates the per unit costs of facilities, other than those employed in storage. The ΣMC curve is equal to the MC curve plus the per unit costs of the storage facilities necessary to provide the indicated quantities during the low flow sub-period. The optimal capacity and use in both periods would be q_e, the quantity at which ΣD is equal to ΣMC. It is assumed that variable costs in both periods are relatively low and that use during the low flow period does not diminish the available quantity of water in the high flow period to less than q_e. Note that q_e is greater than the quantity at which D_s intersects ΣMC, that approximate capacity level which would be optimal were there no use during the low flow period. This is true because increases in the capacity of the water system past that point would lead to benefits in both sub-periods. Prices of P_s and P_w would be required in the low and high flow sub-periods, respectively, in order to ration use in those periods.

In situations of steadily increasing demands in the sub-periods, investment decision rules analogous to those formulated for the uniform flow cases with changing demands would be relevant. The choice between alternative sets of facilities would require the comparison of the net benefits of each, as they would be optimally implemented over time.

The Relationship Between Water and Sewer Systems

The preceding analyses have been concerned with water supply investment dicisions without consideration of the interrelatedness of the water supply and waste water treatment functions which actually exists in most situations. Changes in the level of water use will lead to changes in the quantity of waste water to be treated and, therefore, in expenditures upon waste water treatment. The relationship between the quantity of water supplied and waste water treatment costs must be considered in determining the appropriate level of investment in, and operation of, water supply facilities. If the treatment costs resulting from the supply of a particular quantity of water were to be the same regardless of the relative level of the different types of use, the models developed above would be directly applicable. The treatment costs of any quantity of water could be considered to be equivalent to the costs incurred in supplying the water. In actuality, treatment costs vary considerably with the use to which the water is put. The most obvious example is the case of inside and outside use. Most water used inside buildings is returned to the sewer system for treatment, while virtually all water used outside of buildings, for such purposes as lawn watering and car washing, is not returned to the sewer system. The determination of the optimal level of water and waste water treatment facilities capacities and their use is illustrated in Figure 2.13.

It is assumed that demand is constant within and among the periods and that the total demand for water (D_t) is comprised only of the demands for inside and outside use, D_i and D_o, respectively. The MCW and MCWS curves indicate the per unit costs associated with the supply of each quantity of water and with the water supply <u>and</u> waste water treatment of each quantity of water, respectively. If the inside and outside uses of water could be priced separately, the optimal capacity of the water system would be equal to the sum of the quantity at which D_i intersects MCWS and the quantity at which D_o intersects MCW. The optimal capacity of the waste water system would equal the quantity at which D_i intersects

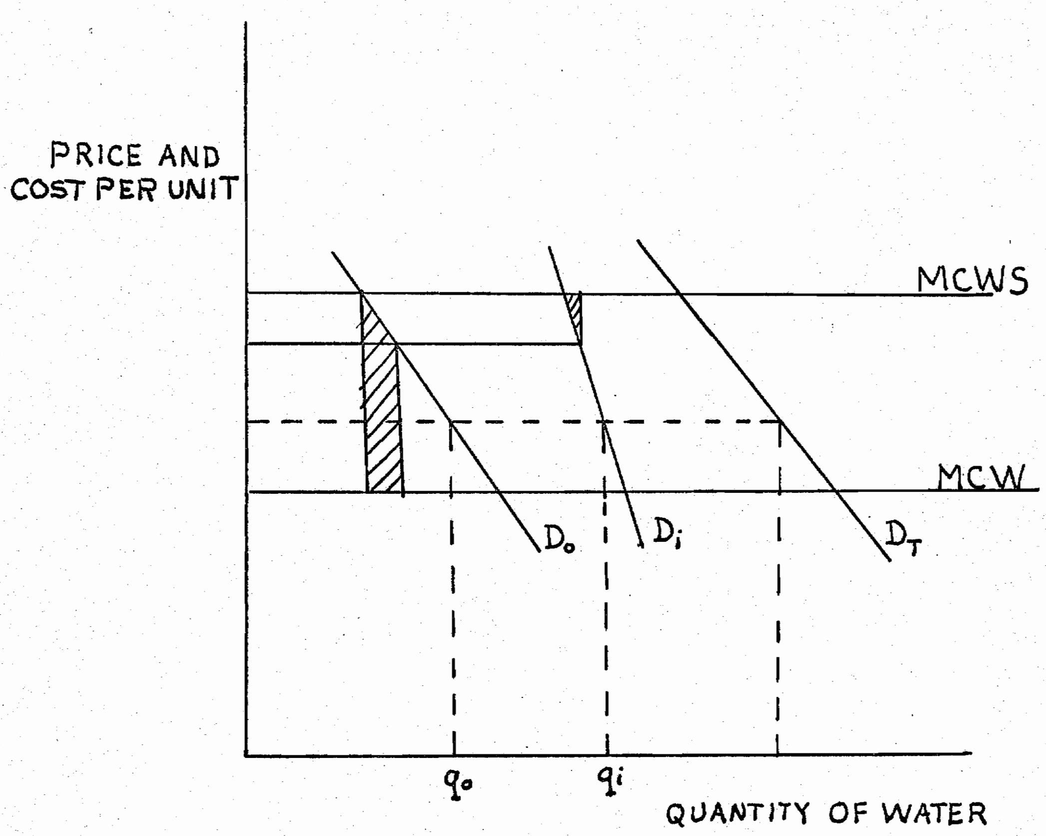

FIGURE 2.13 PRICING OF INSIDE AND OUTSIDE USE

MCWS. In general, however, the separate pricing of the two uses is not feasible and the same price is charged for water regardless of its use.

A determination of the appropriate level of capacity in water and waste water treatment facilities given the above assumptions and in a situation in which the price must be the same for both uses can be made mathematically as shown below.

Maximize:

$$NB = f_i(q_i) + f_o(q_o) - g_o(q_o) - g_i(q_i)$$

subject to the constraint

$$f_i' = f_o'$$

where

NB = net benefit

$f_i(q_i)$ = WTP for water used inside

$f_o(q_o)$ = WTP for water used outside

$g_o(q_o)$ = cost of water used outside

$g_i(q_i)$ = cost of water used inside (includes treatment).

The constraint, which requires that the MEVs in the two uses be equivalent, is dictated by the single price which would be in effect for both uses. The necessary conditions for the maximization of the above objective function can be found by forming the appropriate Lagrangian function and setting its partial derivatives with respect to the independent variables equal to zero as shown below.

$$L = f_i(q_i) + f_o(q_o) - g_i(q_i) - g_o(q_o) + \lambda(f_i' - f_o')$$

$$\frac{\partial L}{\partial q_i} = f_i' - g_i' + f_i'' = 0$$

$$\frac{\partial L}{\partial q_o} = f_o' - g_o' - f_o'' = 0$$

$$\frac{\partial L}{\partial \lambda} = f_i' - f_o'$$

Dividing the first equation by the second yields:

$$\frac{f_i''}{f_o''} = \frac{g_i' - f_i'}{f_o' - g_o'}$$

The maximization of the objective function requires that the ratio of the slopes of the demand curves of the two uses be equal to the ratio of the differences between the marginal costs of the two uses and their respective demands, at the quantities consumed in inside and outside uses. The levels of the uses which would satisfy the above condition at equal MEVs are shown in Figure 2.13. The optimal level of inside use would be q_i, the optimal level of outside use would be q_o, and the optimal capacity of the water system would thus be equal to q_i plus q_o. The optimal capacity of the waste water treatment system would be q_i. The price necessary to achieve the optimal use would be p_e. It is apparent that the price which would lead to the optimal use levels would be less than MCWS and greater than MCW. The optimality conditions can be made apparent by considering the increases in net benefits which would be attained by lowering price from P_a to P_b. The net gains from the increased outside use which would result are indicated by the shaded quadrangle under D_o. The net losses from the resulting increase in inside use are indicated by the shaded triangle above D_i. The increase in net benefits attributable to the lowering of price would be equal to the net gains minus the net losses. As the price is lowered still further, the net gains would diminish as the difference between D_o and the MCW diminishes at the higher quantities consumed at lower prices. The net losses would increase as the differences between D_i and MCWS increases at the higher quantities. The net gain and net loss from a decline in price would be equal at that price at which the greater increase in outside use, relative to the increase in inside use, would be offset by the greater difference between MCWS and D_i than between D_o and MCW. Any further decline in price would lead to a decrease in total net benefit derived from the provision of water at a constant price. The efficient price and the optimal quantities would thus depend upon the relative slopes of the demand curves and their position relative to the marginal cost curves.

A more realistic model can be developed to take account of the seasonality of outside use through the integration of the peak load and second best models. Let it be assumed that inside use occurs uniformly over the period of analysis, while the demand for outside use occurs only during half of that period. Such a situation is illustrated in Figure 2.14. The D_o curve indicates the demand for outside use which occurs during half the period, while D_i indicates the demand for inside use during half the period. The demands for inside use during both halves of the period are assumed to be equal. The D_i curve indicates the vertical summation of the D_i curves in the two sub-periods. The vertical

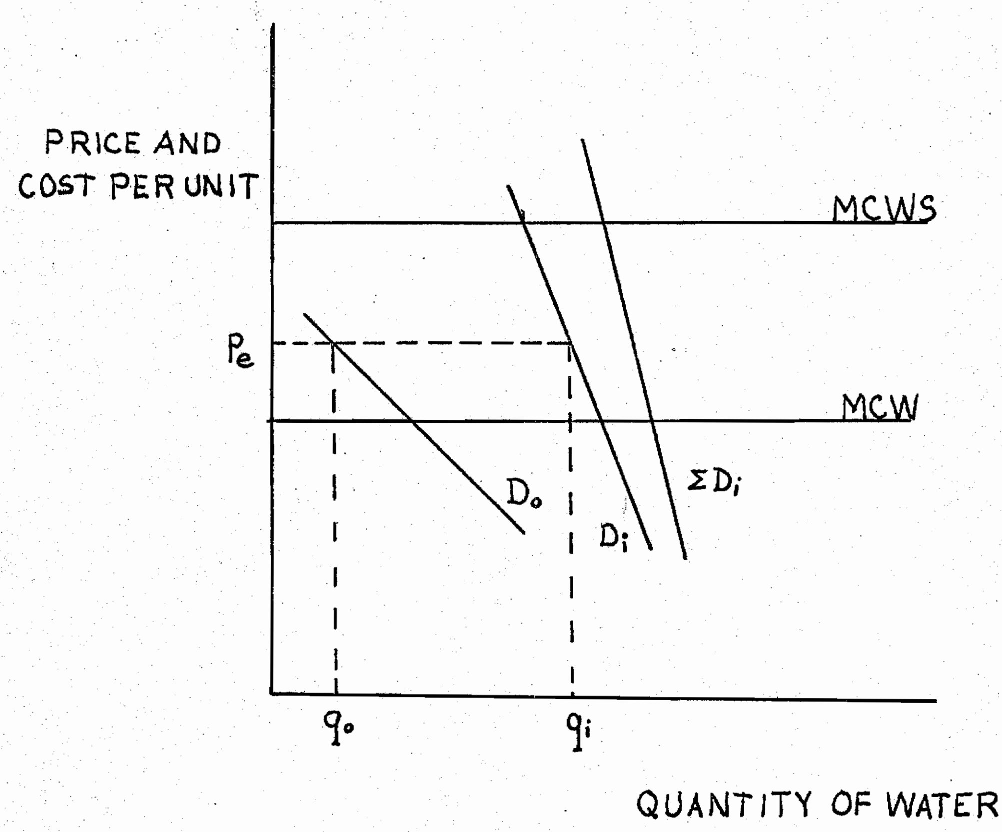

FIGURE 2.14 OPTIMAL CAPACITY WITH SEASONAL PEAK LOADS

summation shows the MEV of each level of capacity because the use of capacity in one sub-period would not diminish the capacity available in the other sub-period. A determination of the appropriate level of capacity of the water and waste water treatment facilities in the above situation can be determined mathematically as shown below.

Maximize

$$NB = f_{is}(q_i) + f_{iw}(q_i) - g_i(q_i) + f_o(q_o) - g_o(q_o)$$

subject to: $f_{is}' = f_o'$

where

f_{is} = WTP for inside use during the sub-period in which outside use occurs

f_{iw} = WTP for inside use during the sub-period in which only inside use occurs

The other symbols are as defined above.

The constraint requires only that the MEVs during the sub-period in which both uses occur be equal, as price can differ between the two sub-periods. The necessary conditions for the maximization of the objective function can be determined by forming the appropriate Lagrangian function and setting its partial derivatives equal to zero.

$$L = f_{is}(q_i) + f_{iw}(q_i) - g_i(q_i) + f_o(q_o) - g_o(q_o) + \lambda(f_{is}'-f_o')$$

$$\frac{\partial L}{\partial q_i} = f_{is}' + f_{iw}' - g_i' + \quad f_{is}'' = 0$$

$$\frac{\partial L}{\partial q_o} = f_o'' - g_o' - \quad f_o'' = 0$$

$$\frac{\partial L}{\partial \lambda} = f_{is}' - f_o'$$

Dividing the first equation by the second yields:

$$\frac{f_{is}''}{f_o''} = \frac{g_i' - (f_{is} + f_{iw})}{f_o' - g_o'}$$

It is necessary that the ratio of the slopes of the demands for inside and outside use in the period in which both occur be equal to the ratio of the difference between the marginal cost of providing and treating inside use and the sum of the MEVs of inside use in both sub-periods to the difference between the MEV of outside use and the marginal cost of providing outside use. These optimality conditions would be satisfied in Figure 2.14 when outside use equals q_o, inside use and capacity of the waste water treatment facilities equals q_i, and the capacity of the water supply system equals q_o plus q_i.

Discrete Increases in Capacity of Water Supply and Sewage Treatment Systems

The preceding analyses were concerned with the determination of the optimal levels of capacity in the water supply and waste water treatment systems in a situation in which the demands for inside and outside use would not change over time. Under these conditions it is appropriate to determine an optimal level of capacity. However, if the demands were to be changing over time, the relevant issue would be the determination of the appropriate times at which to put into operation various sets of additional facilities. A comparison of the net benefits associated with the optimal implementation and use of the various sets of facilities could be made to determine which set should be employed. This type of decision process was illustrated in Figures 2.9 and 2.10 when the costs of water supply along were considered.

Under certain special conditions, the nature of the investment decision when the costs of water supply alone were considered and the nature of the investment decision when the sewage treatment costs were also considered would be exactly analogous. This would be the case if the capacity of the additional water supply facilities were to be exactly matched by the capacity of the sewage treatment system. That is, if the capacity of the proposed sewage treatment plant were to be exactly equal to the volume of waste water which would be produced by water use equal to the capacity of the proposed water supply facility. It would also be necessary that the ratio of inside use to outside use remain constant at the levels of use equal to capacity as the demands shifted over time. It is unlikely that either of these conditions would actually be satisfied.

The problems encountered when the limitations on use imposed by the capacity of the sewage treatment plants and the water supply facilities are not equivalent is illustrated in Figure 2.15. Total demand and the demand for inside use are shown as D_t and D_i, respectively. The existing capacity of the water supply system is q_t, and the capacity of the sewage treatment plant would be exceeded if inside use were to be greater than q_i. The capacity of the sewage treatment plant would be somewhat less than q_i as not all inside use is returned to the sewer system. Additional facilities could increase the capacity of the water supply system to q_t', and the capacity of the sewage treatment plants to inside use of q_i'. The quantity of water which could be consumed would not increase from q_t to q_t' with the construction of the additional

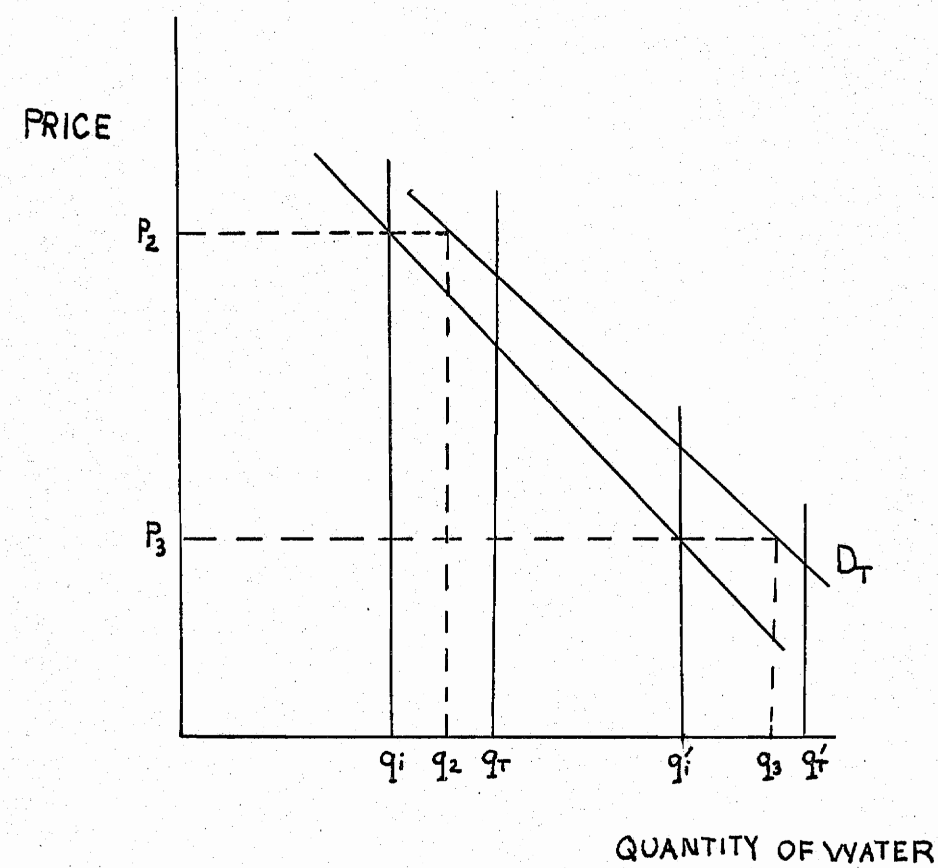

FIGURE 2.15 DISCRETE CAPACITY INCREASES

facilities. Water use at the price (p_2) necessary to limit inside use to the existing capacity of the sewage treatment system would be q_2. Water use at that price (p_3) necessary to limit inside water use to the capacity of the sewage treatment system after the construction of the additional facilities would be q_3. The construction of the additional facilities would thus permit an increase in water use from q_2 to q_3. The WTP for this particular quantity of water would be compared to the total cost of expanding the capacity of the sewage treatment system to q_i' and operating that system at capacity, and expanding the capacity of the water supply system to q_t' and operating that system at q_3. If the level of WTP exceeded the total costs, then the expansions in capacity would be warranted.

This chapter has addressed the principal theoretical issues posed by water supply planning. This inquiry proved useful in defining the problem in the study area. It also led to the development of theoretical models which, while not applicable to that area, should prove applicable in other cases. The analysis of the following chapters will apply the model of discrete increases in water and waste water treatment capacity to the study area in an effort to evaluate and derive alternative courses of action.

Chapter 3

PROJECTION OF FUTURE DEMAND CURVES

Introduction

An essential element in the analysis of alternative water supply planning decisions was the estimation of the value of increments in the quantities of water supplied to the area. As explained in Chapter 2, the estimation of the influence of the price of water upon the quantities used can serve as a basis for the determination of the value of such increments. Because this analysis is concerned with the evaluation of particular quantities of water over time, it was necessary to derive estimates of the water demand curves over an extended period.

Estimation and Projection of Demand Curves

The bases for the estimation of the value of increments in the quantities of water supplied to the area municipalities were estimated demand curves. It was necessary to estimate the demand curves for water in each of the cities through 2030 in order to evaluate alternative courses of action, and in order to derive an efficient response to the situation to be faced by the cities. The projection of water demand curves in the cities of Virginia Beach, Norfolk, and Portsmouth relied upon the projections of use formulated by the COE in their analysis of the water supply situation in Southeastern Virginia.[1] These projections were made through an analysis of past trends in per capita water use in the area and the use of population projections performed by the SVPDC. The COE projected water use through 2030 by multiplying projected population levels by projected levels of per capita water use. Per capita water use in each city was found by dividing total use in the cities by the populations of those cities which received public water service.

The projection of water demand curves in the city of Chesapeake relied upon water use projections developed by the Department of Public Utilities of that city.[2] The COE projections for Chesapeake were not used because there were serious questions concerning the proportion of the projected population of Chesapeake which would be served by municipal sources. There are a substantial number of water users in Chesapeake which now use private wells. The proportion of future water users in the area that would use municipal water and the extent to which the present ground water users would convert to municipal water use would be important factors influencing future water use. The Department of Public Utilities of Chesapeake projected water use on the basis of their previous experience with growth in demand and projected proportions to be served. It was felt that these projections were based upon a more accurate perception of the number of individuals to be receiving municipal water service than were those of the COE. The projections

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[1] U.S. Army Corps of Engineers (projections summarized in a compilation of relevant data by the Virginia State Water Control Board, 1977).

[2] City of Chesapeake, Department of Public Utilities.

employed in this analysis are shown in Table 1.1

The projections of future levels of use were made for each city under the implicit assumption that the real prices of water would not change substantially from existing levels over the period of analysis. The price of water refers to those charges which vary with the quantity of water consumed. The price of water in each of the municipalities consists of the price per unit for water delivered and those charges assessed for waste water treatment services which are based upon the quantity of water consumed. Specifically excluded in discussions of the price of water are those charges for water and sewer service which do not vary with the quantity of water consumed.

The projection of use, given existing prices and the estimation of the composition of that use, permitted the identification of a point on the demand curves of each of the different types of use in the four cities in each year through 2030. As mentioned earlier, the composition of use is assumed to remain unchaged with regard to the relative magnitude of its principal components. The level of a particular type of use in any year could be estimated for each city. Because this use was projected at present real prices, a unique price-quantity combination would, thus, be defined.

The demand curve for a particular type of use could be found if information were available indicating the influence changes in price would have upon the level of that type of water use. For example, the projected average level of total water use in Virginia Beach in 1980 is 22.1 MGD.[3] It was estimated above that domestic residential use constitutes 80 percent of total use in Virginia Beach. Estimated domestic residential use in 1980 would, thus, be 17.1 MGD. The price of water, which consists of the sum of the variable charges for water and sewer service, is $1.59 per thousand gallons for residential water users in Virginia Beach.[4] It has been estimated in a rigorous statistical analysis of domestic residential water use that the direct price elasticity of such use is constant at -.21.[5] Constant elasticity demand curves take the form:

$$q = xp^{e} ,$$

where q = quantity, p = price, e = elasticity, and x is a constant term which fixes the location of the demand curve. If a price-quantity combination and the elasticity were known, the constant term could be found, and the demand curve, thus, derived. In the above example of domestic residential use in 1980, the following equation would be solved for x:

$$17.1 = x(1.59^{-.21})$$

$$x = 15.5$$

The constant term would equal 15.5 and the demand curve for inside use in 1980 in Virginia Beach would, thus, be as shown below if price is

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[3] U. S. Army Corps of Engineers

[4] City of Virginia Beach, Department of Public Utilities; Hampton Roads Sanitation District.

[5] C. W. Howe and F. P. Linaweaver, "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure," Water Resources Research 3 (First Quarter, 1967); R. G. Thompson, et al., "Forecasting Water Use for Policy Making: A Review," Water Resources Research 9 (August 1973).

expressed in dollars per thousand gallons and quantity in MGD.

$$q = 15.5p^{-.21}$$

The demand curves for other years, uses, and cities can be derived in an analagous fashion.

Composition of Water Use

The projection of the different types of use was conducted by assuming that the relative composition of use, at the existing prices, would not change over the period of analysis. It was necessary, therefore, to determine the approximate composition of recent use. The composition of use was found for Norfolk, Portsmouth, Virginia Beach, and Chesapeake. The relative composition of use in each of these cities served as the basis for the projection of the demands for each of the different types of use.

It is generally maintained that there are three principal components of water use which differ substantially in their relative responses to changes in the price of water. These are residential, commercial, and industrial uses.[6] Residential use has been further dissaggregated into domestic use, or use within the home, and outside use because of the significant differences found in the value of water in these uses.[7]

The determination of the composition of use permitted the estimation of the water demand curves for each of the four types of use. This was conducted through the application of previous statistical analyses

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[6] C. W. Howe and F. P. Linaweaver, "The Impact of Price."

[7] Angelo P. Grima, Residential Water Demand (Toronto: University of Toronto Press, 1972).

of the demand curves of the different types of water use. The demand curves could be derived in this fashion because the elasticities of the various types of use, in conjunction with the levels of the types of use and the prices faced by those types of use, are sufficient to define unique demand curves for each type of use. The demand curves for each type use in future years were derived through the use of projections by the COE and the Department of Public Utilities of Chesapeake of water use at existing prices. The only changes in the three variables necessary to define a demand curve in any year came in the projected levels of use. For each year, the prices, quantities used, and elasticities were available if it is assumed that the relative composition of total use, as projected by the COE and Chesapeake would not change over time. Evidence regarding the past stability of the composition of use, as well as the absence of any substantive basis for the projection of changes in the composition of use, make this a reasonable assumption.

Estimation of the Composition of Use

The determination of recent use served as the basis for the estimation of the composition of use. An initial step was the use of a survey presented to the departments of public utilities of the area's municipalities. This questionnaire requested information as to the total level of water use and the levels of use by residential, commercial and industrial water customers by month for 1973, 1974 and 1975.

Response to the questionnaire varied; total use was available for each city, but in none was the composition of use available as indicated. The procedures employed in the estimation of the composition of water use differed somewhat among each of the four cities. The detailed procedures used and results obtained are presented in Appendix 1. The estimated composition of use in each of the cities is summarized in Table 3.1. It is apparent that there is wide variation in the composition of use among the four cities. This variation is a reflection of the diversity of the four cities and would be expected to have a significant influence upon the nature of the demand for water in those cities.

Selection of Appropriate Elasticities

The elasticities employed in estimating the demand curves were important determinants of the nature of those curves. The selection of the elasticities involved a review of previous analyses of the influence of price upon the levels of the different types of water use.

Residential

Residential water use has been a frequent subject of statistical demand analyses. A well known analysis of residential water use was conducted by Howe and Linaweaver in 1967. This study estimated a constant elasticity demand curve for residential water use through a cross-sectional regression analysis of 35 study areas. The elasticity of demand for domestic water use was estimated to range from -.21 to -.23. The same researchers found the elasticity of demand for residential lawn watering use to be -1.57 in a cross-sectional analysis of water demands in 11 study areas.[8]

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[8] Howe and Linaweaver, "The Impact of Price."

TABLE 3.1

ESTIMATED COMPOSITION OF TOTAL WATER USE

	Residential Inside	Residential Outside	Industrial	Commercial
Virginia Beach	80 %	6 %	2 %	12 %
Chesapeake	57	6	21	16
Norfolk	38	2	51	9
Portsmouth	44	2	47	7

A cross-sectional study by Wong in 1970 found the elasticity of total water use in suburban communities surrounding Chicago to range from -.26 to -.81. While all types of use were included in the calculation of these elasticities, the major portion of total use in these communities was residential use.[9]

A time series analysis by Hogarty and Mackay in 1975 found the price elasticity of a residential subdivision in Virginia during the winter months to be -.56. It is reasonable to expect that outside use during the winter months was insignificant and that the elasticity estimate derived, thus, applied to domestic use alone. The price changes analyzed in the calculation of this elasticity were accompanied by the provision of detailed information indicating ways in which water use could be reduced. It is possible that the estimated elasticity may overstate the influence of the price changes as some reduction in water use may be attributable to the increased awareness of water saving techniques.[10]

Grima conducted a cross-sectional analysis of residential water use during the winter months in a group of cities in Ontario, Canada. This study in 1972 found the elasticity of residential use to be -.75.[11]

The substantial variation in the estimates of the price elasticity of domestic water demand precludes the use of a single elasticity

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[9] S. T. Wong, "A Model on Municipal Water Demand: A Case Study of Northeastern Illinois," Land Economics, Vol. 48, No. 34, pp. 34-44.

[10] T. F. Hogarty and R. J. Mackay, "The Impact of Large Temporary Rate Changes on Residential Water Use," Water Resources Research, Vol. 11, No. 6, pp. 791-794.

[11] Angelo P. Grima, Residential Water Demand (Toronto: University of Toronto Press, 1972).

in the estimation of the demand curves for such use in the cities of southeastern Virginia. Two sets of demand curves for domestic use were estimated by employing two different elasticities. The elasticities employed were the lower of the domestic elasticities estimated by Howe and Linaweaver (-.21) and the mean of that elasticity estimate and the domestic elasticity estimated by Grima (-.48).

A single set of demand curves for outside residential use were estimated using the only available estimate of the elasticity of demand for that type of use. That elasticity (-1.57) is considerably greater than the estimated elasticities of domestic use. This would be expected considering the differences between "essential" domestic uses, such as bathing and drinking, and the more discretionary outdoor uses of water.

Commercial

The only in depth analysis of commercial water demand was conducted by Luppold in 1976.[12] This was a cross-sectional regression analysis which indicated that while price was a significant determinant of commercial water use, its effect could be ascertained only if other important variables were included in the statistical models. Luppold derived elasticity estimates for department stores, grocery stores, restaurants and bars, and hotels and motels. Unfortunately, reliable estimates of the remaining commercial water users were not obtained. The estimation of an aggregate commercial demand elasticity, therefore, could not be made with great precision. For this reason, two estimates of the

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[12] William G. Luppold, "The Commercial Demand for Water" (Master's thesis, University of Florida, 1976).

aggregate elasticity were employed. An approximate aggregate elasticity was found by determining the approximate proportion of use by the four classes of establishments listed above that each represented, then weighting the elasticities of each by the appropriate amounts. The aggregate elasticity estimated in this manner was -.525. Elasticities of -.425 and -.625 were employed in the estimation of the demand curves in order that deviation from the aggregate elasticity of the uses listed above by the elasticity of other commercial uses could be accounted for.

Industrial

The industrial price sensitivity of water use has been found to vary quite substantially among various industries, reflecting the differences in the uses to which water is put. The nature of any firm's response to price will depend primarily upon the nature of that firm's productive processes. Each firm would be expected to respond to changes in the price of water in a manner which maximizes expected profits. The responses to price changes include changes in the amount of water used in the basic manufacturing process, as well as the extent to which water is recycled after being used in those processes.

A staff study by the U.S. Department of Commerce examined the simulated response of selected industries to water price changes. This study attempted to identify the profit maximizing use of recycling by the modeled firms.[13]

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[13] U. S. Department of Commerce, An Analysis of Price/Cost Sensitivity of Water Use in Selected Manufacturing Industries (Bureau of Domestic Commerce Staff Study, June 1976).

A study by Leone et al. estimated water demand elasticities for selected industries through a cross-sectional statistical analysis. This study found a range of elasticities from -.7 to -1.6.[14] This range of elasticities was generally consistent with the price responses estimated in the simulation study.

De Rooy conducted a cross-sectional regression analysis of the influence of price upon water use in a group of 30 large chemical manufacturers. He derived elasticity estimates of -.745 and -.741 for processing and steam power use, respectively, by those firms.[15]

The wide variation in industrial water demand elasticities and the lack of any information concerning the water demands of many industrial processes necessitated the use of two substantially different estimates of demand elasticities. The extreme values of the range of elasticities estimated in the study by Leone (-.7 and -1.6) were, therefore, employed in the estimation of industrial water demand curves.

The water use projections employed in the estimation of the demand curves are shown in Table 1.1. The rates of growth between the projected levels of use in each tenth year are linear due to the projection methodology employed. There are not substantial differences among the rates of growth in the different ten year periods for any particular city. The uncertainty concerning the nature of the demand curves led to the use of two sets of curves. It was felt that the probable importance of the

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[14]Robert Leone et al., "Changing Water Use in Selected Manufacturing Industries" (Washington D. C.: National Bureau of Economic Research, 1974).

[15]Jacob De Rooy, "Price Responsiveness of the Industrial Demand for Water," Water Resources Research, Vol. 10, No. 3, pp. 403-406.

elasticities employed upon the results of the following analyses necessitated the use of two different sets of elasticities. It is felt that it would be highly unlikely for the actual elasticities to fall outside the range of those employed in the estimation of the demand curves.

The prices and elasticities of the different types of water use employed in the estimation of future water demand curves are shown in Table 3.2.

TABLE 3.2

PRICES AND ELASTICITIES EMPLOYED IN ESTIMATION

	Elasticities		Price Per Thousand Gallons			
	High	Low	Virginia Beach	Chesapeake	Norfolk	Portsmouth
Domestic Residential	- .48	- .214	1.59	1.89	1.27	1.24
Outside Residential	-1.57	-1.570	1.59	1.89	1.27	1.24
Commercial	- .63	- .425	1.54	1.84	1.22	1.15
Industrial	-1.60	-.7000	1.54	1.84	1.18	1.09

CHAPTER 4

ESTIMATION OF NET BENEFITS OF ALTERNATIVE LEVELS OF WATER SUPPLY

Introduction

This chapter will present the methodology employed in the estimation of the net benefits associated with the provision of different quantities of water from several different sets of water supply and waste water treatment facilities. The actual calculation of those net benefits is described in Apprndix 2. Net benefits for each of the following responses were calculated for the period 1980 through 2030.

1. Providing the projected levels of water use as shown in Table 1.1
2. Providing 15% less than the projected levels of use, with the reduction achieved through proportionately equal reductions by all water users.
3. Providing 15% less than the projected levels of use, with the reduction achieved through a single, higher level of price for all water users.
4. Providing 15% less than the projected level of use, with the reduction achieved through the installation of water-saving devices.

The time period 1980 through 2030 was chosen because all projects currently under construction should be operation by 1980 and because the expected life of water supply facilities is traditionally set at fifty years. The analysis by the COE also examined the water supply situation through 2030.

The value of the water used in each of the above situations, in excess of projected 1980 use levels, was found through an analysis of the projected demand curves. The value of water used was found only for the quantities of water in excess of projected 1980 use because demand curves are not available for the entire range of water use. In addition, for each of the proposed levels of use, the projected 1980 levels would be a constraint upon the minimum level of use. The only difference in the value of use for each of the situations would be due to the differences in the level of use in excess of projected 1980 use.

The costs associated with the different levels of use were also found for the quantities of water in excess of projected 1980 use. The costs associated with providing levels of use would consist of the costs of operating the existing water supply and waste water treatment facilities and the costs of constructing and operating the required additional facilities. These costs were found for several alternative sets of facilities by determining the quantities of water to be supplied and treated during each year. The scheduling of additions to capacity and the quantities of water to be supplied and treated by the existing and proposed facilities could then be determined. The costs associated with the different levels of use could then be obtained by examining the costs of operating the existing facilities and projected costs of the alternative sets of additional facilities.

Evaluation of Alternative Levels of Use

The evaluation of use in excess of projected 1980 use was conducted in a similar manner for each of the different levels of use and/or means of achieving the levels of use. The following sections present the procedures employed in the evaluation of the levels of use in excess of projected 1980 use, for each of the different situations.

Evaluation of Projected Levels of Use

The projected levels of use shown in Table 1.1 were accepted as given. Any variation from those levels, as could result from restrictions upon water use or changes in the price of water, was ruled out.

The benefits of providing the projected levels of use were estimated by determining the WTP for the quantities of water greater than the projected levels of use in 1980. This was done by determining the projected levels of use by each type of use for every year through 2030. The estimated demand curve for each particular use in each year was then integrated over the interval between the level of use in a particular year and the level of use in 1980. This procedure can be illustrated for domestic residential use in Virginia Beach in 2000, as shown in Figure 4.1.

Projected averare domestic residential use during 1980 is 17.7 MGD (80% of 22.1 MGD total use) and during 2000 is 27.0 MGD. D and D' indicate the demand curves for domestic residential use in 1980 and 2000, respectively. The intersection of these demand curves with the existing price levels would occur at the projected levels of use. The WTP for the quantity of water consumed in 2000, in excess of that quantity of water which would be consumed in 1980, can be found by integrating D' from 17.7 MGD to 27.0 MGD. The shaded area under D' represents that WTP, and is the amount that the residential users of water would be willing to pay to increase the domestic consumption of

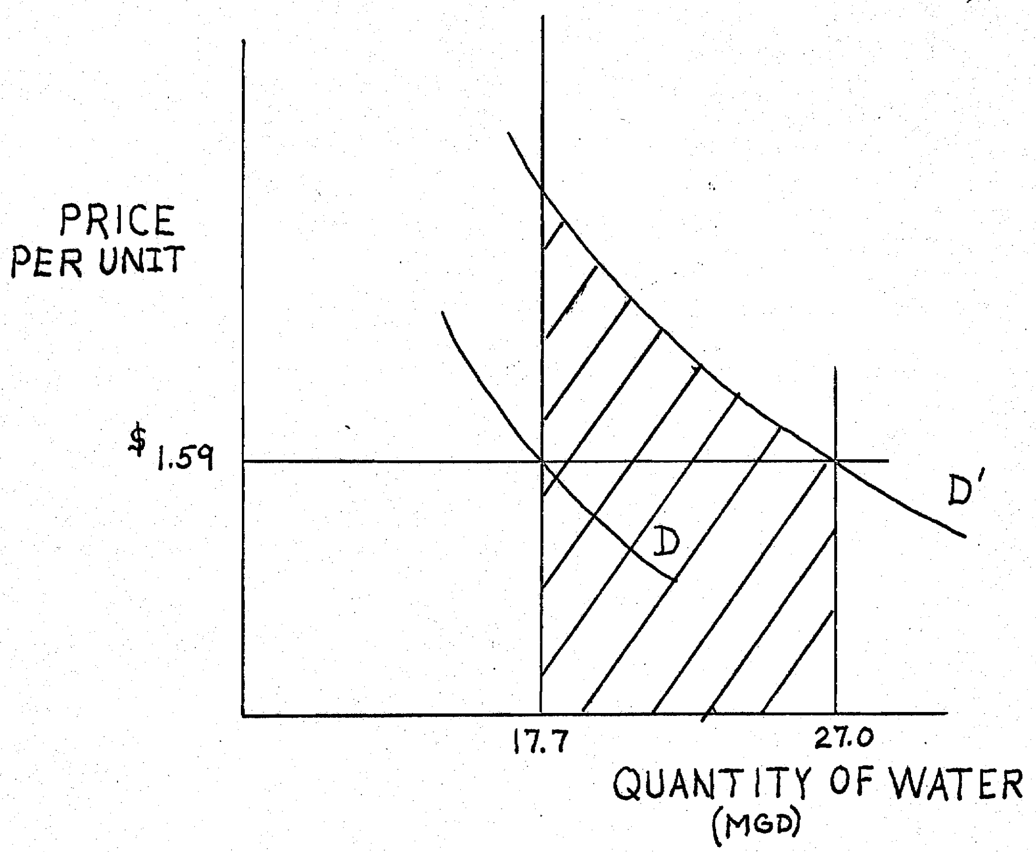

FIGURE 4.1 ESTIMATION OF WTP

water from 17.7 to 27.0 MGD during 2000.

The analagous calculation of levels of WTP was performed for each of the use types, in each city, during every year from 1980 through 2030. A computer program was developed which was capable of determinig the equations of the demand curves in each year, as described in Chapter 3, and then integrating those demand curves over the appropriate intervals. The levels of WTP in each year were then discounted at an annual interest rate of 6.375% in order to determine the present value of total WTP over the fifty-year period. The determination of the present value of WTP was made for the two sets of demand curves derived in the preceding section. The total discounted levels of estimated WTP for projected use in excess of 1980 use are shown in Table 4.1 for the two sets of demand curves. The levels of WTP are expressed in terms of the 1977 price level.

The elasticities of the demand curves significantly influenced the estimated levels of WTP for levels of use in excess of 1980 levels. The use of the less elastic set of demand curves led to the estimation of considerably higher levels of WTP than did the more elastic set of demand curves. The cause of this difference can be illustrated in Figure 4.2.

D'' and D' indicate the more highly and less highly elastic demand curves, respectively, for domestic residential use in 2000. The WTP for the quantity of water in excess of projected 1980 use is greater for the less elastic demand curve by an amount equivalent to the shaded area between the curves. It is apparent that the evaluation of the uses of water which would be foregone, were use restricted to 1980 levels,

TABLE 4.1

ESTIMATED WTP FOR PROJECTED USE

	Low Elasticities	High Elasticities
Virginia Beach	$ 1,053,904,000	$ 265,558,300
Norfolk	31,632,430	28,422,740
Chesapeake	343,187,800	102,319,800
TOTAL	1,428,724,200	$ 396,300,840
Portsmouth	19,876,370	16,152,480

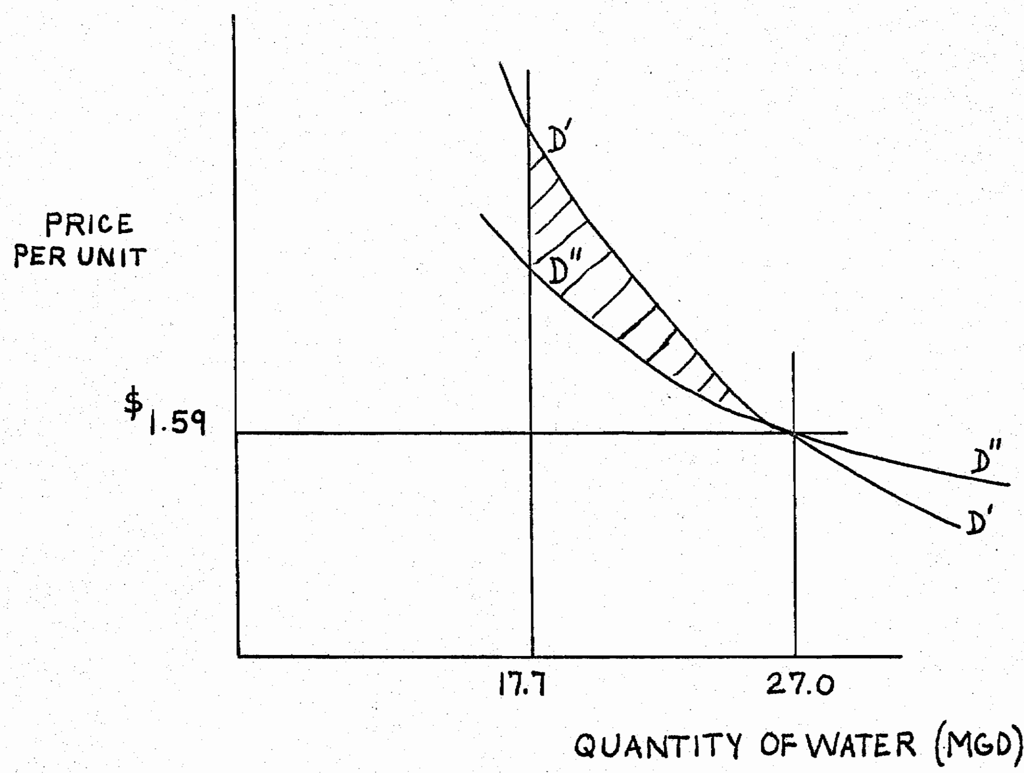

FIGURE 4-2 COMPARITIVE LEVELS OF WTP

would be higher given the less elastic demand curve. While the marginal evaluation of water at 27.0 MGD is the same for both demand curves in 2000, the evaluation of each unit of water between 17.7 and 27 MGD is greater for the less elastic demand curve.

Evaluation of Reductions in Projected Use

It has been suggested by the officials of several agencies having interests in water supply planning that substantial reductions in present levels of water use would lead to significant savings. These savings would be realized through the postponement of, and reduction in the level of, expenditures upon water supply and waste water treatment facilities. This section contains an evaluation of a 15% reduction in water use in Portsmouth and in Norfolk, Virginia Beach, and Chesapeake. The choice of a degree of water reduction to be analyzed is arbitrary to some extent. A 15% reduction has, however, been proposed by officials of the EPA and would not be expected to be outside the range of reductions considered by others involved in water planning processes.

There are three, not necessarily exclusive, means by which substantial reductions in water use could be achieved. One would be the imposition of mandated reductions in water use accomplished through the use of quotas. This would involve the rationing of water by fixing levels of water use of each of the water users in the area. Severe penalties, either in the form of fines or the termination of water service, would be required to achieve the desired levels of water use.

A second means of substantially reducing the water use would be an increase in the price of water. Increases in the price of water would result in the reduction of water use through individual utility and revenue maximizing adjustments. This method would be relatively easy to implement, but its results would be difficult to predict accurately due to the uncertainty concerning the nature of aggregate water demand curves.

The third means by which such a reduction could be achieved would be through the installation of devices designed to reduce water use without substantially reducing the utility derived from water at the original levles of use. Such devices include shower head flow restrictors and toilet tank dams. Difficulties may be experienced in achieving the widespread adoption of such devices; the devices are not costless and the levels of reduction resulting from their implementation are subject to some uncertainty.

The costs and benefits associated with a 15% reduction in water use, achieved through mandated reductions in water use, were estimated for Portsmouth and for Norfolk, Virginia Beach, and Chesapeake. As for the evaluation of projected use, the costs and benefits of interest were those for use in excess of 1980 use. The estimated net benefits of the 15% reductions in water use will, therefore, be on a commensurable basis with the estimated net benefits of projected use. It was assumed in the following analyses that projected 1980 use levels would be maintained until the year in which a 15% reduction in projected use would leave use in that year in excess of projected 1980 use. Reductions in projected use before that year would, therefore, be small initially and would increase to 15% in that year and be maintained at that level thereafter.

There would be two reasons for reducing water use in such a fashion. First, the imposition of quotas calling for immediate reductions of 15% could cause serious problems for many water users. The expected unpopularity of such a mandate would make unlikely its use by public officials. Second, very little would be gained through the reduction of use below 1980 levles. No investment in additional facilities would be necessitated by the levels of use projected for 1980 that would not also be required if use were reduced by up to 15% of those levels of use. The only savings would result from reduced levels of variable costs which would be negligible relative to the WTP for the quantities of water not consumed. The commonly stated rationale for reductions in water use is that substantial savings can be realized through postponing or reducing investment in costly facilities. It is obvious that such savings would not result from reducing use below 1980 levels.

The levels of WTP, for use in excess of 1980 use, when the 15% reduction was achieved as indicated above, were estimated for each type of use. The first year in which use would exceed projected 1980 use would be 1996 due to the relatively low rate of growth in projected use in Portsmouth, for example. The estimation of the WTP with the 15% reduction is illustrated in Figure 4.3 for domestic residential use in 2010 in Portsmouth.

The original projection of domestic use In Portsmouth in 2010 is 20.2 MGD. Use of 17.1 MGD represents a 15% reduction in that level

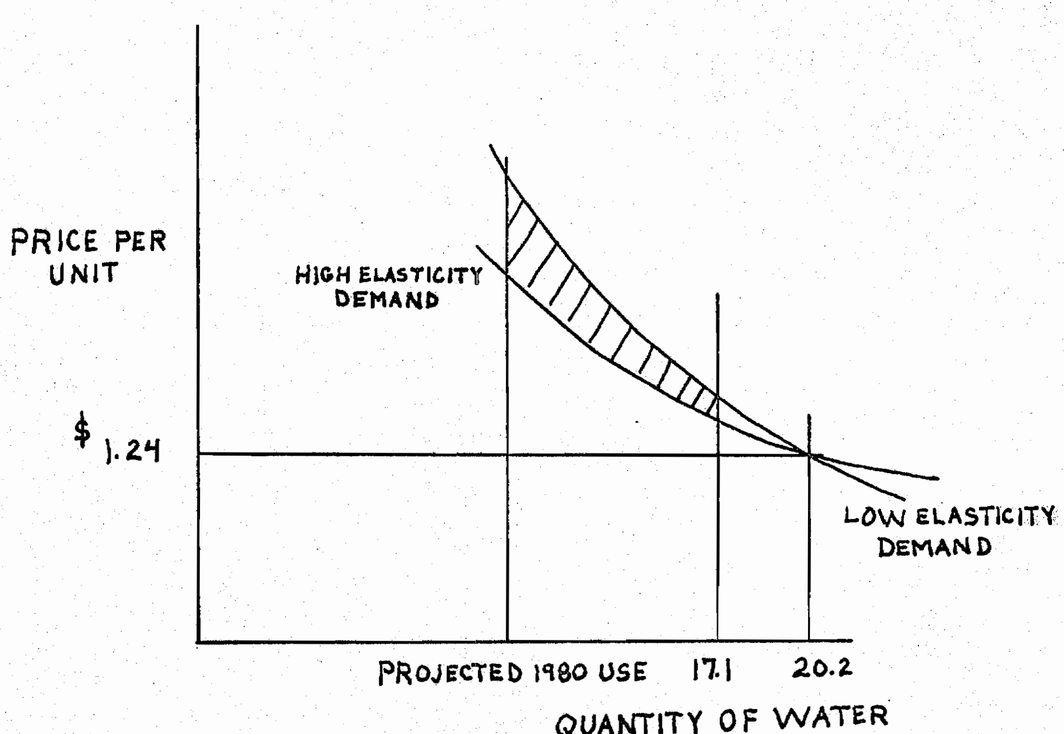

FIGURE 4.3 WTP WITH 15% REDUCTION IN PROJECTED USE

of use. The areas under the demand curves between 17.1 MGD and projected 1980 use indicate the levels of WTP for use in 2010 in excess of projected 1980 use levels. The levels of WTP for high and low elasticity demand curves would differ by an amount equal to the shaded area under the low elasticity demand curve. The levels of such WTP were calculated for each year from 1996 through 2030 for each of the four types of use. The present value in 1980 of the resulting time streams of levels of WTP was calculated by discounting at an annual interest rate of 6.375%. That present value was found to be $3,481,947 with the high elasticity demand curves and $3,547,898 with the low elasticity demand curves.

The evaluation of use in excess of projected 1980 use, given a 15% reduction in projected use achieved by a price increase, is illustrated in Figure 4.4.

The case of Portsmouth in 2010 is used as an example. The level of total use is reduced from 20.2 to 17.1 MGD. However, the WTP is no longer found by integrating the demand curves for each of the different types of use between 85% of originally projected use and projected 1980 use, i.e., between q_3 and q_1 for the example of domestic residential use. Instead, the level of each type of use at that price, p_1, which causes a 15% reduction in total use is found and the demand curve integrated between that level of use, q_4, and q_1. A computer program was developed in order to perform the necessary calculations.

The estimation of the costs associated with providing and treating the different levels of use is detailed in Appendix 2. The calculation

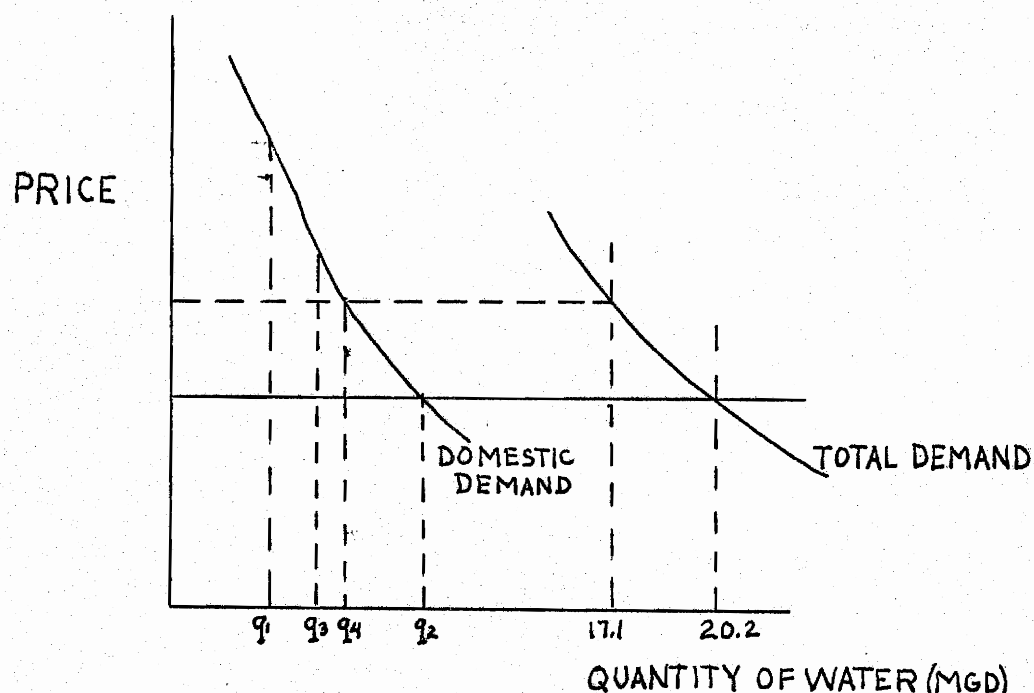

FIGURE 4.4 WTP WHEN REDUCTION IN USE ACHIEVED WITH PRICE INCREASE

of the net benefits of the different levels of use is also demonstrated in that appendix. The estimated net benefits for each of the responses to the water supply situation listed above are presented in that appendix.

CHAPTER 5

DETERMINATION OF OPTIMAL WATER SUPPLY DESICIONS

Introduction

The preceding analyses examined the net benefits derived from the provision of projected quantities of water and from an aribtrarily chosen reduction in that use. The purpose of the following analysis was the determination of the quantities of water which should be provided in order to maximize the net benefits derived from water supply. The estimated demand curves and the estimated costs associated with existing and proposed water supply and waste water treatment facilities provided the basis for a determination of the appropriate use of 1980 facilities and of an appropriate schedule of investments in additional facilities. The projected levels of use no longer dictated the operation of the 1980 facilities nor the times at which additional facilities were required. Examinations of the levels of WTP for particular quantities of water, relative to the costs of supplying those quantities, were made in order to determine the levels of use and dates of investment in additional facilities which would lead to the maximization of the present value of net benefits.

Optimal Response in Portsmouth

Examination of Effective Constraints

The present capacity of the Portsmouth water system is 27.5 MGD. Projected 1980 use is only 15.5 MGD and use is not expected to increase rapidly. The 1980 capacity of the waste water treatment facility serving Portsmouth will be 14.5 MGD, while projected use in that year is 13 MGD. It is unlikely that there would be any economic justification for the expansion of the capacity of the water supply system due to the relatively high level of excess capacity in that system. In addition, cost estimates were not available for expansions of those sizes appropriate for this system. For these reasons, it was assumed that the capacity of the water supply system would remain unchanged over the period of analysis.

The constraint upon the level of water use in Portsmouth would be the capacity of the waste water treatment system. If the existing relative composition of use were to be maintained, the 14.5 MGD capacity of that system would be reached when total water use equaled 17.3 MGD. The maximum level of inside water use which could be attained would be 16.9 MGD. The marginal evaluation of water is considerably in excess of the variable costs associated with its supply and subsequent treatment. The efficient use of the 1980 facilities, therefore, would require that the waste water treatment plant be operated at full capacity. The determination of the appropriate date for the construction of an additional treatment plant, of any particular size, could be made by ascertaining the WTP for the increase in water use made possible through increasing the constraint upon inside use from 16.9 MGD, to the level of inside use permitted by the increased total waste water treatment capacity. The annual level of WTP could be compared to the annual costs associated with the construction and operation at capacity of the additional treatment facility, and the annual costs associated with the supply of the additional quantity of water.

The proper date upon which to place in operation a 5 MGD waste water treatment facility was determined in this manner. A 5 MGD facility was chosen because it would be sufficiently large to permit the use of most of the available water system capacity. Also, an identical 5 MGD facility was analyzed in the previous analysis of the net benefits associated with projected use. Any difference in net benefits between providing projected use and determining appropriate use would, therefore, be attributable to the manner in which the facilities are employed, rather than to differences in those facilities.

Costs of Capacity Expansion

The costs of a 5 MGD waste water treatment plant estimated in Appendix 2 were employed in determining the annual costs of the 5 MGD increase in the maximum level of inside use. These annual costs would include the construction costs, fixed operation and maintenance costs, and variable operation and maintenance costs of the sewage treatment plant. Also included were the variable costs associated with the supply of the additional quantity of water. It was assumed that the composition of use would not change significantly as a result of the price change accompanying the change in the constraint on inside use.

The estimated annual costs of the 5 MGD increase in sewage treatment capacity are shown in Table 5.1.

WTP Associated with Different Levels of Capacity

The annual levels of WTP were estimated by integrating the demand curves for the different types of use over the intervals representing the changes in the levels of use made possible by the increase in the maximum level of inside use. The appropriate intervals for each type of use were found by first determining the prices which would restrict inside use to the existing and the proposed maximum levles. The maximum level of inside use with a sewer system capacity of 14.5 MGD is 16.9 MGD; with a 19.5 MGD sewer system, the maximum level of inside use would be 22.7 MGD. In each year the price which would restrict inside use to 16.9 MGD and the price which would restrict that use to 22.7 MGD were found. It is assumed that a single price would be charged at any given time for the different types of water use. For this reason, the increases in each type of use made possible by the increase in the maximum level of inside use can be determined by ascertaining the levels of the different types of use which would occur at the two different prices. The procedure employed in the estimation of the levels of WTP is illustrated in Figure 5.1. The example shown is for domestic residential use in 1984 and the low elasticity demand curves are used.

D_t, D_i, and D_d represent the aggregate demand for water, the aggregate inside demand for water, and the domestic demand for water,

TABLE 5.1

ANNUAL COSTS OF 5 MGD INCREASE IN SEWAGE TREATMENT CAPACITY IN PORTSMOUTH

Sewage Treatment Plant Construction	:	$ 1,286,952[a]
Sewage Treatment, Fixed O&M	:	161,000
Sewage Treatment, Variable O&M	:	177,880
Water Supply, Variable O&M	:	125,032[b]
TOTAL		$ 1,750,864

[a]A fifty-year life, two-year construction period and 6.375% interest rate were employed.

[b]Based on water use in 1986, given the new constraint on inside use.

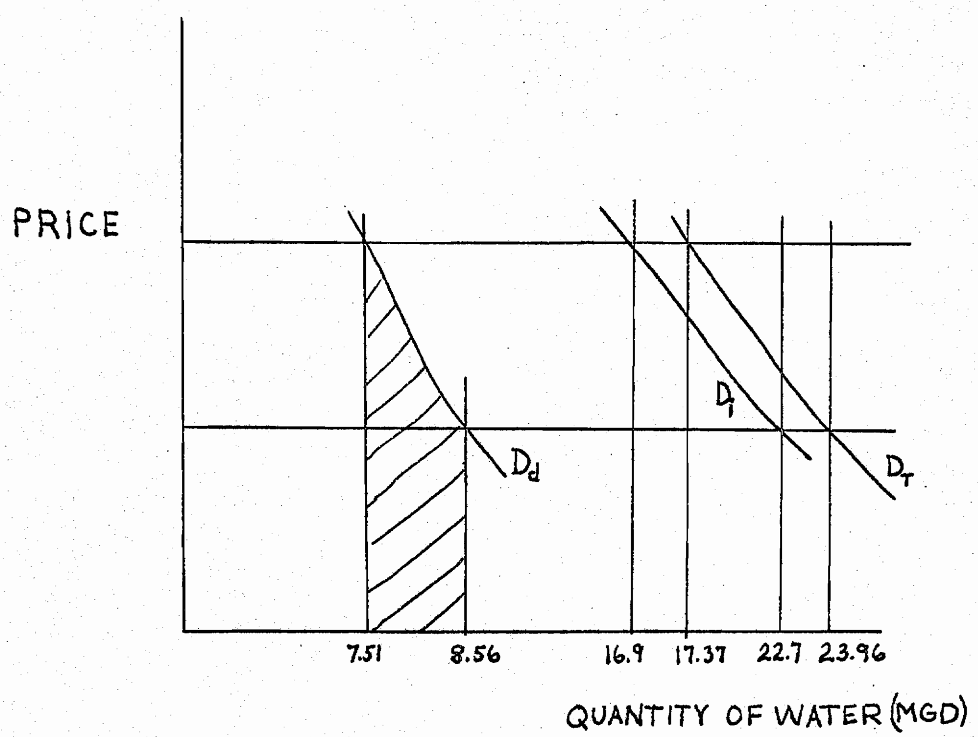

FIGURE 5.1 WTP FOR EXPANSIONS IN CAPACITY

respectively. The prices which would limit inside use in 1984 to the maximum levels permitted by the existing and the proposed sewage treatment capacities are $.96 and $.53 per thousand gallons, respectively.

Total water use at these prices would be 17.37 and 23.96 MGD. An increase in the constraint upon inside use would permit an increase in the level of domestic use. Domestic use at a price of $.96 would be 7.51 MGD; lowering the price to $.53 would result in domestic use of 8.56 MGD. The WTP for the increase in domestic water use permitted by the increase in waste water treatment capacity was found by integrating the domestic demand curve between 8.56 and 7.51 MGD. This level of WTP is represented in Figure 5.1 by the shaded area under the domestic demand curve and was found to be $280,174.

Determination of Optimal Time for Expansion

The levels of WTP for the other types of use were estimated in the same manner for both high and low elasticity demand curves. The total levels of WTP in each year were compared to the annual costs associated with the increased level of water use to determine the year in which the expansion in waste water treatment capacity should take place. The WTP for the increased use, estimated with the high elasticity demand curves, would exceed those costs in 1980. The WTP estimated with the low elasticity demand curves would first exceed those costs in 1986.

Evaluation of Net Benefits with Optimal Expansions

The net benefits associated with use in excess of projected 1980 use were estimated for both of the indicated responses. The levels of WTP in each year were estimated by integrating the demand curves between the levels of use associated with the prices necessary to limit inside use and projected 1980 use. In the case of the high elasticity demand curves, where treatment plant capacity would be expanded in 1980, the same constraint upon inside use would be in effect throughout the period of analysis. In the case of the low elasticity demand curves, where capacity would be expanded in 1986, the 16.9 MGD constraint upon inside use would be in effect through 1985 and the 22.7 constraint in the remainder of the period of analysis. The present values of the levels of WTP were $45,572,420 for the high elasticity demand curves and $38,687,660 for the low elasticity demand curves.

The costs associated with use in excess of projected 1980 use would consist of the variable operation and maintenance costs of the 14.5 MGD sewage treatment plant and of the water supply facilities, and the construction and operation and maintenance costs of the 5 MGD sewage treatment plant. The variable costs of both sewage treatment plants would be constant at capacity levels after their construction. The variable water supply costs would change slightly as the total level of water supplied changed due to the changes in the composition of use caused by the changing prices. The costs estimates employed in the preceding sections were used in estimating the above costs.

A summary of the costs for the levels of use and facilities associated with the high and low elasticity demand curves are shown in Table 5.2.

The net benefits of water use in excess of 1980 use, given the optimal use of existing facilities and the 5 MGD sewage treatment plant, would be $17,935,041 for the high elasticity demand curves, and $19,279,435 for the low elasticity demand curves.

Optimal Response in Norfolk, Virginia Beach, and Chesapeake

Examination of Effective Constraints

The decisions regarding the quantities of water to be supplied in NVBC involved the determination of the appropriate dates for increases in the capacities of the water supply and waste water treatment facilities. A preliminary step in the determination of those dates was the identification of the increases in water use made possible by expansions in the capacities of the water supply system and/or the waste water treatment system.

The capacity of the water supply systems serving NVBC in 1980 will be 90 MGD. The capacity of the sewage treatment plants serving the area will be approximately 77 MGD in that year. Treatment capacity will remain at that level as some smaller plants would be phased out as larger plants were upgraded and expanded. By 1983, the 77 MGD capacity would be provided by plants capable of meeting 1983 EPA standards for effluent quality. The variable costs of water supply and sewage treatment are sufficiently low that these facilities should be used to their

TABLE 5.2

COSTS OF USE IN EXCESS OF 1980 USE, OPTIMUM TIMING OF
5 MGD SEWAGE TREATMENT PLANT

	Present Value	
	High Elasticity Demand Curves	Low Elasticity Demand Curves
Variable sewage costs, 14.5 MGD plant	$ 546,261	$ 546,261
Variable sewage costs, 5 MGD plant	2,841,194	1,921,601
Variable water supply costs	2,391,415	1,889,652
Construction and fixed operation and maintenance costs, 5 MGD sewage treatment plant	21,858,509	15,050,711
TOTAL	$ 27,637,379	$ 19,498,585

full capacity. The constraint upon inside use imposed by the capacity of the waste water treatment system would be 80.21 MGD. This would be the effective constraint upon total water use because the price of water which would restrict inside use to 80.21 MGD would lead to water use of less than the 90 MGD capacity of the area water supply systems. This would be the case throughout the period that the first additional sets of facilities would be considered.

The proposed sources of additional water would be developed in two 35 MGD stages, except for the Blackwater River which would be developed in successive stages of 30, 15, 15, and 10 MGD. It has been proposed that sewage treatment capacity in the area be increased in the future through the construction of a 35 MGD treatment plant.

The increases in water use which could be achieved if the capacities of the water supply and sewage treatment systems were both increased by 35 MGD will be examined initially. If the capacities of both systems were increased by 35 MGD, total water use would be limited to 125 MGD while total inside use would be limited to 116.5 MGD. Whether the constraint on water use or inside water use would actually limit total water use would depend upon the nature of the water demand curves. It was found in the case of the low elasticity demand curves that the capacity of the water supply system would be the effective constraint upon total water use during the period that investment in the 35 MGD facilities was considered.

It was found that the capacity of the sewage treatment system would be adequate to deal with the waste water flows produced if the water system were used to its full 125 MGD capacity. However, it was found that the effective constraint upon total water use in the case of the high elasticity demand curves would be the capacity of the sewage treatment system. The price required to limit inside use to the levels permitted by the capacity of the sewage treatment system would result in total water use of slightly less than the 125 MGD capacity of the water supply system.

The next significant increase in the total level of water use could be realized through the construction of the second 35 MGD stage in the development of the water sources and the construction of an additional 35 MGD sewage treatment plant. The capacity of the water supply system would be 160 MGD and the capacity of the sewage treatment system would be 153 MGD.

In the case of the low elasticity demand curves, the effective constraint upon total water use prior to the construction of the second set of facilities would change over time. As indicated above, the effective constraint upon total water use, if the capacities of the water supply and sewage treatment systems were 125 and 112 MGD, respectively, would be the capacity of the water supply system during the period in which investment in the initial increases in capacity were considered. In the period following those initial increases in capacity, the effective constraint upon total water use would become the 116.5 MGD constraint upon inside use imposed by the capacity of the sewage treatment system. The maximum level of inside use which could be attained with a sewage treatment capacity of 153 would be 159.4 MGD. Since the capacity of the water supply system after the construction of the second set of facilities would be 160 MGD; the effective constraint upon total water use would be that capacity.

The change in the effective constraints upon total water use achieved by the construction of the second set of 35 MGD facilities would be from a maximum inside use of 116.5 MGD to a maximum total use of 160 MGD. These constraints would hold for both high and low elasticity demand curves during the period that investment in the second set of facilities would be considered.

If the Blackwater River were employed as the source of additional water, the initial substantial increase in the total level of water use could be accomplished by the implementation of the first 30 MGD stage in the Blackwater River, and the construction of the 35 MGD sewage treatment plant. As above, the effective constraint upon total water use, given the initial capacities of the water supply and sewage treatment system, would be the 80.21 MGD limit upon inside use. If the capacities of the water supply and sewage treatment systems were increased by 30 MGD and 35 MGD, respectively, the total capacity of the water supply system would be 120 MGD, and of the sewage treatment system, 112 MGD. The 112 MGD capacity of the sewage treatment system would limit inside use to 116.5 MGD. At those water price necessary to restrict total water use to 120 MGD, there would be excess capacity in the sewage treatment system during the period in which investment in the first set of additional facilities was considered. The investment in the initial set of additional facilities would permit total water use to increase from that level dictated by the price necessary to restrict inside use to 80.21 MGD to the 120 MGD capacity of the water supply system following that investment.

The next substantial increase in total water use could be realized through the implementation of the remaining three stages of the development of the Blackwater River and the construction of a second 35 MGD waste water treatment plant. The 120 MGD capacity of the water supply system would remain the effective constraint upon water use prior to the construction of these facilities throughout the period of analysis. The 160 MGD capacity of the water supply system would be the effective constraint upon total water use after the construction of the second set of facilities. The same constrainuts would be in effect for both the low and the high elasticity demand curves throughout the planning period.

WTP Associated with Different Levels of Capacity

The gains which would result from the construction of additional facilities can be estimated with the use of the demand curves for the different types of use, once the effective constraints have been determined. A simplified illustration of the estimation of the WTP for the additional quantities of water use which could be consumed as a result of increased capacity is shown in Figure 5.2.

The example illustrates the initial investment decision for the case in which water supply and sewage treatment capacity would be increased by 35 MGD. The effective constraint upon total water use prior to those increases would be the 80.21 MGD limit upon inside water use imposed by the initial 77 MGD capacity of the sewage treatment plants.

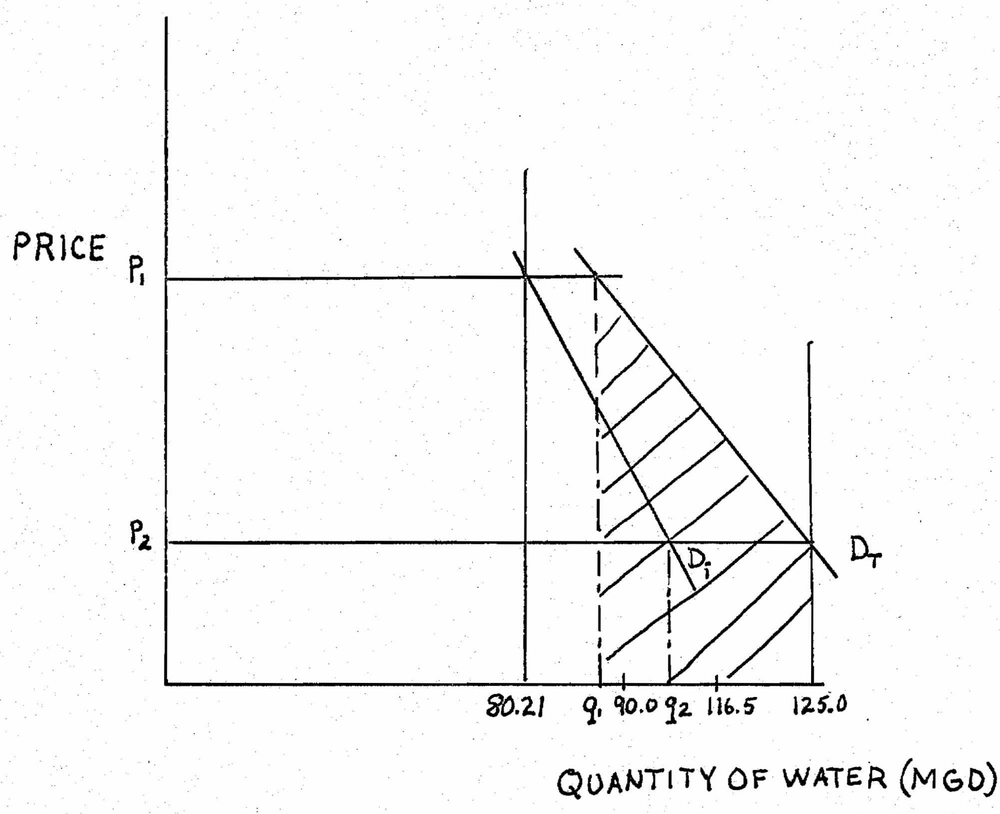

FIGURE 5.2 WTP CAPACITY EXPANSION

At price p_1, which would limit inside use to 80.21 MGD, total water use would be q_1, which would be less than the 90 MGD capacity of the water supply system. The effective constraint upon total water use, after the increases in capacity, would be the 125 MGD capacity of the water supply system. At price p_2, which would limit total water use to 125 MGD, inside water use would be q_2, which would be less than the 116.5 MGD limit upon inside use imposed by the 112 MGD capacity of the sewage treatment system.

The WTP for the increased quantity of water would be equivalent to the shaded area under the total demand curve between 125 MGD and q_1. The actual process by which that level of WTP was found was the integration of the demand curves for the different types of use in the three cities between the levels of use which would occur at the price necessary to limit inside use to 80.21 MGD and those levels of use which would occur at the price necessary to limit total use to 125 MGD.

The levels of WTP for the quantities of water which would be made available by investment in each of the sets of additional facilities were estimated for each year. These levels of WTP were then compared to the annual costs of the additional facilities and their operation and maintenance, in order to determine the appropriate times for investment in those facilities.

Costs of Capacity Expansions

The annual costs of the additional sets of facilities were estimated by employing the cost estimates of the COE and the HRSD. The actual construction costs and operation and maintenance costs of the different facilities are shown in Appendix 2. The annual costs of these facilities were found by assuming a two-year construction period for all facilities. The facilities were assumed to have a fifty-year life and an interest rate of 6.375% was used in the calculation of the annual costs. The annual fixed operation and maintenance costs were used as previously estimated. The variable operation and maintenance costs were estimated at the levels relevant to the constraints which would be effective. The estimated levels of annual cost for the different sets of facilities are shown in Table 5.3. The variable costs included in these annual costs were calculated for use of the facilities at capacity. Slight adjustments were made in order to compensate for the levels of excess capacity which would exist depending upon the year and the demand curves employed.

Determination of Optimal Times for Expansion

The dates upon which these sets of facilities should be put into operation were determined by comparing the levels of WTP for the increased quantities of water made available by them to the annual costs of the sets of facilities. The levels of WTP will differ between the two sets of demand curves. Therefore, the appropriate dates to put the sets of facilities into operation will differ depending on the set of demand curves employed in estimating the levels of WTP. The levels of WTP for the quantities of water made available would increse over time, reflecting the outward shifts in the demand curves. When the WTP for the quantity of water made available by a particular set of facilities exceeded the annual costs of that set of facilities, those

TABLE 5.3

ANNUAL COSTS OF ADDITIONAL FACILITIES

35 MGD Stage I Chowan River and first 35 MGD sewage treatment plant	: $ 13,109,481[a]
35 MGD Stage I Appomattox River and first 35 MGD sewage treatment plant	: 15,348,363
35 MGD Stage I Lake Gaston and first 35 MGD sewage treatment plant	: 16,213,228
30 MGD Stage I Blackwater River and first 35 MGD sewage treatment plant	: 14,105,111
35 MGD Stage II Chowan River and second 35 MGD sewage treatment plant	: 12,899,266
35 MGD Stage II Appomattox River and second 35 MGD sewage treatment plant	: 16,213,045
35 MGD Stage II Lake Gaston and second 35 MGD sewage treatment plant	: 15,932,216
40 MGD Stages II, II, and IV Blackwater River and second 35 MGD sewage treatment plant	: 15,091,109

[a]Stage I of each of alternative includes a connection to the Chesapeake system.

facilities should be put into operation. The annual costs were for the first year of operation and reflect the interest costs incurred during the construction period. The appropriate dates for putting the different sets of facilities into operation are shown in Table 5.4.

Evaluation of Net Benefits with Optimal Expansions

The levels of WTP for the quantities of water, in excess of projected 1980 use, which would be provided by the proposed sets of facilities were estimated in order to determine the net benefits of the optimal use of those facilities. Because the variable costs were negligible relative to the levels of WTP calculated in the preceding section, the capacity of either the water supply or sewage treatment system would be used to its full capacity at all times.

The levels of WTP for use in each year in excess of projected 1980 use were estimated for each of the different sets of facilities by determining the price in each year necessary to restrict inside or total water use to the effective constraint in that year. The quantities of each of the different types of use which would be consumed in each year, given the relative price, were determined. The demand curves for the different types of use were then integrated between the original 1980 projections of the different types of use and the quantities associated with the necessary prices. The resulting levels of WTP for the different types of use in the different cities were summed in each year. The present values of the annual levels of WTP were estimated for each of the different sets of facilities by discounting at an annual interest rate of 6.375%. The present values of the levels of WTP for use, in

TABLE 5.4

OPTIMUM DATES OF IMPLEMENTATION

	Low Elasticity Demand Curves	High Elasticity Demand Curves
Chowan River, Stage first sewage treatment plant	1983	1983
Chowan River, Stage II second sewage treatment plant	2004	1994
Appomattox River, Stage I first sewage treatment plant	1986	1983
Appomattox River, Stage II second sewage treatment plant	2009	2005
Lake Gaston, Stage I first sewage treatment plant	1987	1985
Lake Gaston, Stage II second sewage treatment plant	2008	2005
Blackwater River, Stage I first sewage treatment plant	1987	1983
Blackwater River, Stage II second sewage treatment plant	2005	1997

excess of 1980 use, when the proposed sets of facilities were employed in an optimal fashion are shown in Table 5.5.

Estimates were made of the costs which would be incurred as a result of the provision of quantities of water in excess of projected 1980 use. These costs would include variable costs incurred in the optimal operation of the facilities which would be in existence prior to the development of additional sources, and the construction of additional sewage treatment plants. These costs would also include the construction costs and the operation and maintenance costs incurred in the development of the additional sources of water and the additional sewage treatment plants.

The annual levels of variable costs incurred in the supply of quantities of water in excess of projected 1980 use by the water supply systems of Norfolk and Chesapeake, prior to the development of additional sources, were estimated by determining the levels of water use in excess of projected 1980 use in those systems during that period. These levels of water use were found in the preceding estimation of WTP for use in excess of projected 1980 use. These levels of use in Chesapeake and the combined levels of use in Norfolk and Virginia Beach were multiplied by the levels of variable cost per year per MGD for those systems which were employed in Appendix 2. Both of these water supply systems would be used to their full capacities after the development of the additional water sources and the associated increases in sewage treatment capacity. The annual levels of variable costs incurred in the supply of water from the new sources were found by first subtracting the capacity of the Norfolk and Chesapeake systems from the

TABLE 5.5

WTP OPTIMAL IMPLEMENTATION

	Low Elasticity Demand Curves	High Elasticity Demand Curves
Chowan River	$ 1,664,831,900	$ 571,528,250
Appomattox River	1,617,268,700	542,067,820
Lake Gaston	1,609,460,200	516,561,520
Blackwater River	1,606,264,800	535,397,470

total levels of water use which would be attained, given the relevant constraints upon water use. The variable costs per year per MGD for the new sources employed in Appendix 2 were then used to determine the annual levels of variable costs of these facilities.

The present values of the annual levels of variable costs incurred in the supply of water in excess of projected 1980 use are shown in Table 5.6.

The construction costs and fixed operation and maintenance costs of the development of the additional water sources were estimated by employing the cost estimates of the COE shown in Appendix 2. The dates upon which the different sets of facilities would be put into operation, shown in Table 5.4, established the dates upon which these expenditures would be incurred. The present values of these costs are shown in Table 5.7.

The variable costs incurred in treating the waste water attributable to water use in excess of projected 1980 use would consist of a portion of the variable costs of those sewage treatment plants that would be in operation from 1980 to 1983, and of the 35 MGD sewage treatment plants after they were put into operation. The variable costs of all sewage treatment plants in operation in 1983 and thereafter would be the same. This is true because the variable costs of the facilities capable of meeting 1983 EPA standards would be the same as for the additional 35 MGD plants that would be put into operation in 1983 or in the following years. The variable costs of the facilities in operation between 1980 and 1983 were calculated by determining the weighted average of the variable costs of the facilities which would be in

TABLE 5.6

VARIABLE WATER SUPPLY COSTS, OPTIMAL IMPLEMENTATION

	Low Elasticity Demand Curves	High Elasticity Demand Curves
Chowan River	$ 19,808,804	$ 22,142,503
Appomattox River	17,354,756	20,274,346
Lake Gaston	17,001,836	18,741,670
Blackwater River	16,027,810	20,840,533

TABLE 5.7

CONSTRUCTION AND FIXED OPERATION AND MAINTENANCE COSTS OF NEW WATER SOURCES, OPTIMAL IMPLEMENTATION

	Low Elasticity Demand Curves	High Elasticity Demand Curves
Chowan River	$ 70,207,046	$ 84,050,910
Appomattox River	88,884,631	108,668,050
Lake Gaston	94,587,956	108,620,460
Blackwater River	75,639,680	105,016,300

operation during that period as explained in Appendix 2. The estimated variable costs in all the years included the variable costs of the interceptor system which would deliver the waste water to the treatment plants.

The volumes of waste water in excess of projected 1980 levels were found by subtracting projected 1980 waste water volumes from the waste water volumes which would result, given the prices necessary to limit total water use, or inside water use, to the relative constraint. These volumes would be the same for all years in which a particular level of capacity of the sewage treatment system was an effective constraint upon total water use.

The annual levels of variable costs were dound by multiplying the waste water volumes in excess of projected 1980 levels by the appropriate levels of variable cost per year per MGD. The present values of the annual levels of variable costs which would be incurred in the operation of the waste water treatment plants are shown in Table 5.8.

The construction costs and fixed operation and maintenance costs of the 35 MGD sewage treatment plants were found by employing the costs estimated by the HRSD. The dates upon which those costs would be incurred were determined by the optimum implementation shcedule shown in Table 5.4. The present values of the construction and fixed operation and maintenance costs are shown in Table 5.9. The present values of the net benefits of use in excess of projected 1980 use, given the optimal implementation and use of additional water supply and waste water treatment facilities, are shown in Table 5.10.

TABLE 5.8

VARIABLE SEWAGE TREATMENT COSTS, OPTIMAL IMPLEMENTATION

	Low Elasticity Demand Curves	High Elasticity Demand Curves
Chowan River	$ 15,198,634	$ 18,696,385
Appomattox River	12,724,067	15,965,613
Lake Gaston	12,305,695	14,525,692
Blackwater River	12,067,027	16,689,786

TABLE 5.9

CONSTRUCTION AND FIXED OPERATION AND MAINTENANCE COSTS, 35 MGD SEWAGE TREATMENT PLANTS, OPTIMAL IMPLEMENTATION

	Low Elasticity Demand Curves	High Elasticity Demand Curves
Chowan River	$ 108,667,380	$ 127,260,580
Appomattox River	86,767,827	107,365,380
Lake Gaston	83,616,081	97,462,558
Blackwater River	87,316,963	117,808,170

TABLE 5.10

NET BENEFITS IN NVBC, OPTIMAL IMPLMENTATION

	Low Elasticity Demand Curves	High Elasticity Demand Curves
Chowan River	$ 1,443,173,300	$ 311,601,190
Appomattox River	1,405,078,900	282,017,750
Lake Gaston	1,395,878,000	270,340,130
Blackwater River	1,409,122,700	267,266,000

CHAPTER 6

SUMMARY AND CONCLUSIONS

Portsmouth

Summaries of the net benefits associated with water use in excess of projected 1980 water use in Portsmouth and in Norfolk, Virginia Beach, and Chesapeake (NVBC) are presented in Table 6.1 and in Tables 6.2 and 6.3, respectively. The net benefits shown in these tables represent the differences between the WTP for, and the costs incurred in the provision of quantities of water used in excess of projected 1980 use. The benefits and costs of the different responses were examined in each year from 1980 through 2030 for the high and low elasticity estimated demand curves. The net benefits are expressed as present values in 1980, based upon a discount rate of 6.375%, and are given in terms of the 1977 price level.

Table 6.1 shows the net benefits which would be realized in Portsmouth for each of the examined responses. A comparison of the net benefits associated with the optimal use of the existing water supply system and the existing and proposed sewage treatment facilities, with the net benefits associated with projected use, indicates that substantial gains could be realized by making use of the excess capacity in the water supply system. The relatively low level of variable costs of water supply would result in only marginally higher costs of water

TABLE 6.1

SUMMARY OF NET BENEFITS IN PORTSMOUTH

	Use as Projected	-15% by Quota	-15% by Price	Optimal Implementation
High Elasticity Demand Curves	$ 2,776,503	$ 1,558,302	$ 2,798,778	$ 17,935,041
Low Elasticity Demand Curves	6,490,393	1,624,253	5,487,957	19,279,435

supply, were capacity utilized more fully. The costs associated with the expansion of the sewage treatment system necessitated by the increased levels of water use would be greatly exceeded by the WTP for the increased quantities of water.

The low prices which would be required to bring the substantial increases in use in Portsmouth suggest an alternative use of the capacity of that city's water system. The low prices of water in Portsmouth, relative to those in effect in NVBC, indicate that there is the potential for transfering water from relatively low valued uses in Portsmouth to more highly valued uses in NVBC. The sale of quantities of water, sufficient to approximately equate the marginal evaluation of water in the two areas, would be expected to increase the total WTP for the use of the water supply facilities of the two areas at or near capacity. In addition, it would be expected that financial arrangements could be reached so that the proposed sale would benefit both parties. The economic merit of such a transfer would depend upon its costs relative to the increase in WTP relaized as a result of it. The costs of such a transfer were examined in a previous study and were found to be low relative to the costs of alternative means of incureasing the quantities of water available to NVBC.

The gains from the use of the additional quantities would be due to increased levels of each of the different types of use in approximate proportion to the elasticities of demand.

It is possible that the more stringent environment regulations, which will go into effect in the future, would reduce the benefits derived from the use of the Portsmouth water supply system at full capacity. Regulations reducing permissible effluent discharges and/or charging for total effluent levels would act to shift the industrial demand for water to the left. The WTP for any level of industrial water would be reduced, as would the level of use at any particular price. The net benefits for the use of the full capacity could, for this reason, be overstated. However, the very substantial difference in net benefits of the alternative approaches is an indication that the full use of the capacity may be desirable even with more stringent controls or waste water.

The influence of the more stringent controls upon the net benefits of the full use of capacity could be offset somewhat by the movement of additional industry to Portsmouth. The original projections of water use and of the demand curves were predicated upon a perception of future industrial development given the current price of water. It is possible that the lower levels of price necessary to achieve the fuller use of capacity would attract additional industry to Portsmouth. To the extent that this would occur, the gains from the fuller use of capacity would have been understated.

The superiority of the optimal response, relative to the other responses considered, was maintained with both the high and low elasticity demand curves.

A 15% reduction in projected use by quota, i.e., equal percentage reductions by each type of use, was found to be inferior to all other responses considered. The only sizable savings realized from the reduction in use were attributable to the delay in the construction of an additional sewage treatment plant and the reduction in the necessary size of that plant. Substantial reductions in WTP would result from the reductions in the levels of water use. The low levels of net benefit which would occur with this response are an indication of the lack of significant savings due to reductions in water use, given excess capacity in the water supply system. The gains from the costs foregone were considerably less than the benefits foregone due to the reductions in water use.

A 15% reduction in total water use effected through the use of increased prices would prove significantly superior to the reduction by quota. This is the case because while the costs associated with the reductions would be approximately the same, the reduction in use would be achieved with the minimum reduction in WTP when accomplished through increased prices. The price for each type of use would be the same, and, thus, the MEVs would be equated.

The net benefits of a 15% reduction accomplished through increased prices do not differ significantly from the net benefits associated with projected use. The reductions in WTP due to reductions in water use would be offset by the cost savings attributable to the reduced size of, and delay in the construciton of an additional sewage treatment plant. The greater reductions in use by the more elastic uses would result in considerably smaller reductions in WTP than would be the case for the reduction by quota.

The reductions in the levels of water use could be accomplished, in part, by the installation of relatively inexpensive water saving devices which, while reducing water use, would not significantly reduce the benefits derived from the use of water. If this were the case, the net benefits associated with the reductions in water use would be higher than those shown. It would be expected that the level of use for which such devices are not feasible is sufficiently great that there would remain significant differences in the net benefits of reductions achieved by increased prices and by quotas.

The net benefits associated with the optimal response are dependent upon the elasticity of aggregate water demand. If the actual elasticity of water demand were less than those employed, the net benefits associated with the optimal response would be lower relative to the net benefits of projected use than was found to be the case in this study. In addition, it is possible that the industrial demand for water will be shifted by the technological changes required to meet future water quality standards. This would also be expected to lower net benefits of the optimal response relative to those of projected use. However, the high level of net benefits associated with the optimal response is an indication that reductions in water use, in excess of those required to limit water use to the capacity of the waste water treatment plant, would not be desirable.

Norfolk, Virginia Beach, and Chesapeake

Tables 6.2 and 6.3 present the estimated net benefits which would be realized with each of the examined responses in the three cities of Norfolk, Virginia Beach, and Chesapeake (NVBC). Table 6.2 lists the net benefits derived from the various responses for the high elasticity

TABLE 6.2

SUMMARY OF NET BENEFITS IN NVBC
HIGH ELASTICITY DEMAND CURVES

	Use as Projected	15% Reduction by Quota	15% Reduction by Price	15% Reduction by Devices	Optimal Implementation
Chowan River	$ 213,258,640	$ 108,479,060	$ 197,875,330	$ 287,033,540	$ 311,601,190
Blackwater River	198,684,240	101,448,950	190,845,220	280,003,420	267,266,000
Appomattox River	183,218,340	97,757,590	183,390,450	272,548,660	282,017,750
Lake Gaston	175,011,130	89,369,110	178,765,380	267,923,580	270,340,130

TABLE 6.3

SUMMARY OF NET BENEFITS IN NVBC
LOW ELASTICITY DEMAND CURVES

	Use as Projected	15% Reduction by Quota	15% Reduction by Price	15% Reduction by Devices	Optimal Implementation
Chowan River	$ 1,245,682,050	$ 523,132,180	$ 1,219,342,200	$ 1,319,456,900	$ 1,443,173,300
Blackwater River	1,231,107,600	516,102,070	1,212,312,100	1,312,426,800	1,409.122,700
Appomattox River	1,215,641,700	508,647,300	1,204,857,300	1,304,972,000	1,405,078,900
Lake Gaston	1,207,434,500	504,022,230	1,200,232,200	1,300,346,900	1,395,878,000

demand curves, while Table 6.3 lists the net benefits for the low elasticity demand curves.

It appears that substantial gains in net benefits could be realized through the optimal use of existing facilities and scheduling of investment in additional facilities. The absolute level of the gains in net benefits would be larger with the high elasticity demand curves, but the relative gains would be substantially larger for the low elasticity demand curves. The gains in net benefits would be attributable to the use of facilities at, or close to, capacity at all times and the more rapid development of the additional sources of water. The WTP for the increased levels of water use would more than offset the increased costs incurred. The optimal use of the existing (1980) and proposed facilities would require continual adjustments in the level of price to insure that capacity would be utilized as fully as possible. Miscalculations could result in underutilization of capacity or could lead to shortages. The investment in the proposed facilities at the appropriate time would, of course, require a detailed knowledge of the nature of demand. To the extent that these conditions are not met, the net benefits attributable to the optimal response would tend to overstate the net benefits which could actually be attained.

A related issue is the use of the assumption that price can be used to precisely limit use to capacity as demand shifts and to generate the proper increases in use when capacity is increased. To the extent that use cannot be controlled, the alternative relying on the use of price to control use will tend to have too high a level of net benefit attached to them.

There are very substantial differences between 15% reductions achieved by increased prices and 15% reductions achieved through quotas. The reasons for the differences here are the same as for Portsmouth. The very much higher levels of projected use in excess of 1980 use were the cause of the higher absolute difference in the levels of net benefits.

There was little difference between the net benefits associated with a 15% reduction in projected use by price and use as projected. Which of these two responses was most beneficial depended upon the particular source of additional water employed. The superiority of projected use was lost when the most expensive sources of additional water were employed, given the high elasticity demand curves. If the postponement in investment and reduction in variable costs could be achieved through a 15% reduction in use by price, there would be little difference in the benefits foregone due to reduced water use and the costs foregone as a result of the reduced water use.

The 15% reduction in water use accomplished by the installation of devices would be superior to all the other responses, except the optimal response, for both the high and low elasticity demand curves. It would be superior to the optimum for the two most expensive sources of additional water, given the high elasticity demand curves. The relatively low cost of the devices necessary to achieve the 15% reduction and the lack of any reduction in the utility derived from the use of water, despite the reduction in the level of use, make this a relatively efficient response. While there would be costs incurred in administering the program necessary to achieve the necessary levels of use of the devices, there would be no need to constantly monitor the price of water to maintain use at capacity.

There are several important considerations which must be recognized in interpreting the results of this analysis. First, it was assumed that the rate of inflation of the costs associated with water supply and sewage treatment would not exceed the rate of inflation in the general price level. An increase in construction costs, relative to other goods and service has not been considered. The uncertainty inherent in the projection of relative price levels precluded the analysis of the effect of inflation in construction costs upon the timing of capacity expansions.

Second, the employment of the optimal response requires detailed information concerning the nature of demand in order to determine the appropriate times for expansion in capacity. The demands for this area would be expected to fall within the range of the high and low elasticity demand curves; however, it would be necessary to have more exact knowledge of the demand curves if the optimal response would be effective in actuality. The sensitivity of the dates of investment to the different demand curves demonstrates this.

The use of restrictions on water use or increased prices to achieve reductions in water use would not preclude the adoption of water saving devices, and would actually be expected to encourage their installation. If this were to be the case, the net benefits of reductions in water use by quotas and price increases would be increased because of reductions in the benefits foregone through reduced water use.

The net benefits of the optimal responses are dependent upon the elasticity estimates employed in the estimation of the demands. The superiority of the optimal responses is dependent upon the price responsiveness of water use. If the demand elasticity of water were less than that employed, the difference between the net benefits of the optimal response and use as projected would be reduced.

While the results of this analysis must be interpreted with care, there are some conclusions which can be reached with relative confidence. It seems apparent that the capacity of either the water supply or sewage treatment systems should be used at full capacity at all times. In addition, the relative merits of reducing water use through the use of devices and increased prices indicates that their combined use to restrict water use to capacity would be desirable. The basic process of restricting use to capacity until investment is warranted by the level of benefits relative to costs does seem to hold promise. More detailed analysis of the nature of demand would be required before that practice would be conducted with confidence.

This analysis makes quite clear that regardless of the elasticities employed in the estimation of demand, there are substantial gains to be realized through delaying investment until price approaches long run average costs, then, after the expansion in capacity takes place, lowering price to make full use of capacity. Price should vary over time to effect the necessary changes in the use of capacity. The importance of price in regulating demand has implications for the manner in which price is presented to the consumer. The above analysis is predicated upon a rational and informed response of water users to price. This response can be improved by providing very explicit information regarding price to the water user. Price should be presented in an intelligible manner. The water user should be informed of the cost associated with different uses of water and of the availability of devices designed to reduce water use. The potential for the use of price in this manner has not been fully explored in this area.

Appendix 1

ESTIMATION OF THE COMPOSITION OF WATER USE

Virginia Beach

The total level of all types of use was available for each month from 1973 to the latter part of 1976. No information was available regarding the composition of total use. The monthly levels of use are shown in Table A1.1. The rapid increase in water use during this period is primarily a reflection of the rapid growth in the population of Virginia Beach in the period.

A determination of the composition of water use by type depended upon the estimation of the numbers of water users of each type and the application of estimates of average use by users of each type derived in previous analysis. The extent to which the different types of users could be further disaggregated permitted relatively accurate estimates of use to be derived in this manner. Descriptions of the types of use and the procedures by which consumption by those types of use are presented in the following sections.

Commercial Water Use

This class of users was defined as consisting of those establishments having retail sales taxable by Virginia. The commercial classification was further disaggregated into five sub-classes as shown in

TABLE A1.1

WATER USE BY CUSTOMERS OF THE VIRGINIA BEACH DEPARTMENT OF PUBLIC UTILITIES
(in million gallons)

	1973	1974	1975	1976
January		435	430	460
February		350	360	450
March		350	380	430
April		455	460	530
May		450	445	480
June		445	540	620
July	435	585	510	555
August	455	470	530	630
September	460	475	495	530
October	400	450	465	470
November	405	390	430	
December	375	430	450	
Avg MGD	13.86[a]	14.5	15.1	16.6[b]

[a]Missing months assumed equal to July through December

[b]November and December assumed equal to January and February

Table A1.2. Estimates of water use by these firms were made by multiplying the number of firms of each type by the average levels of use of firms of each type, derived in a previous study of commercial water use. Estimates of such use were derived for 1974 and 1975 as these were the years for which complete data were available regarding total use in the city and the number of firms in each sub-class. Table A1.2 shows the derivation of the levels of the different types of use, except for use by hotels and motels which will be estimated in a manner explained below.

Virginia Beach has a very substantial level of tourism during the summer months. Therefore, it was necessary to estimate the level of use attributable to tourists in order to estimate monthly commercial use.

The use by tourists was estimated by first determining the level of number of overnight visitors to Virginia Beach during 1974 and 1975. The total number of overnight visitors was multiplied by the average length of stay of 3 days to determine the total number of "tourist-days."[1] These total annual tourist-days were allocated to the months on the basis of the proportion of total sales of the hotels and motels of Virginia Beach realized in each month.[2] It was assumed that the typical tourist would consume an amount of water approximately equivalent to average per capita domestic use. While there is some variation in average per capita domestic use among cities, it is felt that 60 gallons per capita per day represents a reasonably accurate estimate.[3] Tourist use for each

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[1]City of Virginia Beach, Tourist Development Division.

[2]Commonwealth of Virginia, Department of Taxation, Taxable Sales in Virginia Counties and Cities (Quarterly Reports for 1974 and 1975, Richmond, Va.).

[3]Howe and Linaweaver, "The Impact of Price."

TABLE A1.2

ESTIMATED COMMERCIAL WATER USE IN CITY OF VIRGINIA BEACH

	Number of Firms		Average Use KG/month [a]	Estimated Annual Use (Average MGD) [b]	
	1974	1975		1974	1975
Department Stores	17	15	179.00	.100	.088
Grocery Stores	135	146	41.70	.185	.200
Restaurants, Bars, etc.	337	363	53.40	.591	.637
Motels, hotels	231	234	248.00	.455	.512
Other Commercial	1891	1940	6.21	.386	.396
TOTAL				1.72	1.83

[a] KG = thousand gallons

[b] MGD = million gallons per day

month of 1974 and 1975, estimated in this fashion, is shown in Table A1.3.

It was felt that the estimation of use by hotels and motels could be made more accurately through the use of the estimates of tourist use than through the use of the average levels of use by hotels and motels in the study cited above. This was the case because there are significant differences in the average size of the hotels and motels in the Virginia Beach area and those in the area for which the average levels of use were originally estimated. It was, therefore, assumed that all use by motels and hotels was attributable to use by tourists. Use by tourists undoubtedly constitutes a significant portion of the water used by restaurants and bars. An approximate estimate of the proportion of water used by restaurants and bars which is consumed by tourists, as given by an official of the Virginia Beach Department of Public Utilities is 50%.[4] This estimate is consistent with the level of tourism relative to the population of Virginia Beach. Fifty percent of the use by restaurants, bars, and similar establishments was subtracted from the total estimated tourist use to obtain the estimated levels of use by motels and hotels shown in Table A1.2.

Industrial Water Use

The estimation of industrial water use In Virginia Beach relied upon the estimated level of industrial water use in Norfolk. While the level of industrial activity in Norfolk is much greater than in Virginia Beach, the relative importance of those types of industrial processes

[4]City of Virginia Beach, Department of Public Utilities.

TABLE A1.3

TOURIST USE BY MONTH
(in million gallons)

	1974	1975
January	8.24	9.99
February	8.24	9.99
March	8.24	9.99
April	10.20	12.30
May	19.20	23.30
June	35.70	43.30
July	60.40	73.30
August	60.40	73.30
September	35.70	43.30
October	10.20	12.30
November	8.24	9.99
December	8.24	9.99

which have been found to use substantial quantities of water is quite similar between the two cities.[5] The similarity of the composition of the industrial sectors and the inconsistencies encountered in applying estimates of industrial water use derived in previous analyses led to the estimation of industrial water use in Virginia Beach through the use of the average levels of water use per dollar of value added estimated for Norfolk.

The estimated levels of industrial water use in Norfolk included the quantities of water delivered to approximately ten large industrial firms in Virginia Beach served directly by the Norfolk water system. Total industrial use within Norfolk, therefore, was found by subtracting the levels of use by these industries from the estimated levels of use of all firms served by the Norfolk water system.[6] The levels of value added in Norfolk during 1974 and 1975 were estimated by multiplying the level of value added in 1972 by the ratio of manufacturing employment in that year to manufacturing employment in 1974 and 1975.[7] The estimated levels of water use per dollar of value added were then obtained. The levels of value added by manufacturers in Virginia Beach in 1974 and 1975 were estimated by multiplying the level of value added in 1972 by the proportionate change in manufacturing employment in Virginia Beach between 1972 and the two more recent years.

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[5]U. S. Bureau of the Census, Census of Manufactures, 1972 Area Series Virginia, MC 72(3)-47 (Washington, D.C.: G.P.O., 1975).

[6]City of Virginia Beach, Department of Public Utilities.

[7]U. S. Bureau of the Census, Virginia Employment Commission, Covered Employment and Wages, 1971 through 1976 (Richmond, Va.)

The estimated levels of value added were then multiplied by the estimated levels of water use per dollar of value added, in order to obtain the estimated levels of total water use by industries in Virginia Beach. The levels of use by those industries served by the Virginia Beach water system were then obtained by subtracting the levels of use by the large firms served directly by Norfolk from the estimated levels of total use by industries. The estimates of industrial water use and their derivation are shown in Table A1.4.

Residential Water Use

Residential water use during 1974 and 1975 was estimated by subtracting estimated industrial and commercial water use from the total quantity of water supplied by the Virginia Beach Department of Public Utilities. Residential use was estimated in this manner because a preliminary examination of the number of households receiving public water service and typical residential use levels indicated that residential use would constitute over 75 percent of total water use. This was confirmed by the relatively low levels of commercial and industrial use which were estimated. The relatively low levels of the two other types of use make unlikely substantial error in the estimation of residential use by subtracting them from the total. Residential use in each month of 1974 and 1975 was estimated by subtracting industrial and commericial use (including estimated tourist use) from total water use. The estimated levels of residential water use are shown in Table A1.5. A comparison of the per capita residential use levels implied by these estimates to residential use levels occurring in other demographically similar communities

TABLE A1.4

ESTIMATION OF INDUSTRIAL WATER USE IN VIRGINIA BEACH

Value Added by Manufacturers in Norfolk
1972: $234.4 million

Manufacturing Employment in Norfolk
1972: 12,700
1974: 13,422
1975: 12,654

Estimated Value Added
1974: $247.7 million
1975: $233.6 million

Estimated Industrial Water Use
1974: 22.38 MGD
1975: 21.22 MGD

Estimated Water Use Per Dollar Value Added
1974: .090 MGD per million dollars value added
1975: .091 MGD per million dollars value added

Value Added by Manufacturers in Virginia Beach
1972: $16 million

Manufacturing Employment in Virginia Beach
1972: 1,100
1974: 1,275
1975: 1,236

Estimated Value Added
1974: $18.5 million
1975: $18.0 million

Estimated Water Use by Manufacturers in Virginia Beach
1974: $18.5 million x .090 MGD/million = 1.665 MGD
level of use by industries served directly by Norfolk: 1.29 MGD

Total use by industries served by Virginia Beach water system: .375 MGD

1975: $18.0 million x .090 MGD/million = 1.638 MGD
level of use by industries served directly by Norfolk: 1.30 MGD

Total use by industries served by Virginia Beach water system: .338 MGD indicates that the estimates are within the range of typical use levels.

Residential water use can be disaggregated into domestic, or use within dwelling units, and outside use. This distinction can be made on the basis of the significant differences in the changes in the levels of use resulting from changes in prices which have been found to exist for these different types of use.[8]

Estimates of the two components of residential use were made through an examination of the seasonal variation in such uses. It was assumed, as has been found to be the case in other studies, that the level of outside use during the first four, and last two, months of the year was negligible.[9] Residential use during this period can, therefore, be seen to consist entirely of domestic use. The mean levels of use during this period can be seen to represent average domestic use during all months if it is assumed that domestic use, while varying from month to month, does not vary in any systematic fashion with the seasons. If this is the case, the differences between the levels of use during the months in which the outside use of water is expected to be significant, May through October, and the estimated average levels of domestic use can be employed as estimates of outside use. The estimates of domestic and outside use derived in this fashion as shown in Table A1.5.

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[8]Grima, Residential Water Demand.

[9]Ibid.

TABLE A1.5

THE COMPOSITION OF RESIDENTIAL USE IN VIRGINIA BEACH
(in million gallons)

	1974			1975		
	Total	Estimated Domestic	Estimated Outside	Total	Estimated Domestic	Estimated Outside
January	387			383		
February	302			313		
March	302			333		
April	405			411		
May	391	353	38	385	371	14
June	370	353	17	460	371	89
July	495	353	142	400	371	29
August	370	353	17	420	371	49
September	400	353	47	415	371	44
October	400	353	47	416	371	45
November	342			382		
December	382			403		
TOTAL	4546		308	4721		270

Norfolk

The total monthly levels of water production by the Norfolk water system were available for 1974 and 1975. Norfolk provides water in bulk to Virginia Beach and Chesapeake. Total water use in Norfolk for each month of 1974 and 1975 was found by subtracting the levels of the bulk sales to Chesapeake and Virginia Beach from the total levels of water use. The monthly levels of water use in Norfolk are shown in Table A1.6. These estimates include use by several large customers in Virginia Beach served directly by the Norfolk water system.[10]

Residential Water Use

The residential use of water in Norfolk was estimated through a determination of the population receiving municipal water service and the application of the average levels of residential water use per capita which occurred in Portsmouth. The entire populations of Norfolk and Portsmouth receive municipal water service. The annual per capita levels of residential water use in Portsmouth receive municipal water service. The annual per capita level of residential water use in 1974 and 1975 were 21.60 KG and 22.22 KG, respectively. These levels of use were derived by dividing residential use in 1974 and 1975 by the estimated population of Portsmouth in those years.[11] Portsmouth and Norfolk are quite similar with regard to those characteristics which have

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[10]Cities of Virginia Beach, Chesapeake, and Norfolk, Departments of Public Utilities.

[11]City of Portsmouth, Department of Public Utilities; U.S. Bureau of the Census, Current Population Reports: Population Estimates and Projections (Washington D. C.: G.P.O., 1977).

TABLE A1.6

TOTAL WATER USE IN NORFOLK
(in million gallons)

	1974	1975
January	1327	1298
February	1215	1200
March	1388	1328
April	1283	1271
May	1442	1392
June	1386	1399
July	1493	1431
August	1469	1506
September	1315	1272
October	1365	1327
November	1327	1256
December	1274	1288
TOTAL	16284	15968
Average MGD	(44.61)	(43.75)

been found to significantly influence average residential water use. The nature of the housing stock and average levels of income are two of the most important factors affecting such use, and differ only slightly between the cities.[12] Residential use in Norfolk in 1974 and 1975 was, therefore, estimated by multiplying the estimated populations in those years by the above levels of per capita use as shown in Table A1.7.

The domestic and outside components of residential use were estimated by assuming that the relative composition of residential use in Portsmouth and Norfolk was equivalent. Domestic and outside use were estimated to consitute 96 percent and 4 percent, respectively, of residential use in Portsmouth during 1974 and 1975. Estimated levels of domestic and outside use in Norfolk during 1974 and 1975, consistent with those relative levels of use, are shown in Table A1.7.

Commercial Use

Commercial water use in Norfolk was estimated through a determination of the numbers of different types of commercial establishments in 1974 and 1975, and the application of estimates of average levels of use by such establishments derived in a previous analysis of commercial water use.[13] The estimates of commercial water use in Norfolk in 1974 and 1975, and their derivation, are shown in Table A1.8.

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[12] U. S. Bureau of the Census, Current Population Reports; U. S. Bureau of the Census, Census of Housing: 1970, Detailed Housing Characteristics Final Report HC(1)B48 Virginia (Washington, D.C.: G.P.O., 1972).

[13] Commonwealth of Virginia, Taxable Sales; Luppold, Commercial Demand.

TABLE A1.7

ESTIMATED COMPOSITION OF ANNUAL RESIDENTIAL USE IN NORFOLK

	Norfolk Population	Per Capita Use in Portsmouth (KG)	Residential Use in Norfolk (MGD)	Domestic Use (MGD)	Outside Use (MGD)
1974	289,000	21.6	17.1	16.4	.69
1975	285,500	22.2	17.4	16.7	.70

TABLE A1.8

ESTIMATED COMMERCIAL WATER USE IN CITY OF NORFOLK

	Number of Firms		Average Use KG/month	Estimated Annual Use (Average MGD)[b]	
	1974	1975		1974	1975
Department Stores	71	67	179.00	.423	.400
Grocery Stores	310	295	41.40	.430	.410
Restaurants, Bars, etc.	610	629	53.40	1.090	1.120
Motels, hotels	86	79	248.00	.710	.653
Other Commercial	3123	2036	6.21	1.290	1.250
TOTAL				3.943	3.830

Industrial Water Use

Water use by manufacturers in Norfolk would be expected to be quite substantial due to the large number of those types of manufacturers which have been found to be heavy water users.[14] As was the case with Portsmouth, the expected relative level of manufacturing use, and the expected variability in estimates of that use compared to residential and commercial use, led to the estimation of industrial use by subtracting the estimates of the other types of use from the total levels of use in Norfolk. The estimates of annual industrial use and their derivation are shown in Table A1.9.

Portsmouth

The total levels of water use in the Portsmouth water system, the levels of residential water use in the City of Portsmouth, and the total levels of water use in the Suffolk division of the Portsmouth water system were available by month for 1974 and 1975.[15] These use levels are shown in Table A1.10. The total level of water use in the Portsmouth system included bulk sales to Chesapeake. The average annual level of these sales during 1974 and 1975 was available and is shown in Table A1.11[16] Table A1.11 also shows the derivation of the average level of use in Portsmouth in 1974 and 1975. Average annual use in Portsmouth

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[14] U. S. Bureau of the Census, Census of Manufactures, 1972 Special Report Series: Water Use in Manufacturing (Washington, D. C.: G.P.O., 1975); Idem, Census of Manufactures, 1972 Area Series Virginia (Washington, D. C.: G.P.O., 1975).

[15] City of Portsmouth, Department of Public Utilities.

[16] City of Chesapeake.

TABLE A1.9

ESTIMATED INDUSTRIAL WATER USE
(Average MGD)

	1974	1975
Total Water Use in Norfolk	44.61	43.75
Estimated Residential Water Use	17.10	17.40
Estimated Commercial Water Use	3.94	3.83
Estimated Industrial Water Use	23.57	22.52

TABLE A1.10

TOTAL USE OF PORTSMOUTH SYSTEM AND IN SUFFOLK AND RESIDENTIAL USE IN PORTSMOUTH (KG)

	1974			1975		
	Total Use	Residential Use in Portsmouth	Total Use in Suffolk	Total Use	Residential Use in Portsmouth	Total Use in Suffolk
January	551136	187640	71123	582686	191290	72766
February	479646	182420	63706	499784	183260	67345
March	551686	186720	70983	54647	188320	73440
April	537433	184400	70211	526137	178600	69606
May	561007	191720	72494	574324	201360	76235
June	548956	190380	72876	649979	226780	85363
July	597150	201260	78011	629016	215900	81762
August	569027	200970	75077	658853	225760	85639
September	577267	202720	71264	566940	201270	76857
October	612835	210680	70601	566350	200120	79582
November	595517	208030	68591	541858	190810	74312
December	585561	203020	69579	569441	194100	76133
TOTAL	676221	2355960	85416	6911897	2397570	919040

TABLE A1.11

AVERAGE ANNUAL USE IN PORTSMOUTH, SUFFOLK, AND CHESAPEAKE IN 1974 AND 1975
(in KG)

	Average Annual Use
Total	6,839,559
Suffolk	886,778
Chesapeake	553,388
Portsmouth	5,399,393

during this two-year period was compared to the estimated average annual levels of residential, industrial, and commercial use during that period in order to determine the relative composition of use.

Commercial Water Use

Commercial use was estimated through a determination of the average number of commercial establishments of different types, as disaggregated in a previous study of commercial water use, and the application of the average use levels estimated for the different types of commercial establishments in that study. The estimates of commercial water use and their derivation are shown in Table A1.12.

Residential Water Use

Residential water use was disaggregated into domestic, or use within dwelling units, and outside use. The estimation of the two types of residential use was conducted through an analysis of the monthly variation in average residential use during 1974 and 1975. It was assumed that the outside use by residential consumers during the first four, and last two, months of the year was negligble. The principal outside use of water by residential customers is lawn watering which is severely curtailed during these months. The residential use during these six months can be seen, therefore, to consist of only domestic water use. Little seasonal variation in the levels of domestic use has been found in previous studies.[17] The average level of use during the six months can be reasonably maintained to represent average domestic use during

[17]Angelo P. Grima, Residential Water Demand.

TABLE A1.12

ESTIMATED COMMERCIAL WATER USE IN CITY OF PORTSMOUTH

	Average Number of Firms, 1974-1975	Average Use (KG/month)	Estimated Use (Average MGD)
Department Stores	29	179.0	.17
Grocery Stores	126	42.0	.18
Restaurants, etc.	156	53.4	.28
Motels, Hotels	11	248.0	.09
Other Commercial	1009	6.21	.29
TOTAL			1.01

the remaining six months of June through October. Levels of residential use during these months, above average domestic use levels, can, therefore, be attributed to outside use. Table A1.13 shows the average total levels of residential use, as well as estimated domestic and outside use, by month, for 1974 and 1975. The relatively small degree of variation in residential use over the year and the resulting low levels of estimated outside use are consistent with the levels of outside use encountered in previous studies, given the characteristics of the Portsmouth service area, the most important characteristics being per capita income and average residential lot size.[18]

Industrial Water Use

Industrial water use in Portsmouth is quite substantial due to the large number of industries in the city, many of which are engaged in manufacturing processes requiring substantial quantities of water.[19] It was apparent from a preliminary examination of residential and estimated commercial use, that industrial use would be the largest of the three uses in Portsmouth. Its high level, relative to commercial use, and the greater variability encountered in industrial water use led to the estimation of industrial use through the subtraction of residential and commercial water use from total water use in Portsmouth. The average annual levels of total residential, estimated commercial and estimated industrial water use are shown in Table A1.14

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[18] Ibid; Howe and Linaweaver, "The Impact of Price,"

[19] U. S. Bureau of the Census, Census of Manufactures, Water Use in Manufacturing; Idem, Census of Manufactures, 1972 Area Series Virginia.

TABLE A1.13

ESTIMATED DOMESTIC AND OUTSIDE RESIDENTIAL WATER USE 1974-1975
(in million gallons)

	Total Residential	Estimated Domestic	Estimated Outside
January	190	190	
February	183	183	
March	187	187	
April	181	181	
May	196	190	6
June	208	190	18
July	208	190	18
August	213	190	23
September	202	190	12
October	206	190	16
November	199	199	
December	199	199	
TOTAL	2372	2280	93

TABLE A1.14

AVERAGE ANNUAL USE BY TYPE IN PORTSMOUTH
1974-1975

	Average Annual Use (Million gallons)
Average Annual Total Use in Portsmouth	5399.4
Average Annual Residential Use	2372.0
Estimated Average Annual Commercial Use	368.7
Estimated Average Annual Industrial Use	2658.7

Chesapeake

The total levels of monthly water use by customers provided water service by the Department of Public Utilities of Chesapeake were available for 1974 and 1975. The levels of use by residential customers and the cobmined levels of use by commercial and industrial customers were also available and are shown in Table A1.15[20]

Residential Water Use

The levels of residential use were available by month and the estimation of the domestic and outside components of residential use was conducted through an examination of the monthly variation in that use. The method employed in the estimation of domestic and outside use was the same as was employed in the other cities. A detailed description of that method is given in the above section dealing with the estimation of domestic and outside use in Virginia Beach. The estimates of domestic and outside use in Chesapeake and their derivation are shown in Table A1.16.

Commercial and Industrial Water Use

The combined levels of industrial and commercial use were available by month for 1974 and 1975. The estimation of the levels of use by establishments of both types was made difficult because the number of such establishments receiving public water service was not available. Estimation of the numbers of such establishments was subject to uncertainty due to the large number of firms in the city which make use of

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[20]City of Chesapeake, Department of Public Utilities.

TABLE A1.15
COMPOSITION OF WATER USE IN CHESAPEAKE
(in million gallons)

	1974			1975		
	Industrial & Commercial	Residential	Total	Industrial & Commercial	Residential	Total
January	73.4	119.0	192.3	78.3	135.3	213.6
February	72.1	104.2	176.3	71.5	117.8	189.4
March	76.0	. . .	164.3	74.0	124.9	190.8
April	77.4	111.7	191.1	77.4	119.2	196.6
May	80.2	140.4	180.6	70.6	131.4	201.5
June	81.3	169.5	290.8	78.9	131.6	210.5
July	80.4	139.2	219.6	80.0	151.7	231.7
August	78.8	125.7	204.5	7412	130.6	204.8
September	86.9	141.5	227.5	77.9	142.9	219.1
October	80.6	137.9	218.5	73.5	132.9	195.5
November	70.6	128.7	199.3	77.7	102.6	180.2
December	78.3	114.3	192.6	85.1	125.3	220.3

TABLE A1.16

ESTIMATED COMPOSITION OF RESIDENTIAL WATER USE IN CHESAPEAKE
(in million gallons)

	1974			1975		
	Total Residential	Estimated Domestic	Estimated Outside	Total Residential	Estimated Domestic	Estimated Outside
January	119.0			135.3		
February	104.2			117.8		
March	88.3			124.9		
April	111.7			119.2		
May	140.4	111		131.4	120.9	10.5
June	169.5	111	58.5	131.5	120.9	10.6
July	139.2	111	28.2	151.7	120.9	30.8
August	125.7	111	1415	130.6	120.9	9.7
September	141.5	111	30.5	142.0	120.9	21.1
October	137.9	111	26.9	132.0	120.9	11.1
November	128.7			102.6		
December	114.3			125.3		
TOTAL	1522.3	1334.1	188.2	1544.3	1450.5	93.8

groundwater. The Department of Public Utilities of Chesapeake has formulated approximate estimates of the proportions of total use which commercial and industrial use constitute. It has been estimated that the commercial use comprises from 12 to 20 percent of total use, while industrial use constitutes from 17 to 25 percent of total use.[21] The mid-points of these ranges of percentages were employed in estimating the composition of use in following sections. While subject to sifnificant error, these estimates are consistent with the levels of water use which would be expected to occur, given the relative magnitude of the commercial and industrial sectors in Chesapeake.

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[21]Ibid.

APPENDIX 2

ESTIMATION OF NET BENEFITS OF ALTERNATIVE LEVELS OF WATER SUPPLY

Introduction

This appendix presents the procedures employed in the estimation of the costs associated with different levels of water and also provides explanations for the selection of those procedures. This appendix also presents the estimated levels of WTP and the present value of the net benefits of the alternative levels of water supply.

Determination of Costs of Projected Levels of Use

The costs of increasing use above the levels projected in 1980 were estimated by determining the costs associated with the operation of the existing facilities at those levels, and with the construction and operation of additional facilities required to deal with projected levels of use.

The benefits and costs of meeting the projected levels of use in Portsmouth were estimated separately from those of Norfolk, Virginia Beach, and Chesapeake. This was the case because Portsmouth currently owns and operates its own water supply and waste water treatment systems which provide those services throughout the entire city.[1] By contrast, Norfolk, Virginia Beach, and Chesapeake presently are provided the major

[1] City of Portsmouth, Department of Public Utilities.

portion of waste water treatment service by an independent authority, the Hampton Roads Sanitation District (HRSD).[2] In addition, the Norfolk water system provides water to Virginia Beach and Chesapeake and it is those cities which would receive additional water supplied from the development of the proposed new sources.

Costs of Projected Use In Portsmouth

The costs incurred in Portsmouth as a result of exceeding projected 1980 use levels were found by examining projected use relative to projected 1980 use and to the capacities of the water and waste water treatment facilities which would be in operation in 1980.

Water use in Portsmouth has been projected to increase slowly over the period of analysis due to the rather limited increase in population expected in that city.[3] The 27.5 MGD capacity of the Portsmouth water system would not be exceeded by projected use through 2030.[4] The only water supply costs which would be incurred as a result of providing quantities of water above projected 1980 levels would be those costs which would vary with the quantity of water provided from the existing water supply system. It was, therefore, necessary to determine which costs would vary with the projected changes in the quantities of water supplied, and to determine the nature of the relationships between the quantities of water supplied and those variable costs.

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[2]Hampton Roads Sanitation District, interview with Mr. Person, Director of Engineering, September 1977.

[3]COE, water use projections compiled by Tidewater office of SWCB.

[4]City of Portsmouth.

An examination of the expenditures of the Portsmouth Department of Public Utilities in past years was made in order to estimate that relationship. The only costs which would vary with the quantities of water provided are those associated with the use of electric power, used primarily for pumping, and the use of chemicals in the treatment of water. The expenditures upon these items during 1975 were available and were equivalent to $19,430 per year per MGD. The levels of these expenditures per MGD during 1977 were estimated by adjusting the above figure by the average rate of increase in these expenditures per MGD from 1973 through 1975. These expenditures increased twelve percent per year during that period, an amount only marginally greater than the rate of inflation in the general price level during that period. The adjusted level of variable costs per MGD employed in the determination of the costs of exceeding projected 1980 use was $24,373 per year per MGD. The costs of providing the quantities of water in excess of 1980 use were found by subtracting projected 1980 use from projected use in each of the years through 2030, and multiplying the differences by the above estimated level of costs per year per MGD. The present value of the resulting time stream of costs in 1980 was found by discounting the costs at an annual interest rate of 6.375%, and was found to be $832,200.

The costs associated with the treatment of the waste water which would result from the projected levels of water use included the costs of operating the facilities which would be on line in 1980 at levels above projected use in that year, and the costs of constructing and operating an additional waste water treatment plant when the capacity of the above facilities would become inadequate. The costs of operating the sewer system which will be on line in 1980 were found by determining the projected use of those facilities and the variable costs associated with that use. The Portsmouth sewage treatment plant at Pinners Point is currently being upgraded to meet U. S. Environmental Protection Agency (EPA) standards for effluent quality which will be in effect after 1983. The upgrading will increase the capacity of the plant to 14.5 MGD and should be completed by 1980.[5]

Estimates of the variable costs of the upgraded facilities were not available. However, the variable costs associated with the secondary treatment stages were available. The variable costs of the primary treatment stages of the present Pinners Point plant were not available. The relatively consistent levels of primary treatment cost among different waste water treatment plants of similar size led to the use of the average level of variable costs incurred in primary treatment by the Lamberts Point plant of the HRSD. The variable costs of the upgraded Pinners Point plant were estimated to be $22,800 per year per MGD, of which $7,700 would be attributable to primary treatment, and $15,000 to secondary treatment.[6]

The estimation of the variable costs incurred in treating waste water flows in excess of those which are expected in 1980 required the

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[5]Greely and Hansen, Engineers, "Report of Preliminary Planning for Pinners Point Sewage Treatment Plant," June 1975.

[6]Hampton Roads Sanitation District, "Vode of Accounts," 1977-78 Budget; Greely and Hansen.

determination of the relationship between water use and waste water flows. Data were available for 1973 and 1974 for both sewer flows and water use. Sewage flows averaged approximately eighty-four percent of total water use during those years[7] This relationship was assumed to hold for the projected levels of water because the relative composition of that use is not expected to change if the price of water does not change. Estimated sewage flows from 1980 through 2030 were then estimated given projected water use. The estimated sewage flow in 1980 was subtracted from the estimated sewage flows in future years until the 14.5 MGD capacity of the plant would be reached. The sewage flows at the Pinners Point plant in excess of 1980 flow would be constant after the capacity was reached. The above variable costs per year per MGD were multiplied by the levels of sewage flow in excess of 1980 flow. The present value in 1980 of the resulting time stream of annual costs was found by discounting at an annual interest rate of 6.375%. The present value was found to be $372,100.

The 14.5 MGD capacity of the Pinners Point plant would be exceeded in 1990, given projected water use and sewer flows. The supply of the projected quantities of water would, therefore, necessitate the expansion of the existing sewage treatment plant or the construction of an additional treatment facility at that time. No estimates have been made of the costs of either of these alternatives. The costs of constructing a sewage treatment plant capable of dealing with projected sewage flow in excess of 14.5 MGD were estimated by employing the

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[7] City of Portsmouth.

estimated costs of a plant proposed by HRSD and information concerning the relationship between the capacities and costs of sewage treatment plants. A 5 MGD plant, in conjunction with the 14.5 MGD facility, would be sufficient to deal with projected sewage flows through 2030. The construction costs of a 5 MGD plant capable of meeting 1983 EPA standards were estimated by adjusting the estimated construction costs of a 35 MGD plant proposed by HRSD. These costs were adjusted by the ratio of the construction costs per unit of capacity of a 35 MGD plant to such costs of a 5 MGD plant, found in a study of sewage treatment plant costs.[8]

The construction costs per unit of capacity for a 5 MGD plant were found to be fifty percent greater than for a 35 MGD plant, reflecting the economies of scale associated with the large plant. The $82,000,000 construction cost of the 35 MGD plant was equivalent to $2,342,000 per MGD of capacity. Increasing this cost by fifty percent to $3,514,350 per MGD of capacity and multiplying by 5 MGD, yielded an estimated construction cost for the 5 MGD plant of $17,570,000.

The fixed operation and maintenance costs per unit of plant capacity were also found to be fifty percent greater for the 5 MGD plant. The fixed operation and maintenance costs of the 35 MGD plant of $21,430 per MGD of capacity were increased by fifty percent to $32,145, then multiplied by 5 MGD to obtain the estimated level of annual fixed operation and maintenance costs of $161,000.

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[8]Malcolm Pirnie Engineers, Inc., "Report of Advanced Wastewater Treatment Plant," March 1975; Rober Smith, "Cost of Conventional and Advanced Treatment of Wastewater," Water Pollution Control Federation Journal , Vol. 44, No. 11, pp. 1548-1574.

The variable operation and maintenance costs per unit of flow were found to be twenty-seven percent greater for the 5 MGD plant than for the 35 MGD plant. The variable costs of the 35 MGD plant of $28,000 per year per MGD were increased by twenty-seven percent to yield the estimated annual variable costs per MGD for the 5 MGD plant of $35,580.

The estimation of the three types of cost and of the levels of flow in excess of 14.5 MGD permitted the estimation of the present value in 1980 of the costs associated with the use of the 5 MGD plant. The costs of the operation of the 14.5 MGD plant at levels above 1980 use and of the construction and operation of the 5 MGD plant are shown in Table A2.1.

The total costs incurred as a result of providing quantities of water in excess of projected 1980 use, the total WTP for those quantities, and the net benefits of providing those quantities, for both sets of demand curves, are shown in Table A2.2.

Costs of Projected Use in Norfolk, Virginia Beach, and Chesapeake

The costs which would be incurred as a result of providing the projected quantities of water, rather than the 1980 levels, in Norfolk, Virginia Beach, and Chesapeake were estimated by examining projected use levels of use of those facilities in 1980. The projected levels of use of the water supply systems and the waste water treatment system serving these cities would exceed the capacities of both of those systems. The cost of providing quantities of water in excess of 1980

TABLE A2.1

COSTS INCURRED IN TREATMENT OF SEWAGE FLOWS IN EXCESS OF 1980 LEVELS IN PORTSMOUTH
(Present Value in 1980)

<u>14.5 MGD PLANT</u>		
Variable O&M costs, 1980-1989:	$	105,894
Variable O&M costs, 1990-2030 (constant at $34,200/year) :		283,190
<u>PROPOSED 5 MGD PLANT</u>		
Construction costs (2-year period) :		10,396,030
Fixed O&M costs, 1990-2030 (constant at $161,000/year) :		1,333,160
Variable O&M costs, 1990-2030:		435,505
TOTAL	$	12,553,775

TABLE A2.2

NET BENEFITS OF ADDITIONAL USE IN PORTSMOUTH

Sewage Treatment Costs	:	$ 12,553,775
Water Supply Costs	:	832,202
TOTAL COSTS		$ 13,385,977
WTP, High Elasticity Demand Curves	:	$ 16,152,480
WTP, Low Elasticity Demand Curves	:	19,876,370
Net Benefit, High Elasticity Demand Curves	:	$ 2,766,503
Net Benefit, Low Elasticity Demand Curves	:	6,490,393

levels would, therefore, consist of a portion of the variable operation and maintenance costs of the existing water supply and waste water treatment systems, and the construction costs and all operation and maintenance costs of the additional facilities necessary to provide the projected quantities.

The variable operation and maintenance costs of the water supply systems which would be operational in 1980 were found by determining the present levels of variable costs per MGD and the differences between the projected levels of use in future years and projected levels of use in 1980.

In 1980, Chesapeake will have in operation a 10 MGD water supply facility on the Northwest River in southern Chesapeake. The estimated annual variable costs per MGD for this facility are $66,795.[9] The quantities of water which would be provided by this facility, in excess of the levels of use in 1980, were multiplied by the above variable costs. The capacity of this facility would be exceeded in 1989 given projected levels of use. A time stream of costs from 1981 through 2030, with equal costs from 1989 through 2030, was, thus, derived. The present value of these costs in 1980 was $2,634,435 when discounted with an annual interest rate of 6.375%.

The variable costs of the present Norfolk water system attributable to use above 1980 levels was found by first estimating present level of variable costs per year per MGD in that system. The information available concerning the expenditures of the Norfolk water system

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[9]City of Chesapeake, Department of Public Utilities.

were not sufficiently disaggregated to permit the determination of the levels of variable costs. The Norfolk and Portsmouth water systems are sufficiently similar that there should not be a substantial difference in the level of such costs per unit volume. The level of variable cost in the Portsmouth system, $24,373 per year per MGD, were, therefore, employed as an approximation of the level of such costs in the Norfolk system.[10]

Projected use in Norfolk and Virginia Beach during 1980 was subtracted from the projected levels of use in those cities in each of the following years through 2030. These levels of use in excess of projected 1980 use were then multiplied by the above level of variable costs per MGD in order to estimate the variable costs in each year until 1988, when the capacity of the Norfolk system would be exceeded by projected use. The variable costs incurred in the operation of those facilities, at levels above 1980 use, would remain constant after that year.

Supplying the projected levels of use in 1988 and thereafter would require the development of additional sources of raw water. The COE has conducted a detailed analysis of several possible source of additional water. This analysis included the estimation of the costs of constructing and operating the facilities necessary to develop the sources. The COE has tentatively selected four possible sources of additional water for the area. Those sources are the Blackwater River, the Roanoke River, the Appomattox River, and the Chowan River. The

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[10]City of Portsmouth.

final recommendation of the COE study will presumably be the development of one of the four sources.[11]

The costs estimated by the COE were used in determining the present value of the costs which would be incurred in developing each of the four sources. The cost estimates by the COE are given in Table A2.3.

The projected levels of use in Norfolk, Virginia Beach, and Chesapeake, in excess of the capacities of the water systems serving those systems, were examined in order to determine the proper times for the implementation of the different stages in the development of the sources. The levels of these shortfalls also determined the quantities of water to be supplied from the new sources.

The plans of the CIE for the development of the alternative sources call for the construction of transmission lines to the Moores Bridges water treatment plant in Norfolk. The shortfalls in the Chesapeake system could be met through the delivery of water to that facility because there is a connection between the Norfolk and Chesapeake water systems. Chesapeake currently serves most of its customers with water purchased from Norfolk which is delivered through that connection. Although these purchases will cease with the completion of Chesapeake's facility on the Northwest River, those purchases would resume when the capacity of that facility becomes inadequate. The capacity of the

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[11]Department of the Army, Norfolk District, COE, "Announcement of the Third Public Meeting on Water Supply Study for Southside Hampton Roads, Virginia," October 21, 1977.

TABLE A2.3

COSTS OF ALTERNATIVE SOURCES OF WATER [a]

	Constituents of Cost	Roanoke River	Chowan River	Blackwater River	Appomattox River
Stage I	Capitol Invst.	$ 99,031,000	$ 55,162,000	$ 70,523,000	$ 86,221,000
	Oper. & Maint.	352,000	261,000	339,000	326,000
Stage II	Capitol Invst.	105,750,000	62,332,000	63,702,000	106,325,000
	Oper. & Maint.	618,000	436,000	514,000	719,000
Stage III	Capitol Invst.	8,352,000	8,532,000	20,545,000	8,532,000
	Oper. & Maint.	636,000	454,000	593,000	737,000
Stage IV	Capitol Invst.	. . .	. . .	14,989,000	. . .
	Oper. & Maint.	636,000	454,000	658,000	737,000

[a]Costs are in terms of 1977 dollars.

connection between the two cities is approximately 4.5 MGD.[12] The elimination of shortfalls in excess of 4.5 MGD would be accomplished through the construction of a connector between the main transmission line and the Chesapeake water treatment plant. The COE has estimated the costs of that connector as shown in Table A2.3.

The cost estimates of the COE did not include the costs which would be incurred in treating the water from the new sources or in distributing that water within the cities. The costs of treatment and distribution within Portsmouth were estimated through an examination of the budgets of that city's Department of Public Utilities. The level of those costs was found to be $12,976 per year per MGD.[13] It was assumed, as for total variable costs, that the level of treatment and distribution costs in the other cities would be equivalent.

The amount of these costs in each year were found by determining the total shortfall in the Norfolk and Chesapeake water systems in each year, and multiplying by the above level of treatment and distribution costs per MGD. The amount of these costs would be the same regardless of the source of additional water employed.

The present values of variable costs associated with the use of the 1980 facilities in excess of projected 1980 use, and of the treatment and distribution costs for the quantities of water to be delivered from the additional sources of water are shown in Table A2.4.

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[12] City of Chesapeake.

[13] City of Portsmouth.

TABLE A2.4

VARIABLE COSTS OF ADDITIONAL WATER USE IN NVBC
PROVIDED BY EXISTING FACILITIES

Variable costs, 1980 Norfolk system :	$ 3,352,322
Variable costs, 1980 Chesapeake system :	2,634,435
Treatment and distribution costs, new sources:	2,536,571
TOTAL	$ 8,523,328
(Present value, 1980)	

TABLE A2.5

TOTAL COSTS OF ADDITIONAL FACILITIES

Chowan River :	$ 55,675,050
Blackwater River:	70,249,450
Appomattox River:	85,715,355
Roanoke River :	93,922,565

The present values of the costs incurred in the development of each of the sources of additional water were found by determining the appropriate dates for the implementation of the different elements of the sets of facilities and the quantities of water to be delivered by those facilities.

The COE estimates of construction costs, fixed operation and maintenance costs, and variable operation and maintenance costs were employed in the estimation of the present value of the costs of the four alternative sources of additional water. The present values in 1980 of the costs incurred through 2030 in the development of these sources, and the delivery of water from them to the Moores Bridges treatment plant are shown in Table A2.5.

The projected increases in water use in Norfolk, Virginia Beach, and Chesapeake would result in substantial increases in the quantities of sewage in those cities. The costs of treating sewage flows in excess of 1980 flows would include the variable costs of the facilities operational in 1980, and the construction and operation and maintenance costs of the additional facilities necessary to treat the increased quantities of sewage. In 1980, the above cities will be served by three large sewage treatment plants and five small plants, all operated by the HRSD. The five small plants will be phased out in 1983 because they cannot be economically upgraded to meet the EPA standards which will be in effect at that time. The capacity of the three large plants in 1983 will be 77 MGD. Present plans call for the construction of an additional large treatment plant, with a capacity of 35 MGD, to treat flows in excess of 77 MGD.[14]

The variable costs of treating quantities of waste water in excess of 1980 levels can be estimated by determining the variable costs per MGD associated with the facilities which will be in operation in future years, and by determining the quantities of waste water in excess of 1980 levels. The variable costs of the facilities which will be on line differ among the facilities, reflecting, primarily, differences in the degree of treatment provided. The 1977 budget of the HRSD was examined in order to determine the variable costs of those plants which will be operated without change before 1983. The level of variable costs of the Army Base Plant, which will be upgraded to 1983 EPA standards in 1980, was estimated through the use of the projected variable costs of the planned 35 MGD plant. The average level of variable costs incurred in waste water treatment from 1980 to 1983 was estimated by weighting the costs of each of the plants by the proportion of total waste water which each is expected to treat. The weighted average level of variable costs was $13,103 per year per MGD.

The variable costs of waste water treatment in 1983 and thereafter are assumed to be equivalent in each of the plants operated by the HRSD because the levels of treatment will be approximately equivalent in all the plants after 1982. The estimated variable costs of the proposed 35 MGD plant are $23,000 per year per MGD. This level of variable costs was employed in the estimation of the costs of waste water treatment after 1982.

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[14]Hampton Roads Sanitation District.

An additional cost is incurred in waste treatment in delivering the waste water to the treatment plants. The HRSD operates an interceptor system which pumps waste water to the treatment plants through an interconnected sewer system. The variable costs of this system in 1977 were $2,526 per year per MGD.[15]

The levels of waste water flows in future years were estimated by determining the existing relationship between water use and waste water flows in the HRSD. Waste water quantities in the area were found to be ninety-three percent of total water use. Future waste water quantities were, therefore, estimated by multiplying projected water use by ninety-three percent.[16] The variable costs incurred in each year in the treatment of quantities of waste water in excess of 1980 levels were found by multiplying the difference between projected use in each year and projected 1980 use by the appropriate levels of variable cost per year per MGD. These variable costs would include the treatment costs and the costs of the interceptor system. The present value in 1980 of the time stream of costs derived in this fashion and discounted at 6.375% was found to be $8,443,821.

The estimated future quantities of waste water would necessitate substantial increases in the total capacity of the area's waste water treatment plants. The capacity of the treatment plants serving the area during 1983 will be 77 MGD if no new plants are constructed before that time. The projected waste water quantities can be examined relative to

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[15] Hampton Roads Sanitation District.

[16] Hampton Roads Sanitation District, "Summary of Basic Treatment Data," July 1977.

that capacity in order to determine the dates at which additional capacity would be required.[17]

The HRSD has completed a detailed analysis of the costs of a 35 MGD sewage treatment plant capable of meeting 1983 EPA standards. This proposed facility, referred to as the "Atlantic Waste Water Treatment Plant," would serve Virginia Beach, Chesapeake, and portions of Norfolk. The construction costs of this facility would be $82,000,000 and fixed operation and maintenance costs would be approximately $750,000 per year.[18] The 35 MGD capacity of this facility would not be sufficient to meet estimated waste water flows through 2030. It was assumed that additional 35 MGD plants, having the same costs, would be constructed as necessitated by the projected quantities of waste water relative to the total capacity of the waste water treatment system serving the three cities. It would be necessary to begin operation of 35 MGD treatment plants in 1983, 2005, and 2029. Table A2.6 shows the present value of the construction costs and of the fixed operation and maintenance costs through 2030. A two-year construction period and interest rate of 6.375% were employed.

The estimated total costs of, and levels of WTP for, projected use in excess of projected 1980 use are shown in Table A2.7. The estimated net benefits associated with such use for each of the different sources of additional water and for both high and low elasticity demand curves are also shown.

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[17] Hampton Roads Sanitation District, interview with Director of Engineering.

[18] Malcolm Pirnie Engineers, Inc.

TABLE A2.6

CONSTRUCTION AND FIXED O&M COSTS OF SEWAGE TREATMENT PLANTS

	1980 Present Value
First Atlantic Treatment Plant	
1981: 41,000,000	$ 38,542,891
1982: 41,000,000	36,233,035
1983: 750,000 per year through 2030	9,861,547
Second Atlantic Treatment Plant	
2003: 41,000,000	9,896,319
2004: 41,000,000	9,393,237
2005: 750,000 per year through 2030	2.134,202
Third Atlantic Treatment Plant	
2027: 41,000,000	2,245,556
2028: 41,000,000	2,110,981
2029: 750,000 per year through 2030	70,427
TOTAL	$ 110,400,000

TABLE A2.7

ESTIMATED COSTS AND BENEFITS OF PROJECTED USE
IN NORFOLK, VIRGINIA BEACH, AND CHESAPEAKE

Total Sewer Costs :	$ 118,843,820
Variable water costs exclusinve of delivery from new sources	8,523,328
WTP Low Elasticity Demand Curve	1,428,724,200
WTP High Elasticity Demand Curve	396,300,840

ESTIMATED NET BENEFIT[a]

	Low Elasticity Demand	High Elasticity Demand
Chowan River	$ 1,245,682,000	$ 213,258,640
Blackwater River	1,231,107,600	198,684,240
Appomattox River	1,215,641,700	183,218,340
Lake Gaston	1,207,434,500	175,011,130

[a]Includes costs associated with proposed sources shown in Table A2.5

Costs of 15% Reduction in Portsmouth

The costs incurred in the provision of quantities of water in excess of projected 1980 use would consist of variable costs of water supply, variable costs of 1980 sewage treatment facilities, the construction costs of an additional sewage treatment plant, and the operation and maintenance costs of that facility.

The variable costs of water supply were found by multiplying the estimated variable costs per year per MGD, $24,373, by the levels of use in each year in excess of 1980 use. The present value of those costs were found to be $178,161

The variable costs of the 14.5 MGD sewer plant, which would be operational in 1980, were found by multiplying projected sewer flows in excess of 1980 levels by the estimated level of variable costs per year per MGD, $22,800. The capacity of this facility would be reached in 2011, given the 15% reduction, and the variable costs in excess of 1980 use would be constant for that facility after that date. The present value of the variable costs of the 14.5 MGD plant were found to be $112,523.

A 2 MGD sewage treatment plant would be sufficient to deal with projected sewage flows in excess of the capacity of the 14.5 MGD plant through 2030, given a 15% reduction in projected use. The construction costs of a 2 MGD plant capable of meeting 1983 standards were estimated through the use of the projected costs for the Atlantic sewage treatment plant and a study which found the relationship between the capacity of waste water treatment systems and their construction and operation and maintenance costs. The estimated construction costs of the 2 MGD plant are $9,059,048.

The operation and maintenance costs were estimated in the same way. The fixed operation and maintenance costs were found to be $82,857 per year. The variable operation and maintenance cost was found to be $52,706 per year per MGD. The actual amounts of variable costs incurred in each year were found by finding the levels of sewage flows in excess of 14.5 MGD and multiplying by the level of variable cost.

The present value of the construction and operation and maintenance costs of the 2 MGD plant incurred through 2030 was found by discounting at an annual interest rate of 6.375%. Construction would occur in 2009 and 2010, as the facility would become operational in 2011. The estimated present value of all costs associated with this plant is $1,782,773.

The costs and benefits associated with the 15% reduction in water use in Portsmouth are shown in Table A2.8. These costs and benefits are for quantities of water in excess of projected 1980 use.

WTP in Norfolk, Virginia Beach, and Chesapeake, 15% Reduction by Quota

The relevant levels of WTP in Norfolk, Virginia Beach, and Chesapeake (NVBC) were estimated in the same fashion as for Portsmouth. The projected 1980 levels of use would again be maintained until such time that projected use, reduced by 15%, would be in excess of projected 1980 use. The rates of growth in water use are different in the

TABLE A2.8

NET BENEFITS WITH A 15% REDUCTION
IN PORTSMOUTH

	Present Value, 1980
Sewer Costs	$ 1,782,773
Water Costs	140,872
WTP, High Elasticity Demand Curve	3,481,947
WTP, Low Elasticity Demand Curve	3,547,898
Net Benefit, High Elasticity Demand Curve	1,558,302
Net Benefit, Low Elasticity Demand Curve	1,624,253

three cities. Therefore, the dates upon which water use would be increased above 1980 levels differ among the cities. Those dates are 2009 in Norfolk and 1984 in both Virginia Beach and Chesapeake.

The WTP for the levels of use in excess of projected 1980 use were found for each of the cities. The present values of the levels of WTP estimated with the low elasticity demand curves were in Norfolk: $1,204,600; in Virginia Beach: $468,572,900; and in Chesapeake: $154,579,840. The present values of the levels of WTP estimated with the high elasticity demand curves were in Norfolk: $1,169,350; in Virginia Beach: $148,625,300; and in Chesapeake: $56,367,150.

The costs incurred as a result of providing quantities of water in excess of projected 1980 use would include the variable costs of the water supply and waste water treatment facilities which would be in operation in that year in which use, given a 15% reduction from projected use, would first exceed projected 1980 use. Also included would be the costs associated with the construction and operation and maintenance of the additional facilities necessitated by the future levels of water use.

The variable costs of the water supply facilities which would be operational when use would first exceed projected 1980 use were found by employing the estimated levels of variable costs per year per MGD of the facilities which would be operational in 1980.

The variable cost of the 1980 Chesapeake water supply system has been estimated to be $66,795 per year per MGD. This level of variable cost was multiplied by the levels of use in excess of projected 1980 use in those years following the imposition of the full 15% reduction. The capacity of the Chesapeake facility would be exceeded in 1993. Variable costs of that facility in 1993, and subsequently, were constant as the facility would be operated at capacity. The present value of the time stream of variable costs was found to be $2,008,834.

The variable cost of the Norfolk water system, serving Norfolk and Virginia Beach, has been estimated to be $24,373 per year per MGD. Use in excess of projected 1980 use in this system was found by subtracting projected 1980 use from projected use in Norfolk and Virginia Beach, less 15%. After the capacity of the Chesapeake facility was reached in 1993, that city would resume its purchases from Norfolk. The projected use in the Chesapeake system, given the 15% reduction, was added to the projected use in the Norfolk system after that date. The capacity of the Norfolk system would be reached in 1997 and water use remain constant at 80 MGD thereafter. The present value of the variable costs of the 1980 Nofolk facilities was found to be $1,784,456.

An additional source of water would be required in 1987 if the projected levels of use were to be attained. The analysis by the COE of potential water sources provided the information necessary to estimate the costs of developing additional sources. The projected levels of use in NVBC were examined relative to the capacities of the facilities serving the three cities in order to determine the appropriate dates for developing the additional sources. The Chowan River, the Appomattox River, and Lake Gaston would be developed in two 35 MGD stages. The first stage of each would be required to be operation in 1997, and the second in 2023. The COE has proposed that the Blackwater

River be developed in stages of 30, 15, 15, and 10 MGD. The fourth stage would not be required with a 15% reduction in originally projected use. The 30 MGD stage would be put into operation in 1997, the first 15 MGD stage in 2019, and the second 15 MGD stage in 2030. The present values of the construction and fixed operation and maintenance costs associated with the development of these sources are shown in Table A2.9.

Chesapeake would resume its purchases of water from Norfolk in 1993, and these purchases would prove adequate to alleviate the shortfalls in the Chesapeake system until 2006. In that year, the shortfall in that system would exceed the capacity of the connection between the tow systems. The COE has estimated the cost of a connection between the main transmission line and the Chesapeake treatment plant. The present value of the construction and operation and maintenance costs of that connection is $1,867,340 if it were to become operational in 2006.

The variable operation and maintenance costs associated with the use of the additional sources were found by first determining the shortfalls to be eliminated in each year. The variable costs would consist of the cost of delivering water to the area water system, the cost of treating that water, and the cost of distributing it within the systems. The variable costs of delivery varied among the sources, while the treatment and distribution costs were estimated to be $12,976 per year per MGD for all the sources. Employing the appropriate levels of variable cost to the estimated shortfalls, and discounting the resulting time stream of annual costs at an annual rate of 6.375%, led to the present values of the variable costs of the additional sources

TABLE A2.9

CONSTRUCTION AND FIXED O&M OF ADDITIONAL WATER SOURCES

	Present Value, 1980
Chowan River	$ 28,797,333
Blackwater River	35,827,450
Appomattox River	43,132,170
Lake Gaston	47,742,243

TABLE A2.10

VARIABLE COSTS OF ADDITIONAL WATER SOURCES

	Present Value Variable Costs[a]
Chowan River	$ 1,817,051
Blackwater River	1,817,051
Appomattox River	1,967,094
Lake Gaston	1,982,098

[a]Includes delivery, treatment, and distribution within the systems.

shown in Table A2.10. The differences in variable costs are due, primarily, to the differences in the distances over which the water would be pumped from the sources to the area's water systems.

The projected levels of water use, given the 15% reduction, would be accompanied by increased quantities of waste water. The quantities of waste which would be associated with the future water use were estimated in order to determine the quantities of waste water to be treated by the facilities which would be in operation when the projected 1980 quantities would first be exceeded. In addition, it was necessary to project waste water quantities in order to determine the times at which additional waste water treatment facilities would be required and the quantities of waste water to be treated by those facilities.

The levels of waste water flows in future years were estimated by examining the existing relationship between water use and waste water quantities in the HRSD. Waste water quantities in the area were found to be ninety percent of inside water use. Future waste water quantities were estimated by assuming that this relationship would be unchanged in the future. It was found that the originally projected level of waste water flow in 1980 would not be exceeded by projected waste water flows until 1988, given the 15% reduction in water use. All the waste water treatment plants operated by the HRSD would meet the 1983 EPA standards by that time. The variable operation and maintenance cost of those plants has been estimated to be $25,526 per year per MGD. This level of cost includes the cost of operating the interceptor system which would deliver the waste water to the treatment plants. This is the same level of cost associated with the proposed treatment plants which would be put into operation after the capacity of the 1983 plants was reached. The variable costs incurred in 1988 and thereafter were, therefore, estimated by multiplying waste water quantities in excess of projected 1980 quantities by the above level of variable cost. The present value of the time stream of costs was found to be $4,311,680 when an interest rate of 6.375% was employed.

The projected levels of use, given the 15% reduction, were compared to the 77 MGD capacity of the plants which would be in operation after 1983. The capacity of those facilities would first be exceeded in 1991. The HRSD has conducted a detailed analysis of a 35 MGD waste water treatment plant designed to provide required capacity in the future. It was assumed in this analysis that this proposed plant would be employed when waste water flows exceeded 77 MGD and that another, identical 35 MGD plant would be built when necessary. The first 35 MGD plant would become operational in 1991 and the second in 2018. The construction and fixed operation and maintenance costs estimated in the analysis by the HRSD were employed in the estimation of the present value of the costs associated with the two plants. The present value of the above costs was found to be $60,638,103.

A summary of the costs, levels of WTP, and net benefits associated with use in excess of originally projected use, given a 15% reduction in that use, is shown in Table A2.11.

15% Reduction by Price Increases

A 15% reduction in projected water use could be effected through appropriate increases in water prices. A reduction achieved in this

TABLE A2.11

SUMMARY OF EVALUATION OF A 15% REDUCTION
IN USE BY QUOTA IN NVBC

Total Waste Water Treatment Cost:	$ 64,949,783
Variable Water Supply Costs :	3,793,290
WTP Low Elasticity Demand Curve:	624,356,980
WTP High Elasticity Demand Curve:	206,161,800

Estimated Net Benefit

	Low Elasticity Demand	High Elasticity Demand
Chowan River	$ 523,132,180	$ 108,479,060
Blackwater River	516,102,070	101,448,950
Appomattox River	508,647,300	97,757,590
Lake Gaston	504,022,230	89,369,110

manner would offer approximately the same cost savings as a reduction achieved through proportionately equal reductions in each type of use. However, it would be expected that a higher level of WTP could be attained if the reduction in use were accomplished through increases in prices. This would be the case because the marginal evaluations of the different types of use would be equated and the total WTP for a particular quantity of water, therefore, would be maximized.

The relevant levels of WTP in Portsmouth and NVBC were estimated by first determining the price level in each city which would result in a 15% reduction from projected use. Because the demand curves for each of the different types of use have constant elasticities, the aggregate demand curves have constant elasticities. The level of price which would result in a 15% reduction in projected use in each year, therefore, would be constant throughout the period of analysis. The levels of price which were found to cause 15% reductions, given the low elasticity demand curves, were, in Portsmouth $1.60, in Norfolk $1.68, in Virginia Beach $2.69, and in Chesapeake $2.79. Those levels of price, given the high elasticity demand curves, were, in Portsmouth $1.33, in Norfolk $1.68, in Virginia Beach $2.10, and in Chesapeake $2.30. All the above price are expressed in dollars per thousand gallons.

The levels of each of the different types of use, given the above prices, were found in each year. The levels of WTP for use in excess of projected 1980 use were found by integrating the demand curves between projected use at the above prices and projected 1980 use in those years in which total use would exceed projected 1980 use.

The water supply costs associated with use in excess of projected 1980 use would be the same for a 15% reduction in projected use achieved through increased prices and a 15% reduction achieved through quotas. The waste water treatment costs would differ slightly because the generally less elastic inside uses would not be reduced as much as the less elastic outside use. An examination of future sewer flows accompanying both methods of achieving the 15% reduction indicated that the difference would be minimal. Additional treatment plants would be required at the same dates regardless of the method by which the reduction were achieved and only minimal differences in the levels of variable costs would exist. For these reasons, the water supply and waste water treatment costs derived in the preceding section were employed in the determination of the net benefits of a 15% reduction achieved through increased prices. These net benefits are shown in Table A2.12

15% Reductions by Installation of Devices

It has been found that sifnificant reductions in domestic water use can be achieved through the installation of devices which restrict the water flow of showers and water faucets, and devices which reduce the volume of water used by flush toilets. It has been estimated that reductions of from 20 to 30% in domestic water use would result from the installation of these devices in a typical dwelling unit.[19] Domestic water currently comproses approximately sixty percent of total water use in the water systems of Norfolk and Chesapeake. The

[19] State of California, Department of Water Resources, "Water Conservation in Californis," Bulletin No. 198, May 1976, p. 18.

TABLE A2.12

NET BENEFITS OF WATER USE, 15% REDUCTION WITH INCREASED PRICES

	High Elasticity Demand Curves	Low Elasticity Demand Curves
Portsmouth	$ 2,798,778	$ 5,487,957
NVBC		
Chowan River	197,875,330	1,219,342,200
Blackwater River	190,845,220	1,212,312,100
Appomattox River	183,390,450	1,204,857,300
Lake Gaston	178,765,380	1,200,232,200

installation of the water saving devices in all dwelling units served by both systems, therefore, would result in approximately a 15% decline in water use in those systems. It was assumed that the installation of the devices would proceed at a schedule which would result in total levels of water use approximately equivalent to those achieved with the 15% reductions by quota and price. It was assumed that the 15% reduction in each city would be achieved through the installation of the devices in 1980 and thereafter at such a rate that 1980 levels of total water use would be maintained until those years in which projected use, less 15%, would be in excess of projected 1980 use. In those years, all dwelling units would be fitted with the devices in a particular city. In the following years, all new dwelling units would have the devices installed.

The costs of employing the devices in this manner were found by first determining the number of dwelling units in each city in which the devices would be installed in each year. The number of dwelling units in which the devices would be installed by the years in which the 15% reductions in use would first exceed projected 1980 use, were found by employing the population projections and average household size data provided by the SVPDC. All dwelling units in a particular city would have the devices by those years. It was assumed that the devices would be added at constant rates (which would differ for each city) before all dwelling units would have the devices. After those dates, the devices would be installed in all additional dwelling units. The number of additional dwelling units requiring the devices were estimated on the basis of the projected populations and current average household size.

The devices have been estimated to last for a minimum of ten years. Replacement of devices after ten years was assumed and the replacement units were added to the original installation in the appropriate year to determine the number of dwelling units to be "treated" in each year through 2030. The cost of the devices necessary to treat a typical dwelling unit has been estimated to be $22.00.[20] The schedule of installation was converted into a time stream of costs with this estimate of cost per installation. The present value of that time stream of costs was found to be $8,042,503, when discounted at 6.375%. The costs incurred in water supply and waste water treatment, including the costs associated with the construction and operation of additional facilities, would be approximately equal to those estimated for the 15% reductions by quota in the preceding sections.

It was assumed that the WTP for the quantities of water used with the devices would be the same as the WTP for originally projected use. It can be maintained that the reductions in water use would not result in reductions in the utility derived from the use of water. For example, the installation of a flow restrictor on a shower head would reduce the flow of water, but by achieving greater dispersion and velocity, could produce the same showering experience as a larger flow of water.

A summary of the present value of net benefits associated with a 15% reduction in water use achieved with the use of water saving devices is shown in Table A2.13. These net benefits are equivalent to

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[20] State of California, Department of Water Resources

TABLE A2.13

ESTIMATED NET BENEFITS, 15% REDUCTION
BY DEVICES

	High Elasticity Demand Curves	Low Elasticity Demand Curves
Chowan River	$ 287,033,540	$ 1,319,456,900
Blackwater River	280,003,420	1,312,426,800
Appomattox River	272,548,660	1,304,972,000
Lake Gaston	267,923,580	1,300,346,900

the levels of WTP in excess of the levels of WTP associated with the projected level of use in 1980, less the costs associated with the levels of use in excess of projected 1980 use.

VITA

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AN ECONOMIC APPROACH TO WATER SUPPLY PLANNING IN SOUTHEASTERN VIRGINIA

by

William Bagwell Anderson

(ABSTRACT)

An examination was conducted of alternative responses to the water supply situation in four cities in southeastern Virginia. Cost/benefit analyses were performed for the provision of projected levels of use and for reductions in those levels of use achieved with the use of quotas, price increases, and water saving devices. An important element of these analyses was the consideration of the costs incurred as a result of waste water treatment with different levels of water use. The levels of the principal types of water use were estimated for each city. This provided a basis for the projection of water demand curves necessary for estimating the value of water.

Optimal schedules for the development of additional water sources were derived through the examination of water demand, relative to the costs of operating and expanding water supply and waste water treatment facilities.