BOLAND

AN ASSESSMENT OF RATE-MAKING POLICY ALTERNATIVES FOR THE WASHINGTON SUBURBAN SANITARY COMMISSION

by

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CHAPTER ONE

SUMMARY AND CONCLUSIONS

SCOPE OF STUDY

This report describes an assessment of a set of fourteen alternate rate-making policies which have been specifically formulated for consideration by the Washington Suburban Sanitary Commission (WSSC). These alternate policies include proposals for spatially differentiated prices, seasonal prices, changes in the relative role of fixed charges and prices, adoption of a flat rate charge system for sewer service, and an increasing-block rate structure. The rate-making policy actually implemented by the WSSC has major implications for the cost of water and sewer service to the WSSC's customers, the quantities of water and sewage which must be processed, and the required capital investment. The purpose of this report is to describe the probable impact of each rate-making policy alternative on various classes of customers and on the WSSC. The information thus obtained is offered to the Commission to guide it in considering possible modifications to its current rate-making policy.

Estimates of the impact of various policy alternatives have been obtained through a computer simulation of the operation of the WSSC over the period 1972-2001. To perform such a simulation, a large number of assumptions must be made regarding such variables as the behavior of individual customers and groups of customers, the behavior of the WSSC, patterns and rates of growth in the WSSC service area, etc. The behavioral assumptions, which have been drawn from studies of other water and water/sewer utilities operating in similar service areas, are embedded in the simulation model described in Appendix B to this report. The descriptive data and growth assumptions required for the simulation are discussed in Chapter III and in Appendix A.

It must be emphasized that these assumptions do not represent predictions of the future state of events. The purpose of this report has been to prepare assumptions which seem to the authors to be reasonable and consistent. All results from the simulations described in this report should be treated as conditional, being based upon the validity of the assumptions. Since these assumptions are consistent and uniform, valid comparisons can be made between individual rate-making policies, but the results of any single simulation cannot be treated as a reliable forecast of any of the parameters.

We feel certain that the techniques used to develop the assumptions will be of interest to the WSSC. These techniques have been outlined and are discussed in Chapter III as well as in Appendix A. The explicit nature of the required assumptions suggests another use for the simulation model: that of testing the sensitivity of operating and fiscal variables to various types of behavior and growth trends. This application appears to have considerable potential as a planning technique (see Appendix C for a detailed discussion).

One of the most noticeable effects of variation in rate-making policy is the shift in the quantity of water demanded and the quantity of sewer flow produced. In an era of decreasing clean water sources and heavy demands on the environment's capability to serve as a waste sink, the importance of these considerations should exceed their fiscal impact on the utility. In fact, the WSSC is currently pursuing a comprehensive program to reduce water use and associated sewer flows through customer education and plumbing code modification. To the extent that such a program is successful, it has important implications for the formulation of rate-making policy. The basic assumptions made in this study are dependent upon both the availability of plumbing fixtures and water-using appliances, and customer behavior. The relationship between water-saving programs and rate-making policy evaluation is discussed in Appendix D.

An important consideration in the evaluation of any rate-making policy is the cost of implementing that policy. This can best be illustrated by considering the proposal, analyzed in this report, to adopt seasonal prices. At the present time, the WSSC's meter reading organization operates year-round: meter routes are billed on a continuing schedule--some in January, some in February, etc. If a seasonal rate scheme should be adopted, all meters would have to be read within, at the most, a two-month period. This step would approximately triple the number of meter readers required during the meter reading period, as well as introduce the problem of finding useful employment for the meter readers during the rest of the year. Additional costs may also be incurred in the process of concentrating the billing, collection and complaint adjustment activities within such a short time span.

The assessments reported here do not consider implementation cost, except parenthetically. A full analysis of this important cost aspect requires a thorough study of the WSSC's operations and, at this early stage of evaluation, is not justified. Should any of the policies described herein seem worthy of further investigation, the costs of implementation must be determined before any final decision can be reached.

CONCLUSIONS

A detailed simulation and analysis of the effects of fourteen alternate rate-making policies has been carried out for the WSSC. The major policy issues underlying these rate structures are:

Spatial differentiation of prices
Seasonal prices
Increasing-block prices
Average variable cost prices
Flat rate sewer service charges

Chapters II and III of the report describe the formulation of the policy alternatives, the assumptions used and the simulation procedure. Chapter IV presents the results of the analyses of the fourteen alternatives with discussion of these results in the context of the policy issues listed above.

Spatial Differentiation of Prices

Water and sewage system demands were found quite insensitive to price differentiation based on an arbitrary allocation of costs between counties. The prices actually required in the two counties were very similar and investment requirements essentially unchanged. If the service area is disaggregated on the basis of the eight meter-reading districts now in existence, and costs are allocated in a suitable manner, the following effects are produced. The largest districts require price levels similar to those which are required under uniform pricing, but the smaller districts require substantially higher or lower prices, according to the existence of a high or low rate of growth, respectively. Maximum water demands and sewer flows are reduced about three percent and investment requirements are about one and one-half percent lower. In general, the results appear sensitive to spatial disaggregations on the basis of service area characteristics (by districts), and insensitive to disaggregations where characteristics are similar (by counties).

Seasonal Prices

The practice of seasonal pricing requires that capital costs be recovered from those users who create the capacity requirement; in this case, the summer users of the water supply system. Sewer systems have not been assumed to be significantly seasonal in operation. The simulation disclosed that the implementation of seasonal pricing can be expected to create seasonal sewer flows, with the maximum flows occurring in the winter. This phenomenon creates an increased requirement for sewer facilities which more than offsets--in investment cost--the reduced requirement for water supply facilities. The overall result is that the seasonal pricing alternative, admittedly difficult to implement, confers no particular advantage except where water supply considerations are of overwhelming importance.

Increasing-Block Prices

An alternative to seasonal pricing is the implementation of an increasing block rate schedule--in this case for residential customers only. The effect of such a policy cannot be simulated with the existing model; however, it was estimated through manual analysis. Since the second, higher-priced block of water usage includes only the highest fraction of residential demand, it can be assumed to consist largely of water used for lawn irrigation and other high-elasticity seasonal uses. Because of the specificity of the second block price, maximum day water demands can be reduced without the necessity of large increases in sewer flow, as with seasonal prices. For this reason, increasing-block rate schedules hold some promise for a rate-making policy which reduces investment requirements without unduly penalizing consumers.

Average Variable Cost Prices

A policy of recovering all capital costs through fixed charges--basing the commodity charge on average variable costs only (operating and maintenance costs)-- results in several marked shifts in operating parameters. Water demands increase substantially, as a result of the lower price levels; required investment in main facilities is considerably higher. The total cost of water to individual consumers will also rise, although more water will be used and more sewage flow produced. In the absence of a need to stimulate greater use of water, this alternative appears to have little merit.

Flat-Rate Sewer Service Charges

Another possible rate-making practice is the use of fixed charges (flat-rate charges) to recover the costs of sewerage service. This would result in a much lower commodity charge for water service, and higher total fixed charges. The simulation indicated that it would also result in substantially higher water demands, sewer flows and investment requirements, comparable to those associated with average variable cost pricing. The total cost of water to individual consumers rises noticeably, when both fixed and variable charges are considered. As before, if there is no requirement for stimulating higher water and sewage flows, this alternative offers no advantage.

RECOMMENDATIONS

If the objective of the Commission is to provide a fair and equitable rate schedule which recovers the full cost of operations while providing inducements to customers for efficient use of the water and sewerage systems, the rate-making policy now in use is an effective one. Continued use of this policy would not appear to create any particular problems other than those necessitated by the sharply rising costs now predicted by the WSSC.

Several possible improvements to this policy should be considered by the Commission, however. This study has shown that improvement in efficiency of the system is possible through a properly conceived system of district rates. To evaluate this possibility fully, a study should be made of the cost of implementing such a scheme, including the rather laborious task of allocating costs rationally among the districts. It appears that the effect of such a policy would be lower rates for residents of densely-settled, slowly-changing districts near the District of Columbia boundary, and higher rates for the less dense, rapidly-growing areas along the outer edges of the sanitary district. The overall effect of this policy should be slightly lower water demands, lower sewer flows and lower investment requirements than would otherwise be expected. On the other hand, this alternative is likely to have the highest implementation cost of any of the options studied.

A second area proposed for further investigation concerns the use of an increasing-block rate schedule. This rather innovative measure appears to hold promise for reducing water supply costs without unreasonably penalizing any group of customers. It is suggested that the increasing-block structure be applied only to single-family residences, and that the limit of the first block be set at a level somewhat higher than the normal winter demand of residential customers. The first block price should be slightly lower than the uniform price in effect for other customers, and the second block price considerably higher. The prices can be manipulated to produce about the same total cost of water/sewer service that would occur with uniform pricing, while retaining a strong incentive to minimize summer uses. A special simulation of this specific policy could produce the guidelines required to set appropriate price levels, as well as providing predictions of the overall impact of such a policy.

Based on the assumptions made in this study, and the simulation model chosen, the other policy issues--seasonal prices, average variable cost prices, and flat-rate sewer service charges--appear to offer no advantage to the WSSC or its customers. The present rate-making policy is an effective one, but rising costs will place a heavy burden on the WSSC's customers. Continued investigation of the two policy issues described above is recommended, particularly since their implementation may minimize the impact of rising costs on those customers who have the smallest role in creating them.

CHAPTER TWO

RATE-MAKING POLICY ALTERNATIVES

THE NATURE OF RATE-MAKING

Public water supply and wastewater disposal in urban areas is provided by government agencies; special government corporations; or by investor-owned, regulated utilities. The cost of water and sewerage services is usually covered, in whole or for the most part, by a number of special-purpose charges, levies, and/or taxes. Self-sustaining government corporations, such as the Washington Suburban Sanitary Commission, are required to adopt a system of charges, levies, and taxes to produce revenues at least equal to the full cost of services provided, which, when actually implemented together with attendant terms, conditions, exceptions, etc., constitutes the rate structure of the utility. The conventions, guidelines and procedures used by the utility to determine the nature and level of the charge system comprise the rate-making policy of the utility.

A water/sewer utility rate structure may contain many different elements, depending upon local conditions and policies. Table II-1 lists some of the more commonly employed categories of rate structure elements. Rate-making policy is concerned with several fundamental questions:

a. Which rate structure elements are to be employed?
b. What are the terms of application of each?
c. What portion of the required revenue will be derived from each element?

These considerations can be illustrated by briefly considering the rate structure now in effect within the WSSC sanitary district.

The Commission's current rate-making policy considers most of the rate structure elements listed on Table II-1. Customers are billed at regular intervals (semi-annually, except for large accounts which are on a monthly basis) for water and sewer commodity charges, including service charges for certain customer classes. Front-foot benefit assessments and connection charges are used to provide the remainder of the required revenue.

Table II-1
Typical Rate Structure Elements

RATE STRUCTURE ELEMENT	BASIS OF LEVY	METHOD OF COLLECTION
Water use commodity charges (price)	Per Unit of water use	Periodic billing
Sewer use commodity charges (price)	Per Unit of water use	Periodic billing
Service charges	Fixed charges	Periodic billing
Readiness-to-serve charges	Fixed charges	Periodic billing
Minimum charges	Fixed charges	Periodic billing
Water benefit assessments	Property Front footage	Annual assessment
Sewer benefit assessments	Property Front footage	Annual assessment
Ad valorem taxes	Property value	Annual assessment
Fixed assessments or taxes	Fixed charges	Annual assessment
Connection charges	Water/sewer connections	One-time charges
Capital contributions	Fixed charges	One-time charges
Miscellaneous charges for special services	Fixed charges	One-time charges

The water and sewer use charges currently in effect are uniform for all quantities of water used; these total $0.95 per thousand gallons of water used (for customers with both water and sewer service). Front-foot benefit assessments are levied for twenty years after the construction of water and/or sewer lateral lines; the rate of assessment is determined by the system-wide unit cost of lateral construction during the year preceding the original levy.

The commodity charges and service charges, together with certain minor miscellaneous charges for specific services, are intended to recover the full cost of operating and maintaining the Commission's water and sewer systems, as well as the capital costs of certain major components of these systems ("basic main facilities;" e.g., treatment plants, storage and pumping facilities, water mains 16 inches in diameter or larger, sewers 15 inches in diameter or larger, etc.). The smaller water and sewer lines are financed by the front-foot benefit assessments; customer connections are funded directly by connection charges. The Commission also levies ad valorem taxes, but the proceeds of these are restricted to the capital costs of certain storm drainage facilities at the present time.

Given these decisions and criteria, rate-making consists of periodic review of costs and revenues and an occasional adjustment of the various charge levels to insure that total costs are covered and that specific charges maintain the desired relationships with various components of cost. In recent years, this process has resulted in regular increases in the commodity charges for water and sewer use, with minor adjustments in other charges. Commission projections of costs and demands indicate that the commodity charges will continue to rise rapidly throughout the next five years, provided that the current rate-making policy is retained.

Of the rate structure elements now in use by the WSSC, the water and sewer commodity charges (prices) and the front-foot benefit assessments are currently the most important from the standpoint of total revenue. While other types of charges have an important place in an effective rate structure and must be carefully selected and designed, they tend to be marginal in their impact on either the consumer or the utility. The front-foot benefit assessment, on the other hand, has a significant impact on many consumers. A customer who in 1971 built a new home within a subdivision served by water and sewer, is required to pay $148.00 in front-foot benefit assessment (based on 100 feet of assessable frontage) each year for the next twenty years. This can be compared to his expected water and sewer commodity charges--approximately $110.00 during the fiscal year 1973.

Although important, front-foot benefit assessments are seldom reexamined in the rate-making process. In most cases, the water and sewer line construction costs to which they are dedicated have been funded by revenue bonds. The terms of sale of these bonds may obligate the utility to specific assessment practices throughout the life of the bonds. Even where these constraints are not present, a major change in the method of recovering general construction costs involves difficult questions of equity between beneficiaries of new construction and persons who have wholly or partially retired previous assessments.

The commodity charges set for water and sewer use are the most common subject of review during rate-making. When the rate-making policy itself is reviewed, consideration may be given to such policy adjustments as changing that portion of total cost recovered through commodity charges; adopting uniform, decreasing-block, or increasing-block charge structures; using seasonal prices; etc. All of these alternatives have important implications for the operation and growth of the utility, since price plays a unique role in influencing customer behavior.

THE ROLE OF PRICE

In analyzing the production and consumption of goods and services, economists often speak of the "law of demand". This term refers to the observed fact that, except in a very few special circumstances, a negative functional relationship always exists between price and quantity demanded. If the price of a good or service rises, other things being equal, consumers will demand lesser quantities. Conversely, if the price falls, the quantity demanded can be expected to rise. Since supply costs are related, to some degree, to the quantity of good or service produced, the possible existence of a relationship between price and quantity demanded has important implications for rate-making.

A number of investigators have analyzed quantity-price relationships for urban water systems. A recent report reviewed ten previous studies, all concluding that a significant negative functional relationship exists (Hittman Associates, 1970). The most complete detailed set of demand data available is that collected by members of the Residential Water Use Research Project at The Johns Hopkins University (Linaweaver, Geyer and Wolff, 1966). These data have been analyzed by Howe and Linaweaver (1967), producing the most informative description to date of the behavior of urban water users in response to price. Four of the 41 field areas studied in this research are located within the WSSC sanitary district.

All of these studies, based on many of the largest water utilities in the United States, have concluded that a negative relationship does exist between the price of water and sewer services and the quantity of water (and sewer flow) demanded. The nature of this relationship is often specified by reference to the "price elasticity of demand." This can be defined as follows:

> the percentage change in quantity demanded resulting from a one percent increase in price.

A price elasticity of zero implies no relationship between demand and price. Price elasticities less than zero (negative elasticities) imply the negative relationship which has been observed.

The explanation of such a negative relationship is the existence of substitutions for use of public water supply systems. These substitutes need not be alternate commodities, but may take the form of benefits or amenities foregone. Samuelson offers a hypothetical example:

> When water is very dear, I demand only enough of it to drink. Then when its price drops, I buy some to wash with. At still lower prices, I resort to other uses; finally, when it is really very cheap, I water flowers and use it lavishly for any possible purpose (Samuelson, 1967).

In most parts of the United States, consumers of municipal water find themselves at the latter extreme of Samuelson's example--water is indeed very cheap by comparison to other goods and services required for everyday life and it is used, by many standards, extravagantly. If the price of water rises significantly, consumers may elect to have brown lawns, increase their attention to plumbing repair, adopt less wasteful washing and cleaning techniques, etc.

Howe and Linaweaver (1967) found that the use of municipal water for sprinkling purposes is relatively elastic with respect to price--a one percent increase in price can be expected to produce a greater than one percent decrease in quantity demanded. Domestic uses (i.e., all water used within the home for ordinary domestic purposes) are much less elastic, reflecting the limited range of substitutions available for such uses at current price levels. This marked divergence in behavior for two components of residential water use leads to proposals for seasonal or increasing-block rate structures designed to recognize the greater elasticity of seasonal (sprinkling) demands. Many commercial, industrial and institutional water users also have seasonal components in their demand; indirect evidence indicates some spread in the elasticities associated with seasonal and year-round uses, perhaps less pronounced than that measured for residential users.

The formulation and implementation of rate-making policy should take account of the price elasticity of water/sewer demands, both with respect to the overall effect and the diversity of elasticities among different categories of users and purposes. The rate structure chosen influences the level and pattern of demand because of these relationships and, therefore, the costs and capacity requirements of the system as well. Knowledge of such effects is important not only for the rate-making process itself, but in managing and operating the utility in general.

POLICY ALTERNATIVES STUDIED

One method of reviewing the effectiveness of a rate-making policy is to formulate a number of alternate policies, then compare the predicted effects of each to those predicted for the actual policy in use. If the alternate policies are properly selected, and the prediction methodology for probable effects sufficiently reliable, this type of review can provide considerable insight into the strengths and weaknesses of alternate policies and assist in making rational choices among alternatives. In the case of the present study, fourteen alternate rate-making policies were proposed. Their probable effects were analyzed with the aid of a computerized simulation model. The simulation process is described in Chapter III and Appendix B gives additional details of the model itself.

In the development of policy alternatives, it has been assumed that revisions in the practices of levying benefit assessments, *ad valorem* taxes, and special and one-time charges are either not feasible or not appropriate at this time. Accordingly, the discussion of rate-making policy which follows is limited to the section of the rate structure which affects the semi-annual and monthly billings; the portion of total costs which is related to system operation, maintenance, and administration; and the capital costs of the "basic main facilities."

This simplification limits policy alternatives to variations in the practices of levying water and sewer commodity charges, and fixed service charges. The major variations considered are related to geographical variation in prices, seasonal price fluctuation, and increasing-block prices, as well as changes in the portion of costs recovered through the commodity charges. The policy alternatives studied are listed in Table II-2. The probable effects of the use of each of these alternate policies were predicted by simulating the operation of the water-sewer system for thirty years, as described in Chapter III. The results of these simulations are presented and discussed in Chapter IV.

Table II-2
Rate-Making Policy Alternatives Studied

ALTERNATIVE	DESCRIPTION
A	Existing Policy: Uniform rates throughout year, uniform rates throughout sanitary district, uniform rates for all quantities of water, commodity charges recover all operating and maintenance costs as well as 86 percent of annual capital cost of basic main facilities, service charges recover 14 percent of annual capital cost of basic main facilities.*
B	Same as Alternative A, except that commodity and service charges are separately calculated for Montgomery and Prince Georges counties.**
C	Same as Alternative A, except that commodity and service charges are separately calculated for eight separate service areas.**
D	Separate seasonal commodity charges. Summer rates cover proportionate share of operating and maintenance costs and 86 percent of the annual capital cost of basic main facilities; winter rates cover proportionate share of operating and maintenance costs only. Uniform rates throughout sanitary district, uniform rates during each season for all quantities of water, service charges recover 14 percent of annual capital cost of basic main facilities.
E	Same as Alternative D, except that summer and winter commodity and service charges are separately calculated for Montgomery and Prince Georges counties.**
F	Same as Alternative D, except that summer and winter commodity and service charges are separately calculated for eight separate service areas.**
G	Uniform rates throughout year, uniform rates throughout sanitary district, uniform rates for all quantities of water, commodity charges recover operating and maintenance costs only, service charges recover 100 percent of annual capital cost of basic main facilities.
H	Same as Alternative G, except that commodity and service charges are separately calculated for Montgomery and Prince Georges counties.**

Table II-2 (continued)

ALTERNATIVE	DESCRIPTION
I	Uniform rates throughout year, uniform rates throughout sanitary district, uniform rates for all quantities of water, commodity charges recover operating and maintenance costs of water system as well as 86 percent of the annual cost of basic main water facilities, service charges recover operating and maintenance costs of sewer system, 100 percent of annual capital cost of basic main sewer facilities and 14 percent of annual capital cost of basic main water facilities.
J	Same as Alternative I, except that commodity and service charges are separately calculated for Montgomery and Prince Georges counties.**
K	Same as Alternative I, except that separate seasonal commodity charges are used. Summer rates cover a proportionate share of operating and maintenance costs of water system and 86 percent of annual capital cost of basic main water facilities; winter rates cover a proportionate share of operating and maintenance costs of water system only.
L	Same as Alternative K, except that summer and winter commodity and service charges are separately calculated for Montgomery and Prince Georges counties.**
M	Uniform rates throughout year, uniform rates throughout sanitary district, uniform rates for all quantities of water except residential customers living in single-family dwellings; their rates are set at less than the regular commodity charge for all quantities purchased up to some set number of gallons per six months, and at a level higher than the regular commodity charge for additional quantities. Commodity charges recover all operating and maintenance costs as well as 86 percent of annual capital cost of basic main facilities; service charges recover 14 percent of annual capital cost of basic main facilities.
N	Same as M, except commodity and service charges are separately calculated for Montgomery and Prince Georges counties.**

NOTES: * Allocation of costs of basic main facilities to commodity and service charges is merely a convention; service charges are not dedicated to any specific purpose. They are credited to an operating fund from which basic main facilities costs are debited.

** The simulation of policy alternatives involving geographical divisions is based on an arbitrary allocation of capital and operating costs to the service areas involved. Implementation of these policies would require a major study of costs to permit a more meaningful allocation.

CHAPTER THREE

SIMULATION METHOD

WATER/SEWER UTILITY SIMULATION MODEL

The probable effects of the rate-making policy alternatives listed in Table II-2 have been predicted with the aid of a computerized simulation model. This model is intended to reflect, in a simplified way, the response of the utility to changing demands and customer behavior. Its principal features are described in Appendix B. Briefly, the model begins with estimates of demands, costs, and revenue for the current year. The expected surplus or deficit is calculated and the demands, costs, and revenue are estimated for the next year. This process continues for thirty years. Whenever rates must be revised--based on specified criteria--the new rate structure is calculated for the next year and estimates of demands, costs, and revenue are updated accordingly.

At the end of the simulation, thirty-year forecasts of most parameters are available, including average water use, maximum day water use, average sewer flow, capital cost, operating cost, revenue, price, etc. These forecasts are based on the specific rate-making policy assumed for that simulation. Other assumptions produce other simulations for comparison in order to reveal the probable effect of each variation in policy. All of these results are, in turn, dependent upon assumptions regarding customer behavior and the nature of demand growth within the utility's service area. The following sections outline the data collection effort required to support these assumptions and to operate the model.

DATA COLLECTION

Existing Water Use Patterns

Demand Sectors

The Water/Sewer Utility Simulation Model permits separate treatment of up to six categories of water use, excluding unmetered public/unaccounted uses. This disaggregation permits the simulation to account for variation in customer behavior, growth rates, and pricing which might be associated with different use sectors. Table III-1 lists and describes the water use sectors which were specifically employed in the WSSC study.

Table III-1
Water Demand Sectors

Sector Number	Sector Name	Description
1	Residential, sprinkling	Water used for lawn irrigation and other outside, seasonal uses by single-family residences.
2	Residential, domestic	Water used within single-family residence for ordinary, non-seasonal, domestic purposes; including cleaning, laundry and sanitary uses.
3	Apartment, garden	Water used within apartment complexes not more than three floors high, for both domestic and seasonal purposes.
4	Apartment, high-rise	Water used within apartment complexes which are more than three floors high (elevator apartments), for both domestic and seasonal purposes.
5	Commercial/Industrial	Water used for all purposes within commercial (retail, wholesale, service, recreational activities) and industrial (manufacturing, conversion, and processing activities) establishments.
6	Institutional	Water used for all purposes within Federal, State and local government installations, charitable and non-profit institutions, and other establishments such as schools, hospitals, etc.

Since the residential use of water for lawn sprinkling is known to have a much higher price elasticity of demand than residential use for domestic purposes, it is helpful to specify sprinkling use as a separate sector. In this way, the response of consumers to various kinds of seasonal and block pricing structures can be estimated. Little is known of the nature of seasonal water demands within other sectors; therefore, no further distinctions of this type are possible. The separation of apartment uses into garden and high-rise sectors recognizes several differences in water use patterns, including the much higher incidence of central, water-cooled airconditioning units in the relatively more modern high-rise units. As older, non-airconditioned walk-up apartment units are replaced by new facilities, there may be less need to divide apartments into two sectors.

The combined sector of Commercial/Industrial water use is justified by the very low incidence in the WSSC service area of process-water-using industry. As a suburban area containing a high proportion of commuter households, the service area has relatively little local industry; it consists largely of "clean" industry, e.g., laboratories, publishers, bottling plants, bakeries, etc. These activities use only small amounts of water for cleaning, sanitary uses, airconditioning, and lawn irrigation; only a few industries in the bi-county service area (Montgomery and Prince Georges counties) are known to produce industrial wastes which differ significantly from domestic sewage. Except for these few, industry does not differ appreciably in water use and wastewater production characteristics from commercial enterprises (retail, wholesale, service, and recreational activities) which make up the bulk of this combined sector.

Another unique feature of the WSSC service area is the major role played by institutional water users. Among the major Federal installations served by the WSSC are the National Institutes of Health, NASA, the U.S. Bureau of the Census, the National Bureau of Standards, the Atomic Energy Commission and the National Ordnance Laboratory. The service area also includes the University of Maryland and numerous other schools, hospitals, government offices and public facilities. This concentration of Federal, state, local, and private institutions is the basis for selecting a separate water use sector for these activities.

Analysis of Existing Use

The simulation model requires estimates of existing water use in each sector for each season, as well as estimates of the number of customer connections as of December 31 in each category. This information was obtained by analysis of the Commission's billing records for the period July 1971 through June 1972 (approximate). The required information was obtained for each of the eight service districts described in Table III-2. This geographical division is facilitated by the organization of the Commission's meter books into these eight divisions. Districts Number 10, 50, and 60 lie within Prince Georges County, while Number 20, 30, 40, 70 and 80 are located in Montgomery County.

Table III-2
Service Districts

District Number*	Communities**
10	Mount Rainier
20	Takoma Park
30	Silver Spring
40	Glen Echo, Chevy Chase, Bethesda
50	Brentwood, Bladensburg, Bowie, Seat Pleasant, etc.
60	Fort Washington, Riverdale, College Park, Laurel, Hyattsville
70	Kensington, Viers Mill Village, Randolph Hills, Derwood
80	Gaithersburg, Germantown, Damascus

NOTES: *District boundaries established by WSSC meter routes.

**Place names associated with WSSC districts.

Computer listings were obtained of billing information for each customer account during the 1971-1972 period. The listings for the 204,832 accounts billed semi-annually were analyzed by the Commission's data processing staff; the remaining 2,168 accounts billed monthly were reviewed manually. In each case the accounts were separated into the demand sectors, as listed on Table III-1, and the following information for each district obtained: average summer use per connection, average winter use per connection, and number of connections. In addition, variances were computed for the sectors in the semi-annually billed category. "Summer" is defined as the period of April through September, inclusive; "winter" is the remaining six months. Only a small portion of the semi-annual accounts are billed at a time which permits identifying the seasonal uses. The remainder were estimated by extrapolation from the data available. This procedure overlooks the possibility of significant variation in seasonal water use ratios among the districts, but it is the only feasible alternative using the available data. "Residential, sprinkling" is taken as the difference between summer and winter residential use; domestic use is assumed constant over the year. This convention was developed by Linaweaver *et al.* (Linaweaver, Geyer, and Wolff, 1966).

Commercial uses were separated from the semi-annual accounts by two methods: (1) districts with the highest variances were assumed to contain a relatively large proportion of commercial accounts and were manually reviewed to separate these uses, and (2) the remaining districts were estimated from the results of the manual analyses. All "Residential, sprinkling" data were normalized to weather conditions similar to the years 1961-1963, an adjustment based on previous work which established a linear relationship between actual sprinkling use and the theoretical sprinkling requirement--the difference between summer potential evapotranspiration and six-tenths summer precipitation (Linaweaver, Geyer and Wolff, 1966). Summer evapotranspiration in the WSSC service area for the year 1971, computed by a modified Thornthwaite method, was 25.51 inches. The difference between potential evapotranspiration and six-tenths precipitation is 25.51 - 0.6 (30.92), or 6.96 inches. The comparable figure for 1961-1963 is 17.09 inches, a level more typical of recent decades. Based on these climatic measures, sprinkling use in 1971 was estimated at 41 percent of that experienced ten years earlier (other variables held constant). This result was used to adjust all measured "Residential, sprinkling" uses to normalized "Residential, sprinkling" uses. Forecasts based on these normalized levels should provide "normal" estimates of sprinkling use; actual levels can, of course, be expected to exceed the forecast in dry years and to fall short in wet years.

The average annual water use observed during 1971-1972 for each sector and each district is reported on Table III-3. These data are given in terms of gallons/connection/day for the entire year. The unmetered sector of use--the public/unaccounted category--does not appear on this table. The uses shown comprise the metered water sales of the utility, which have historically made up about 90 percent of the total water produced. Public/unaccounted uses are estimated at approximately 10 percent of total water production, or 11.1 percent of metered water sales. Table III-4 lists the number of customer connections in each user sector and each district.

The ratio of summer water use to winter water use is reported in Table III-5 for each sector, except residential; and each district. The residential sectors are not included since the summer-winter separation is implicit in the computation of

Table III-3
Average Water Use Data — 1971-1972

Use Sector	Service Districts 10	20	30	40	50	60	70	Service Districts (continued) 80
Residential, sprinkling**	55	81	76	80	78	71	82	64
Residential, domestic	201	296	276	291	282	259	296	232
Apartment, garden	6805	7363	21243	12713	20121	15297	20769	28493
Apartment, high-rise	23285	22162	25399	36011	33540	26587	43048	32616
Commercial/Industrial	3234	2925	3531	4243	4436	3287	4168	5082
Institutional	-0-	12600	39849	137645	36012	87361	151463	336297

NOTES: * Water use expressed as gallons/connection/day, annual average.

** Residential sprinkling water use is normalized to 1961-1963 weather conditions.

Table III-4
Customer Connections — 1971-1972

Use Sector	Service Districts 10	20	30	40	50	60	70	80	Totals
Residential, Single-family	1360	2610	48556	16588	69279	40744	18146	5049	202332
Apartment, Garden	13	45	110	64	497	450	100	14	1293
Apartment, High-Rise	1	34	75	34	39	40	26	3	252
Commercial/ Industrial	47	49	554	515	849	614	232	169	3029
Institutional	-0-	3	11	8	15	39	15	3	94
TOTALS	1421	2741	49306	17209	70679	41887	18519	5238	207000

sprinkling uses as a separate sector. Although actual ratios were available for all monthly accounts, they could not be measured for most semi-annual customers; these ratios were estimated, based on those observed for similar uses. No normalization was attempted for sectors other than residential, since little is known of the nature of seasonal uses in these sectors. If they respond to climate in a manner similar to single-family residential sprinkling use, the ratios given may be underestimated. In the context of this study, such an estimation tends to understate the differences between alternate rate structures; i.e., producing a conservative assumption.

Finally, Table III-6 presents the average and maximum day water use estimates implied by data given on Tables III-3, III-4 and III-5. These figures include public/unaccounted uses and are given in millions of gallons per day (MGD). The annual average is the simple mean of the winter and summer averages, since in this model the seasons have the same length. Maximum day uses are calculated as 1.67 times the annual average use. These estimates are subsequently revised by the simulation model, as described in Appendix B. Since the actual maximum day is related to a number of factors which are not included in the model (e.g., length of most extreme dry spell, maximum day evapotranspiration, coincidence of extreme weather conditions with weekend or holiday, etc.), maximum day estimates are at the mid-point of a range of possible maximum day use levels. Montgomery and Prince Georges counties' figures were obtained by combining the appropriate service districts, as described above.

Water Use Forecasts

Connection Forecasts

The simulation model requires a base forecast of water use; i.e., estimates of future levels of water use which would be expected if there is no change in the real price of water/sewer services. These estimates can be stated as the product of two components: (1) the expected number of customer connections in each sector, and (2) the expected average water use per connection. The number of connections expected at any future time varies in response to development patterns and changing service area characteristics, while average water use per connection reflects trends in life-style, technology, and existing incentives for greater or less water use (including price). When combined, these factors produce an estimate of future water use which embodies all such considerations.

Table III-5
Summer/Winter Use Ratios

Use Sector	Service Districts 10	20	30	40	50	60	70	80
Apartment, Garden	1.05	1.10	1.12	1.13	1.17	1.06	1.20	1.05
Apartment, High-Rise	1.10	1.10	1.10	1.13	1.39	1.13	1.25	1.05
Commercial/ Industrial	1.15	1.05	1.27	1.45	1.16	1.10	1.45	1.05
Institutional	1.10	0.85	1.05	1.56	1.26	1.02	1.25	1.10

Table III-6
Estimated Water Production by District — 1971-1972

District	Winter Average	Summer Average	Annual Average	Maximum Day
10	0.58	0.78	0.68	1.13
20	2.21	2.79	2.50	4.17
30	21.80	31.00	26.40	44.00
40	10.40	15.10	12.70	21.20
50	37.60	52.50	45.10	75.10
60	26.10	33.50	29.80	49.70
70	12.30	17.20	14.80	24.60
80	3.84	4.74	4.29	7.15
Prince Georges County	64.30	86.9	75.60	126.00
Montgomery County	50.50	69.8	60.10	100.20
TOTAL**	114.80	157.4	136.10	226.80

NOTES: * All figures in million gallons per day.
** Columns may not add to total because of rounding errors.

Forecasts of customer connections depend upon a number of assumptions. One of the most important ones concerns the relationship between the nature of service area development and the operating policies of the water/sewer utility. The utility's water and sewer main extension practices, for example, influence the rate of growth of the area as a whole, as well as land use patterns within the area. In the case of Montgomery and Prince Georges counties, the rapid growth of apartment units within the Commission's service area is almost certainly related to the availability of public water and sewerage. Many types of commercial and industrial activities are strongly influenced in their locational decisions by this consideration. The availability of these services may also affect the pattern of growth of single-family dwellings, certainly with respect to density.

The same line of reasoning may be used to predict that growth patterns and rates will also be affected both by the cost of water and sewer services and by the rate-making policy adopted by the utility. This effect, although present, is usually considered to be quite small due to the insignificant portion of average household or commercial activity budget allocated to water and sewer taxes, assessments and rates. Only certain types of manufacturing industries use water and sewer services in quantities which require special consideration of cost. In general, this type of industry is not found in the WSSC service area.

In preparing the connection forecasts described here, three assumptions have been made: (1) that present extension policies of the WSSC will be continued, (2) that rate-making policy selected by the WSSC will have no significant effect on the development of the service area, and (3) that no major change in the present boundaries of the service area will occur. Forecasts of residential, garden apartment and high-rise apartment connections were based on the predicted resident population in the service area and assumptions regarding the changing mix of housing stock. The forecast methodology is detailed in Appendix A to this report. Commercial/industrial and institutional connections were forecast by extrapolating past trends while adjusting for overall rates of growth in each district. The assignment of population growth and other trends to various districts was, of necessity, somewhat arbitrary. It was assumed that areas closer to the District of Columbia will experience little expansion of single-family dwelling growth, significant increases in apartment units and relatively mild rates of overall population growth. The major share of growth in population and in number of single-family units is expected to occur in outlying districts where tracts of undeveloped land remain.

The forecasts of connections, disaggregated by water use sector and by district, are presented as Table III-7. The actual

Table III-7: Connection Forecasts by Sector and District — 1972-2007

		District								Counties		
Sector Use	Year	10	20	30	40	50	60	70	80	P.G.Cty.	Mo.Cty.	TOTALS
RESIDENTIAL, SINGLE-FAMILY	1972	1360	2610	48556	16558	69279	40744	18146	5049	111383	90949	202332
	1977	1376	2641	54844	18717	81580	48009	22696	10747	130965	109645	240610
	1982	1389	2662	61132	20876	93896	55274	26449	15342	150559	126461	277020
	1987	1397	2671	67410	23039	106089	62535	30040	18245	170021	141405	311426
	1992	1409	2678	73689	25203	118282	69796	33640	21332	189487	156542	346029
	1997	1442	2676	79980	27381	130444	77080	37229	24134	208986	171400	380386
	2002	1475	2654	86276	29560	142606	84364	40823	27264	228445	186577	415022
	2007	1510	2700	92638	31530	158803	91682	44450	29900	251995	201218	453213
APARTMENT, GARDEN	1972	13	45	110	64	497	450	100	14	960	333	1293
	1977	14	48	138	67	608	517	130	24	1139	407	1546
	1982	14	50	166	70	719	584	139	27	1317	452	1769
	1987	15	49	204	72	886	630	132	29	1531	486	2017
	1992	15	51	242	74	1053	677	119	30	1745	516	2261
	1997	15	53	290	74	1218	692	110	31	1925	558	2483
	2002	15	58	338	74	1382	707	102	33	2104	605	2709
	2007	15	57	385	74	1541	722	97	34	2278	647	2925
APARTMENT, HIGH-RISE	1972	1	34	75	34	39	40	26	3	80	172	252
	1977	1	36	95	38	74	64	37	4	139	210	349
	1982	1	38	116	42	108	88	43	5	197	244	441
	1987	1	38	140	45	160	111	47	5	272	275	547
	1992	2	40	174	48	211	135	48	6	348	316	664
	1997	2	43	214	50	278	156	48	6	436	361	797
	2002	3	46	254	52	345	177	49	7	525	408	933
	2007	3	47	295	54	413	198	49	7	614	452	1066
COMMERCIAL/ INDUSTRIAL	1972	47	49	554	515	849	614	232	169	1510	1519	3029
	1977	48	50	644	599	1003	725	290	242	1776	1825	3601
	1982	49	51	735	683	1157	837	339	304	2043	2112	4155
	1987	50	51	806	749	1311	947	389	366	2308	2361	4669
	1992	51	52	878	816	1464	1058	441	427	2573	2614	5187
	1997	52	52	946	879	1617	1169	497	489	2838	2863	5701
	2002	53	52	1015	943	1770	1281	556	550	3104	3116	6220
	2007	55	53	1127	1006	1935	1390	612	615	3380	3413	6793
INSTITUTIONAL	1972	-0-	3	11	8	15	39	15	3	54	40	94
	1977	-0-	3	15	11	17	46	15	3	63	47	110
	1982	1	3	19	15	20	53	16	3	74	56	130
	1987	1	3	22	17	22	59	17	4	82	63	145
	1992	2	4	25	19	25	65	17	4	92	69	161
	1997	2	4	28	21	27	71	18	4	100	75	175
	2002	3	4	31	23	30	78	19	5	111	82	193
	2007	3	4	34	25	32	84	20	5	119	88	207
Totals	1972	1421	2741	49306	17179	70679	41887	18519	5238	113987	93013	207000
	1977	1439	2778	55736	19432	83282	49361	23168	11020	134082	112134	246216
	1982	1454	2804	62168	21686	95900	56836	26986	15681	154190	129325	283515
	1987	1464	2812	68582	23922	108468	64282	30625	18649	174214	144590	318845
	1992	1479	2825	75008	26160	121035	71731	34265	21799	194245	160057	354302
	1997	1513	2828	81458	28405	133584	79168	37902	24664	214285	175257	389542
	2002	1549	2814	87914	30652	146133	86607	41549	27859	234289	190788	425077
	2007	1586	2861	94479	32689	162724	94076	45228	30561	258386	205818	464204

increases in number of apartment units are understated by these figures since the average number of units per apartment complex is assumed to be increasing concurrently; e.g., in District 60 the average size of garden apartment complexes is now 75 units and by 2007, it is expected to be 110 units. Where current apartment stock is dominated by a few very large complexes, the average size is expected to diminish over time. The overall trend, however, appears to be a moderate increase in average size as older, smaller units are replaced by modern, large-scale multiple-building complexes. As required by the simulation model, forecasts are presented for five-year intervals over a total time span of 35 years.

Forecasts of Use Per Connection

Estimates of future water use per connection in a particular sector must include many variables. In the "residential, domestic" sector, average water use per connection is related to average number of persons per household, life-style, availability of water-using fixtures and appliances, price of water and any restrictions or constraints on water use that may be in existence; e.g., the "Residential, sprinkling" water use sector results from the existence of irrigable lawns and gardens, seasonal weather conditions and such variables as price of water. Water used in apartments, whether high-rise or garden type, depends largely on these same factors, but also on number of apartment units per connection. Commercial/industrial water use per connection is related to types and sizes of commercial/industrial establishments, as well as the nature of water use within each one. An increase in average size of a retail store, for example, might result in sharply rising quantity of water used per connection without any actual change in water use practices. Institutional water uses are similarly dependent upon size of institutional establishments as well as on the level and nature of their water-using activities.

The base forecast of water use required by the simulation program consists of future use estimates within each sector assuming static real price of water and sewer services. The influence of price on water use per connection may, therefore, be neglected. The remaining considerations were reduced to assumptions regarding rate of growth in use per connection. Various growth rates were selected for the individual sectors and districts based on expectations of changes in the mix and size of apartment, commercial/industrial, or institutional establishments, as well as trends in water use practices. The forecasts used in the simulation are displayed on Table III-8. Pre-

Table III-8: Average Water Use per Connection by Sector and District — 1972-2007

(water use in gal/connection/day)

		Districts								Counties		
Sector Use	Year	10	20	30	40	50	60	70	80	P.G.Cty.	Mo.Cty.	TOTALS
RESIDENTIAL, SINGLE-FAMILY	1972	256	377	352	371	360	330	378	296	348	358	352
	1977	263	386	361	380	369	338	384	306	357	364	360
	1982	269	396	370	390	378	347	391	316	366	372	369
	1987	276	406	379	400	388	356	396	327	375	380	377
	1992	283	416	389	410	398	365	403	337	385	389	387
	1997	290	427	399	420	408	374	410	349	395	398	396
	2002	298	437	409	431	418	383	416	360	404	407	405
	2007	305	449	419	442	429	393	423	373	415	417	416
APARTMENT, GARDEN	1972	6805	7363	21243	12713	20121	15297	20769	28493	17679	17890	17733
	1977	7575	7549	21997	13034	20732	15683	21296	29216	18279	19019	18474
	1982	7961	7960	22778	15186	21362	17152	22047	29955	19353	20167	19561
	1987	8686	8841	23587	15569	22010	18684	23453	31130	20511	21326	20707
	1992	9129	9762	24424	17559	21648	20293	24269	34017	21015	22694	21398
	1997	9595	10723	25291	18002	22306	21950	25776	36591	22079	23664	22435
	2002	10084	11727	26189	20135	21881	23689	26662	37967	22406	24784	22937
	2007	10515	12020	27119	20644	22553	26716	28500	41159	23793	25993	24280
APARTMENT, HIGH-RISE	1972	23285	22162	25399	36011	33640	26587	43048	32616	29984	29651	29757
	1977	23300	22732	26695	36921	35356	27531	44140	33443	31666	31068	31306
	1982	23400	24601	28056	29685	35470	28508	45257	34290	32299	32679	32509
	1987	23500	25222	29487	40687	35505	30504	46402	35157	33420	33724	33573
	1992	23500	29125	30992	44924	35450	31587	47576	36047	33883	35487	34646
	1997	25000	31256	32572	46059	35297	32708	48779	36959	34323	36511	35314
	2002	25000	34334	34234	53968	35037	34962	50013	37894	34954	38718	36600
	2007	27000	35200	35980	55331	34658	36203	51300	38845	35119	39916	37153
COMMERCIAL/ INDUSTRIAL	1972	3234	2925	3531	4243	4436	3287	4168	5082	3931	4023	3977
	1977	3571	3024	3711	4459	4662	3455	4310	5211	4140	4232	4187
	1982	3942	3127	3900	4687	4900	3631	4456	5343	4357	4433	4396
	1987	4353	3233	4099	4926	5150	3816	4607	5478	4585	4640	4613
	1992	4805	3343	4308	5177	5413	4011	4763	5616	4824	4851	4838
	1997	5306	3456	4528	5441	5689	4215	4924	5759	5075	5068	5071
	2002	5858	3574	4759	5719	5979	4430	5091	5905	5338	5291	5314
	2007	6366	3696	5002	6011	6284	4894	5265	6053	5714	5516	5615
INSTITUTIONAL	1972	50000	12600	39839	137645	36012	87361	151463	336297	73097	109550	93674
	1977	50000	13028	41264	141122	37290	90462	159220	344826	76114	119855	94803
	1982	50000	13470	42728	144687	38614	93674	167341	353550	78203	120726	96521
	1987	50000	13927	44245	148341	39985	96999	175875	362495	81129	126616	100892
	1992	51000	14400	45816	152089	41405	100443	184844	371666	83325	126401	101786
	1997	56000	14889	47443	155930	42874	104008	194272	381069	86542	129115	104788
	2002	61000	15395	49127	159869	44396	107701	204180	390710	89329	135298	108860
	2007	66000	15916	50871	163907	45972	111524	214500	400463	92749	138446	112176

dictions are made at five-year intervals over 35 years. Data reported for 1972 are calculated from actual water use information.

Elasticity Assumptions

Each individual water user can be expected to respond differently to any change in the price of water, the response being related to quantity of water used, the value placed by the user on the service, the relative cost of water compared to other commodities and services which he purchases, etc. In order to estimate the effect of price changes on total water use, it is necessary to aggregate individual users with others likely to exhibit similar behavior. The water demand sectors described in Table III-1 represent one possible classification of water uses. Within each sector, response to price changes by users varies--some making considerable changes in quantity of water demanded, while others do not alter use patterns at all.

The overall effect of these actions can be described as a negative functional relationship between the price of water and the quantity demanded within any one sector: as price rises, the quantity demanded falls. This relationship is measured by the price elasticity of demand; as defined earlier, this is:

> the percentage change in quantity demanded resulting from a one percent increase in price.

Price elasticities were measured for several demand sectors by Howe and Linaweaver (1967): residential, sprinkling; residential, domestic; and residential, maximum day sprinkling. Their estimates are: -1.6, -0.2 and -1.3, respectively; i.e., a one percent increase in price can be expected to reduce average sprinkling uses 1.6 percent, domestic uses 0.2 percent, etc. The separate estimate for maximum day sprinkling uses recognizes that extreme behavior (the behavior of residential water users on the day of their maximum use of water during any year) is likely to be less responsive to price than overall behavior.

Estimates of elasticities in other sectors have been proposed by various investigators; a limited amount of research has been undertaken to verify these estimates (Hittman Associates, 1970). In general, it can be assumed that the elasticity of domestic uses within apartment units is somewhat less than that measured for domestic use in single-family dwellings. This is due to the fact that apartment dwellers normally pay the water bill only indirectly (via the rent payment) and are likely to be less conscious of the impact of higher price. The seasonal uses associated with apartments are composed mainly of lawn irrigation and airconditioning, which are under the control of the building management. These uses can be expected to respond appreciably to price changes, although perhaps not as strongly as single-family residential sprinkling uses.

Commercial, industrial and institutional water uses are not expected to exhibit high elasticities. Since little process water is used in the WSSC service area, substitutions for water use in these sectors are limited and the cost of water and sewer service is an insignificant item in the budget of the average retail store, office, or institution. Institutions, in particular, are expected to be relatively insensitive to price changes, even with respect to seasonal uses. This follows from government ownership of many of these establishments and the associated bureaucracy which provides little incentive for cost-saving. The seasonal component of commercial and industrial water use may be somewhat more sensitive to price, since uses such as lawn irrigation and airconditioning have many possible substitutions. The price elasticities of demand assumed for each water use sector, including maximum day residential sprinkling uses, are listed in Table III-9. These estimates are intended to refer to establishments and water uses now in existence.

An additional problem is presented by the prospect of further construction and development in the service area. As new residences, apartments and commercial establishments are designed and built, choices must be made regarding plumbing fixtures, water-using appliances, and such factors as the acreage of irrigable lawn. If water and sewer services continue to become more expensive and if public awareness of water supply problems is maintained or increased, it is reasonable to assume that more attention during planning will be given to the water-using potential of new facilities. The effect of this attention will be to provide more substitutions for water use, permitting individual users to make larger reductions in water use in response to increasing price, without sacrificing important values or conveniences. Stated another way, water use in new structures and facilities will probably exhibit a somewhat higher price elasticity of demand than comparable use in existing facilities. Table III-10 lists the elasticity assumptions made for water use associated with new or remodeled structures.

To develop estimates of price elasticity for each district and sector, the expected mix of new and previously existing structures must be estimated. Elasticities at the present time are those shown on Table III-9. These will steadily increase as new buildings are added to the total stock. Unfortunately, the simulation program, at its present stage of development, does not permit elasticities to vary over time. Instead, the elasticities estimated to be in effect on the tenth year of the simulation (1982) were employed over the entire thirty years. This approximation serves the central purpose of revealing the differences between the various districts, and of predicting the

Table III-9
Price Elasticity of Demand Assumptions – Existing Structures

Sector	Use	Winter Season	Summer Season
1	Residential, sprinkling		
	(average day)	n.a.	-1.6
	(maximum day)	n.a.	-1.3
2	Residential, domestic	-0.2	-0.2
3	Apartment, garden	-0.1	-0.14
4	Apartment, high-rise	-0.1	-0.17
5	Commercial/Industrial	-0.2	-0.29
6	Institutional	-0.3	-0.3

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Table III-10
Price Elasticity of Demand Assumptions – New or Remodeled Structures

Sector	Use	Winter Season	Summer Season
1	Residential, sprinkling		
	(average day)	n.a.	-1.7
	(maximum day)	n.a.	-1.4
2	Residential, domestic	-0.4	-0.4
3	Apartment, garden	-0.3	-0.31
4	Apartment, high-rise	-0.3	-0.33
5	Commercial/Industrial	-0.4	-0.43
6	Institutional	-0.3	-0.3

Table III-11: Price Elasticity of Demand Assumptions by Sector, Season and District

			Districts								Counties		
Sector	Use	Season	10	20	30	40	50	60	70	80	P.G.Cty	M.Cty.'	TOTAL
1	Residential, sprinkling												
	(average day)	Winter	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
		Summer	-1.60	-1.60	-1.62	-1.62	-1.63	-1.63	-1.63	-1.67	-1.63	-1.63	-1.63
	(maximum day)	Winter	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
		Summer	-1.30	-1.30	-1.38	-1.32	-1.33	-1.33	-1.33	-1.37	-1.33	-1.33	-1.33
2	Residential, domestic	Winter	-0.20	-0.20	-0.24	-0.34	-0.25	-0.25	-0.26	-0.33	-0.25	-0.25	-0.25
		Summer	-0.20	-0.20	-0.24	-0.34	-0.25	-0.25	-0.26	-0.33	-0.25	-0.25	-0.25
3	Apartment, garden	Winter	-0.10	-0.13	-0.17	-0.12	-0.16	-0.14	-0.16	-0.20	-0.15	-0.15	-0.15
		Summer	-0.10	-0.12	-0.19	-0.15	-0.19	-0.18	-0.19	-0.22	-0.19	-0.18	-0.19
4	Apartment, high-rise	Winter	-0.10	-0.12	-0.17	-0.14	-0.23	-0.21	-0.18	-0.18	-0.22	-0.16	-0.19
		Summer	-0.20	-0.19	-0.23	-0.20	-0.27	-0.26	-0.23	-0.23	-0.27	-0.22	-0.24
5	Commercial/Industrial	Winter	-0.20	-0.21	-0.25	-0.25	-0.25	-0.25	-0.26	-0.29	-0.25	-0.26	-0.25
		Summer	-0.30	-0.28	-0.32	-0.32	-0.33	-0.33	-0.33	-0.35	-0.33	-0.33	-0.33
6	Institutional	Winter	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30
		Summer	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30

general effect of price changes without excessive error at either end of the study period. The price elasticity of demand assumptions used for each sector and district are displayed on Table III-11.

Capital Cost Forecast

To provide public water and sewer service requires a substantial investment in physical facilities. Many utilities recover a portion of this investment through the variable and fixed charges that appear on the periodic bill received by utility customers. The WSSC finances its "basic main facilities (treatment plants, pumping and storage facilities, and transmission mains)" in this manner. As the size of the service area and the quantities of water and wastewater processed increase, the investment in physical facilities must keep apace. Furthermore, as existing facilities deteriorate or become obsolete, they must be replaced and the cost of those replacements recovered.

To estimate capital costs associated with future levels of water use and wastewater production, the Water/Sewer Utility Simulation Model requires a base forecast of capital costs for both water and sewer "basic main facilities." These capital charges are expressed on an annualized basis, so that the cost of any particular component is spread over its probable useful life. A pumping station costing $100,000 with an expected life of 50 years is considered to represent an annual capital cost of $6,344 (assuming an interest rate of 6 percent). This annual cost is the amount required each year to repay a loan of $100,000 at 6 percent in 50 years. The pumping station could then be replaced, a new loan negotiated, and the payments would continue.

Water/sewer utilities are more accustomed to the terms and repayment conditions of municipal-type general obligation and revenue bonds, which, almost universally, fund major construction activities. In the case of the WSSC the annual debt service (interest plus principal repayment) required by the Water Supply and Trunk Sewer bonds is an adequate approximation of the annualized capital cost of water and sewer "basic main facilities." A forecast of capital cost for water and sewer facilities can be prepared by predicting the annual total debt service requirements for these classes of bonds.

The base forecasts of capital cost must correspond to the base forecasts of water use. Water capital costs are assumed to be primarily related to the maximum day water demand, although they are clearly affected by other considerations. Sewer capital costs are more difficult to correlate with demand predictions. The major sewer facilities–treatment plants, pumping station and major interceptors--must be sized to accommodate peak flows. Peak flows can be reasonably correlated with maximum day flows, but these are not clearly related to water use patterns. Considerable ground water and surface runoff are known to enter most sewerage systems. The WSSC's system is no exception. Total monthly flows frequently reach a peak during February, a month characterized by high ground water tables and frequent freeze-thaw cycles. Winter sewage flows are generally higher than summer flows, although the quantity of Commission-supplied water returning through the sewer is probably lower in the winter, under uniform prices.

The sewage arriving at the treatment works can be considered to have two components: (l) the contribution to the sewerage system of the homes and businesses connected to the lines, and (2) the ground and surface water entering the system at other points. The first component is slightly seasonal, reaching a minimum in the winter; the second is highly non-uniform, apparently peaking during the winter. To produce estimates of sewer capital costs, the average winter day water demand was used as a proxy for sewer flows. Examination of the results suggests that this assumption does not lead to significant errors. A more careful evaluation would require that before the capital cost of sewer facilities is estimated, each year's predicted sewer flow contribution be studied in detail and combined with estimates of infiltration volumes and seasonal patterns.

The forecasts of water and sewer capital costs associated with maximum day water demand and average winter day water demand, respectively, are shown as Table III-12. These were prepared by analyzing the Ten-Year Water and Sewerage Plan and the Six-Year Capital Improvements Program of the WSSC, making suitable adjustment for such technology shifts as the introduction of advanced waste treatment and extrapolating facility construction trends for thirty years. The major increase in sewer capital cost occurring between 1973 and 1976 is intended to reflect the construction of additional sewage treatment capacity and the provision of advanced treatment.

Table III-12
Base Forecast of Water and Sewer Capital Costs – Total Area

Year	Water	Sewer
1972	8,612	4,159
1973	9,100	5,900
1974	14,400	21,400
1975	16,000	32,700
1976	17,500	39,100
1977	18,000	43,100
1978	18,600	45,200
1979	19,250	47,300
1980	19,800	49,000
1981	20,600	50,800
1982	21,300	52,500
1983	21,800	54,000
1984	22,400	56,000
1985	23,000	57,800
1986	23,600	59,500
1987	24,300	61,500
1988	24,800	62,500
1989	25,500	65,000
1990	26,100	66,500
1991	26,600	68,000
1992	27,250	70,000
1993	27,800	72,000
1994	28,500	73,800
1995	29,000	75,000
1996	29,600	77,500
1997	30,100	79,000
1998	30,800	80,500
1999	31,300	82,500
2000	32,000	84,000
2001	32,500	86,000
2002	33,000	88,000

*Dollars spent per annum.

The costs shown apply to the entire service area of the WSSC. No estimates are available for smaller areas because of the joint nature of almost all major capital costs. The process of allocating the cost of a treatment plant or transmission main among several districts or jurisdictions was not attempted due to its complexity and the time required. To perform district and county simulations, a completely arbitrary allocation was made: each capital cost estimate was divided among the districts in proportion to the total number of connections in each. As with other assumptions described above, this one was found to have a minor impact on the results of the study, but it should be carefully re-examined before more detailed studies are attempted.

Other Data Requirements

Operating and Maintenance Costs

The other major category of costs recovered through variable and fixed charges for water and sewer service includes the cost of operating, maintaining and administrating the utility. This category of cost has been studied by Hittman Associates (1970) in 46 randomly selected water and water/sewer utilities, who found that operating and maintenance costs vary with such factors as the average water demand (sewer flow), the maximum day water demand, the service area population, and the number of customer connections served. Although the influence of these factors showed substantial similarity from utility to utility, the overall level of costs varied considerably as a result of local conditions.

Operating and maintenance cost forecasts for the WSSC were made by use of a cost model, that described in Appendix B, which contains the various terms known to influence these costs. The model includes a constant which sets the overall price level. This constant was computed to duplicate fiscal year 1972 costs, given the levels of the other variables in 1972. The simulation program was arranged to increase the value of the constant by 50 percent prior to the year 1974, an increase which approximates the upward shift in operating cost primarily related to the installation of advanced wastewater treatment facilities which the WSSC projects for that year. Operating costs are allowed to remain at the high level throughout the simulation, varying in response to shifts in demand, population, and number of connections.

Rate Review Trigger Points

The simulation model is arranged to review the level of the water and sewer rates automatically every five years, unless triggered at an earlier time. The trigger points are related to the level of the cumulative surplus or deficit resulting from rate structures in effect. When a maximum permissible surplus or a maximum permissible deficit is exceeded, the rate review process is initiated. The maximum levels of surplus and deficit were set at about one-sixth and one-third of the total capital cost expected in the first year (1972), respectively. This specification is arbitrary, but it does not appear to affect the results of the study in any measurable way. For the total area, the maximum cumulative surplus permitted without rate review is $2,000,000; the maximum cumulative deficit permitted is $4,000,000. Proportionate limits were set for the counties and districts.

Population Forecasts

A forecast of service area population must be provided for each district simulated. These forecasts were obtained by disaggregating a population forecast for the total service area. The source of this total forecast is discussed in Appendix A. Disaggregation began with estimates of 1972 population in each district, described in Appendix A, and employed assumptions regarding differential growth rates. These assumptions were similar to those employed in the preparation of connection forecasts, discussed above. The population forecasts for the districts, counties and the total area are listed on Table III-13.

Base Year Prices

The simulation program begins with the price of combined water and sewer service in the base year, maintaining that price

Table III-13
Population Forecasts by Sector and District – 1972-2007

Year	10	20	30	40	50	60	70	80	Pr. Geor. County	Montgom. County	Total
1972	7.62	19.52	243.6	80.9	436.3	260.8	98.1	25.2	705	566	1,271
1977	7.82	20.09	278.9	91.5	528.0	309.8	124.4	52.2	846	567	1,413
1982	7.89	20.84	314.3	102.1	617.6	363.6	146.5	73.3	989	657	1,646
1987	8.16	20.91	351.5	112.6	721.5	416.2	160.5	86.5	1,146	732	1,878
1992	8.39	22.26	390.6	123.2	814.8	469.3	175.2	100.9	1,292	812	2,104
1997	8.60	23.38	432.1	133.9	917.9	517.5	190.7	113.8	1,444	894	2,338
2002	8.95	24.88	473.7	144.6	1,007.3	567.3	205.9	128.2	1,584	977	2,561
2006	9.07	25.46	507.2	152.6	1,100.0	611.3	218.7	138.0	1,721	1,042	2,763

*All population figures in 1,000's.

for as long as possible, then recomputing future prices. The base year price in effect in the WSSC service area was $0.385 per thousand gallons for water service and $0.28 per thousand gallons for sewer service, totalling $0.665 per thousand gallons. Since the WSSC now employs uniform pricing over all demand sectors and use quantities, this price applies to all customers.

SPECIAL INSTRUCTIONS

The Water/Sewer Simulation Model predicts the probable effect of twelve alternate rate-making policies, based on data collected for the WSSC service area. These policies are described in Chapter II, Table II-2, Alternatives A through L. In addition, the two policy alternatives M and N in Table II-2 were reviewed by comparison to simulation model results without actually simulating them. For purposes of predicting the effect of each policy, the simulation model requires the basic data described above, as well as special instructions which characterize the rate-making policy under consideration. Alternatives are briefly reviewed here.

Alternatives A, B and C

Alternative A, the existing rate-making policy of the WSSC, is simulated by providing the data for the total service area, setting the FF variable (fraction of fixed costs recovered through fixed charges) equal to 0.14, and specifying uniform prices. Alternative B employs the same instructions, except that the program is run twice, once with data from each county. These results are combined to produce estimates for the total service area. Alternative C employs district data, and the simulation model must be run eight times, once for each district. The combined results are then comparable to those from Alternatives A and B.

Alternatives D, E and F

These alternatives are simulated exactly as the alternatives A, B and C, except that seasonal prices are specified.

Alternatives G and H

Alternatives G and H provide for average variable cost pricing; all operating and maintenance costs are recovered through the commodity charge, while fixed charges are levied sufficient to recover capital costs. The FF variable is, therefore, set equal to 1.0. Alternative G uses data for the total service area and uniform prices are specified. Alternative H uses county data, and the results are combined for comparison to G. Seasonal prices have no application under these assumptions, since capital costs are always recovered through fixed charges and never enter into commodity charge computations.

Alternatives I, J, K and L

These alternatives assume that the commodity charge is used to recover the operating and maintenance cost of water supply only, as well as 86 percent of the capital cost of water facilities. Fixed charges are levied to recover the total costs of sewer service, as well as the remaining 14 percent of water capital costs. This corresponds to the practice of many municipalities of charging a flat rate for sewer service or including it in the general tax bill. All four alternatives require that the computer program be modified to reflect this rate-setting logic. After these modifications are made, the FF variable is set at 0.14; data from the total service area is used for Alternative I, data from the counties is used for Alternative J, and the uniform pricing model is specified. Alternatives K and L are identical, except that the seasonal pricing model is employed.

Alternatives M and N

The impact of seasonal prices can be approximated by creating a suitable increasing-block rate structure. As contemplated here, this structure employs uniform rates derived exactly as those in Alternatives A or B for all customers except single-family residences. This group of customers would face a two-part rate structure: the first block would cover all water used per six months up to a quantity approximating the average winter use; and the second includes all additional water use in any six-month period. The price of water in the first block is less than that paid by other users, and the price for the second is greater. By suitable adjustment of the block sizes and the price levels, the average price of water sold to single-family residences may be equal to that purchased by other customers.

A computer simulation program which accurately reflects the behavior of consumers under an increasing-block rate structure must be more detailed than the program now in use. Furthermore, the size of such a program is not suitable to the teletype-terminal/time-sharing mode of computer operation now employed. As an example of the necessary complexity, if the first block size is set at or near the average winter use of residential customers, some number of customers will never exceed this level, while others will exceed it only in summer, and still others will exceed it at all times. Each group of customers must be separately accounted for. The present simulation deals with average behavior within a given sector, but this simplification is not acceptable for an increasing-block simulation. The fact that this requirement only applies to one class of customers further increases the complexity, since some method must be provided to deal with the other sectors.

Accordingly, the increasing-block policy option was not simulated, but was analyzed manually and contrasted to the alternatives which were successfully simulated. These results are presented and discussed in Chapter IV.

CHAPTER FOUR

SIMULATION RESULTS

METHOD OF COMPARISON

The Water/Sewer Utility Simulation Model was used to simulate the effects of twelve alternate rate-making policies over the years 1972-2001, inclusive. The policy alternatives studied are described in Chapter II of this report. For policies involving separate prices in Montgomery and Prince Georges counties, Alternatives B, E, H, J and L, each county was simulated separately, and the results combined. Alternatives C and F required that each district be simulated, and the eight districts combined. A total of 31 computer simulations were required to analyze the twelve alternatives.

For each alternate rate-making policy, the following parameters were estimated for each year:

Average day water demand
Average winter water demand, by sector, and total
Average summer water demand, by sector, and total
Maximum day water demand
Average winter contribution to sewer flow
Operating and maintenance cost
Capital cost
Total cost
Revenue from commodity charges
Revenue from fixed charges
Total revenue
Surplus (deficit) on operations
Price in effect for each sector and season

In addition, the cumulative surplus or deficit at the end of the thirty-year simulation period is estimated.

In order to present useful comparisons between alternatives, the discussion that follows is organized around specific rate-making policy issues: spatial differentiation of prices, seasonal prices, etc. As each issue is discussed the parameters which best illustrate the features of various policies will be presented. These include the following:

Average day water demand
Maximum day water demand
Average winter contribution to sewer flow
Capital cost

The capital cost time stream is expressed as a present value, rather than attempting comparisons between various investment patterns. The present value of a stream of future costs is simply the amount of money which, if invested now at a given interest rate, would fully fund all required future outlays. The present values given here assume an interest rate of six percent. Other interest rates ranging up to eight percent were tested, and found not to change the comparisons in any substantive way. Water demands and sewer flows are presented graphically. Other parameters are discussed as required to illustrate specific issues.

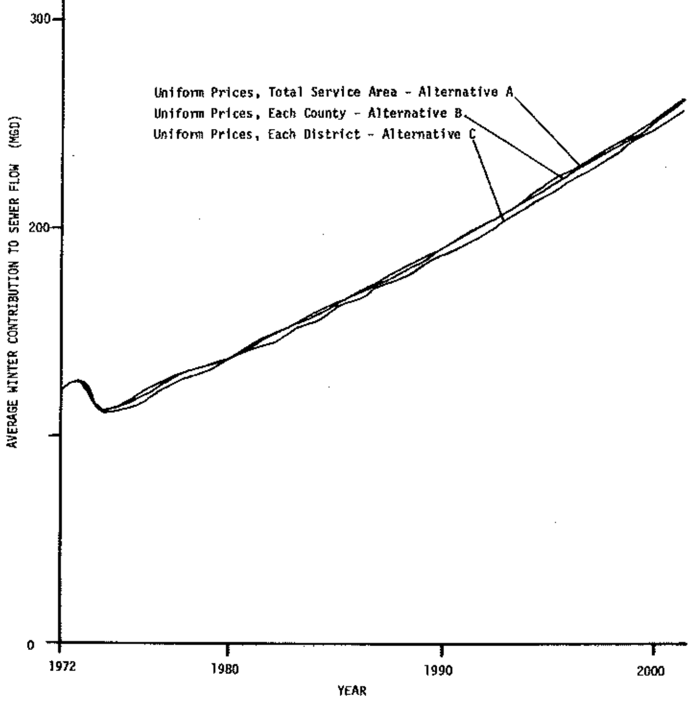
The result of this analysis is a good understanding of the sensitivity of major operating parameters to changes in rate-making policy. Specific rate-making issues can be related to their role in determining the levels of water demands, sewer flows, and investment requirements. In this way a policy can be devised which is consistent with the long-term policy objectives of the utility, but also satisfies short-term revenue requirements.

SPATIAL DIFFERENTIATION OF PRICES

To examine the effect of differentiating prices between customers living in different parts of the WSSC service area, two spatial disaggregations were simulated and compared to the total service area. The first divides the service area into the two constituent counties, Montgomery and Prince Georges. The counties have similar populations and characteristics, although Prince Georges County has experienced lower personal income and higher rates of growth. A second level of disaggregation was obtained by simulating each of eight districts, three of them located in Prince Georges County and the remaining five in Montgomery County.

Figure IV-1 displays the forecasts of average day water demand under rate-making policy Alternatives A, B and C. All three policies, as described in Table II-2, utilize uniform prices for all demand sectors, and both seasons. In Alternative A, the prices are uniform over the entire service area; in Alternative B, they are set individually for the two counties; and in Alternative C they are set individually for each district. Average day

Figure IV-1
Average Day Water Demand for Spatially Differentiated Prices



demand under all three alternatives rises slightly for 1973, then falls significantly to its 1974 level before resuming the upward trend. This reflects an abrupt rise in price level, occasioned by the shift to advanced waste treatment scheduled to occur at about that time. Cost assumptions are described in Chapter III. After 1975, the average day water demands associated with Alternatives A and B are indistinguishable; those associated with C are only slightly lower.

The seasonal price model was simulated with the same two levels of disaggregation, forming Alternatives D, E and F, and the same results were noted; disaggregation by county made no perceptible change in average day demand, and disaggregation by district caused a slight reduction. The county disaggregation was simulated for the average variable cost pricing Alternatives G and H; the uniform price, flat-rate sewer Alternatives I and J; and the seasonal price, flat-rate sewer Alternatives K and L. In each case no significant difference in average day water demand was found.

Figure IV-2 displays the forecasts of maximum day water demand obtained for Alternatives A, B and C. As before, no perceptible difference results from disaggregation by county (Alternative B). Setting prices by district succeeds in reducing maximum day demand somewhat, generally less than four percent. Identical results were obtained from disaggregation under other rate-making policies. As before, the downward trend in demand between years 1973 and 1974 is due to the sudden increase in costs, and therefore, in prices, in 1974. Maximum day water demands are of particular interest since they generally determine the level of capital investment in major water supply facilities.

Figure IV-2
Maximum Day Water Demand for Spatially Differentiated Prices

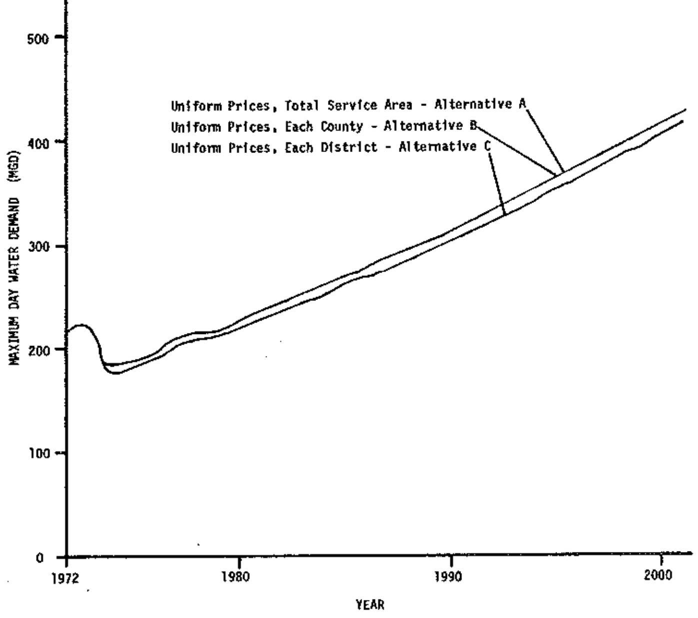
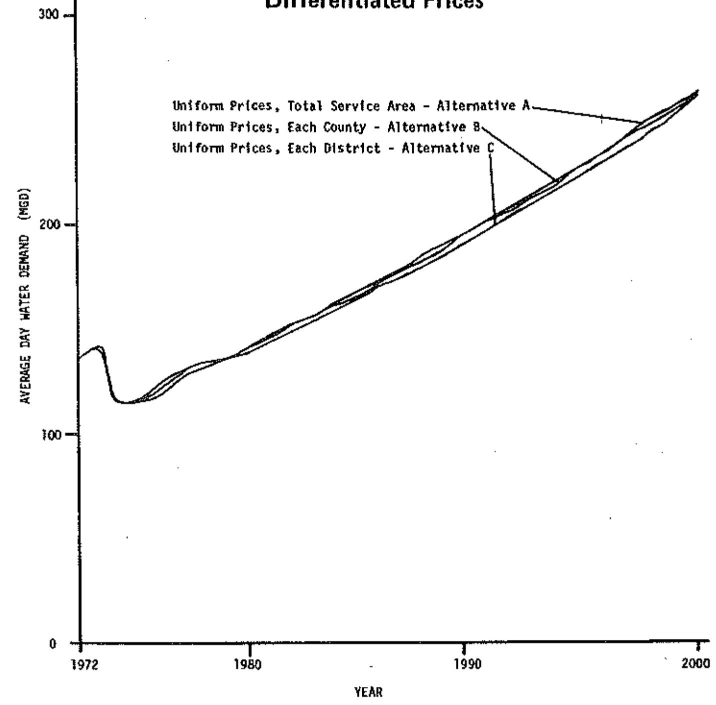


Figure IV-3
Average Winter Contribution to Sewer Flow for Spatially Differentiated Prices



Capital investment in major sewerage facilities is a function of maximum sewer flows, which are determined, in part, by the quantity of supplied water which enters the sewer system in the winter, the time of maximum flows. This contribution to sewer flow was estimated by the simulation program, and forecasts are shown as Figure IV-3. Results are nearly identical to those for water demand; total service area prices and county prices give nearly identical results, and district prices produce slightly lower flows.

Each of the policy alternatives compared above implies a particular stream of capital investment. The level of capital cost for each year of each simulation is determined by the required capacity of the water supply system (related to maximum day water demands) and the sewage collection and disposal system (related to average winter contribution to sewer flow). Each thirty-year forecast of capital cost can be replaced by its present value for purposes of comparison. The present value of a stream of future costs is that sum of money which, invested now at a given discount (interest) rate, will yield future proceeds just sufficient to cover each cost as it comes due. The use of present values allows dissimilar streams of future costs to be compared on a consistent basis.

Table IV-1 lists present values of capital cost streams for various alternatives, based on a discount rate of six percent. Policy Alternatives B and E (county prices) result in slightly higher capital costs than do Alternatives A and D (total service area prices). Alternatives C and F (district prices) require significantly lower capital investments, a result of the lower water demands and sewer flows. In the case of average variable cost pricing, where increased capital cost is not passed on to the customer in the form of higher prices, the difference between county prices and total service area prices (Alternatives H and G) was magnified somewhat. The flat-rate sewer Alternatives I, J, K and L resulted in slightly lower capital costs associated with county prices.

The price levels forecast by the simulation model are presented graphically on Figures IV-4, IV-5 and IV-6. Figure IV-4 shows the price level forecast for Alternative A, uniform pricing over the entire service area, as contrasted to the price level forecast prepared by the WSSC and published in the Ten-Year Water and Sewerage Plan. Both forecasts rise sharply through 1975. The simulation forecast is unsteady from 1975 through

Table IV-1
Present Values of Capital Cost Forecasts

Rate-Making Policy	Alternative	Present Value **
Uniform Prices, Total Service Area	A	715,567,000
Uniform Prices, Each County	B	718,274,000
Uniform Prices, Each District	C	704,993,000
Seasonal Prices, Total Service Area	D	723,996,000
Seasonal Prices, Each County	E	725,500,000
Seasonal Prices, Each District	F	715,000,000
Average Variable Cost Prices, Total Service Area	G	833,205,000
Average Variable Cost Prices, Each County	H	850,599,000
Flat Rate Sewer, Uniform Prices, Total Area	I	829,855,000
Flat Rate Sewer, Uniform Prices, Each County	J	793,084,000
Flat Rate Sewer, Seasonal Prices, Total Area	K	824,460,000
Flat Rate Sewer, Seasonal Prices, Each County	L	783,250,000

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*All present values computed at discount rate of six percent.

**Expressed in dollars.

Figure IV-4
Existing Rate-Making Policy Price Forecast vs. WSSC Forecast

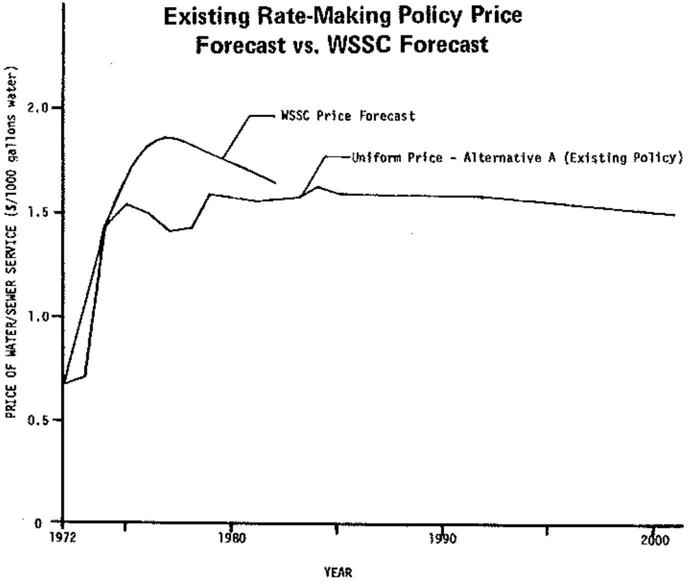
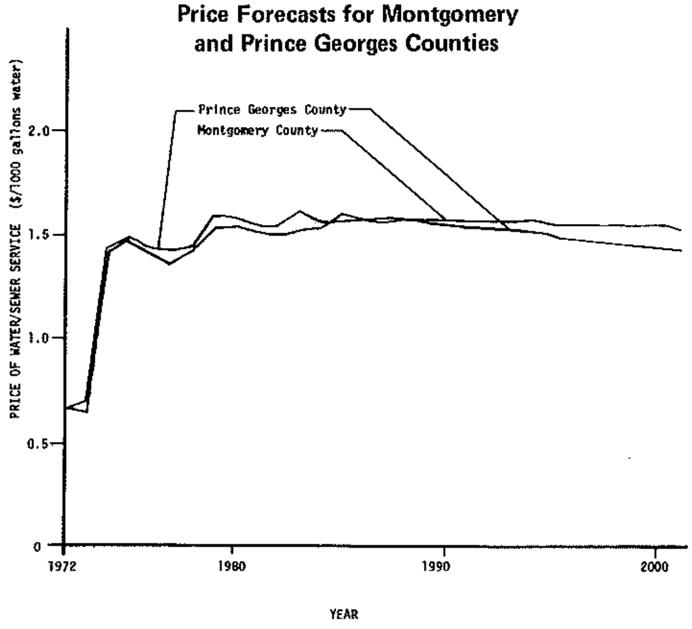
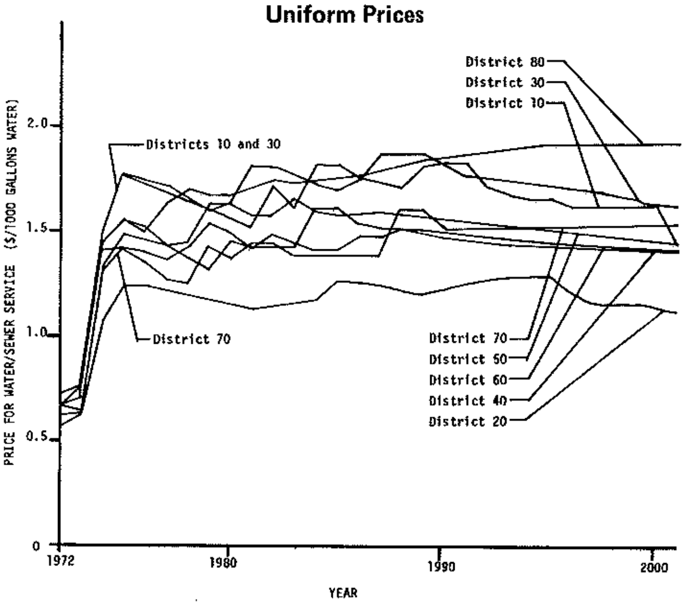


Figure IV-5
Price Forecasts for Montgomery and Prince Georges Counties



ALTERNATIVE B: Uniform Prices, Each County

Figure IV-6
Price Forecasts for Districts, Uniform Prices



ALTERNATIVE C: Uniform Prices, Each District

1979, inclusive, where it approaches $1.60 per 1000 gallons, falling slowly to about $1.50 per 1000 gallons by 2001. The WSSC forecast continues to rise after 1975, reaching a peak in 1977 and falling to a level very close to that of the simulation forecast by 1982.

The results of separate county prices can be seen in Figure IV-5 which illustrates the price forecasts associated with Alternative B. Prince Georges County prices are slightly higher than those of Montgomery County for the first fifteen years of the simulation period, but their relative positions are reversed for the last fifteen years. When district prices are employed, a much more complicated pattern emerges, as shown on Figure IV-6. Districts 10, 30 and 80 have generally higher prices than others, with District 80 reaching the highest level of almost $2.00 per 1000 gallons. The rate of growth in total connections assumed for District 80 is the highest of the districts. Districts 40, 50, 60, and 70--largest in terms of number of connections--have prices relatively close to those calculated for the total area. District 20, a small area with an assumed low growth rate, has consistently lower price levels throughout the period.

In summary, spatial differentiation of prices, when performed at a county level, produces very small changes in water demands, sewer flows, and price levels. When spatial differentiation by counties accompanies uniform pricing practices similar to those now in use by the WSSC, or when it accompanies seasonal prices, capital costs are not significantly different from total service area pricing. When average variable cost pricing is practiced, spatial differentiation by counties produces a stream of capital cost having a present value $17 million higher than that associated with total service area pricing. When a flat rate is used to recover sewerage costs, the present value of capital cost is lower: the uniform pricing policy reduces this value by $37 million and the seasonal policy causes a $41 million reduction.

Spatial differentiation of prices at a district level was investigated for uniform pricing practices similar to those now in use, and for seasonal prices. In both cases water demands and sewer flows were reduced slightly (3 to 4 percent) by setting prices independently for eight districts. The price levels resulting from this policy varied widely, ranging from $1.20 per 1000 gallons for small areas with low growth rates, to almost $2.00 per 1000 gallons for small areas with high growth rates. The larger districts tended to have prices similar to those calculated for the total service area. District prices reduced present values of capital costs by $9 million (seasonal prices) or $11 million (uniform prices).

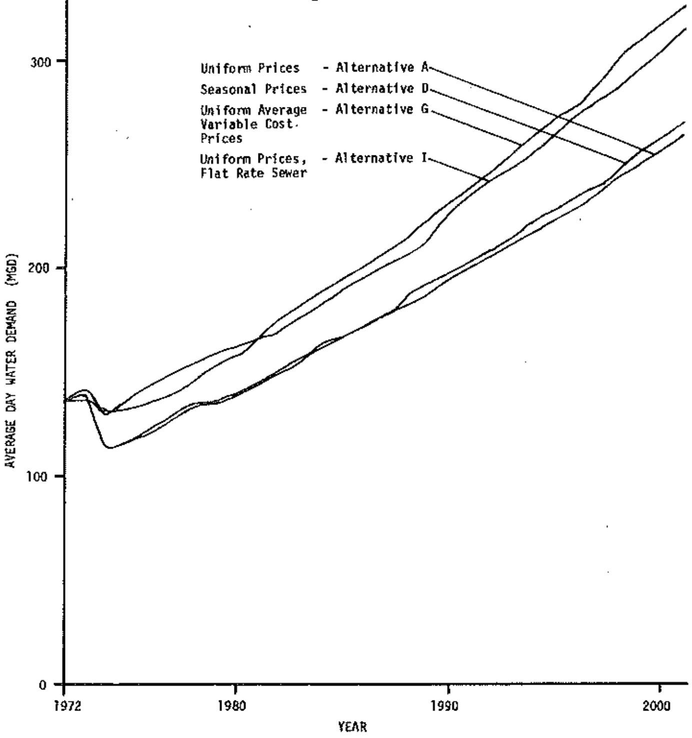
SEASONAL PRICES

Water supply systems in the United States experience their heaviest demands during the summer months. This characteristic results from the use of water to irrigate lawns and gardens, particularly in suburban areas. The supply works, treatment plants, major pumping stations and certain of the larger transmission mains must be sized to meet the daily demand at its maximum level for the year even though this level may not be approached during the winter months. Since the capital cost of the water system is largely determined by the customers who contribute to the maximum day demand (largely individuals irrigating residential lawns), a number of schemes have been proposed to discourage high levels of summertime use.

One of these schemes is seasonal, or peak-load pricing. As analyzed here, seasonal pricing is based on two six-month seasons: "winter" and "summer." The commodity charge for water and sewer service during the winter is set equal to the average variable cost of providing the service (operating and maintenance costs). During the summer, however, the price equals the average variable cost plus a proportionate share of the capital cost. In this way only summer customers are required to pay the capital cost of the system, and winter customers, who normally do not press on capacity, are not required to contribute to this cost. In some cases the application of this rule leads to a "shifting-peak" problem: winter customers receive such a low price that they begin to demand more water than summer customers. This situation requires that some of the capital cost be shifted back to winter consumers until their demand is equal to, or just less than, that of the summer consumers. When this pricing rule was applied to the WSSC, the shifting-peak correction was required in almost every instance.

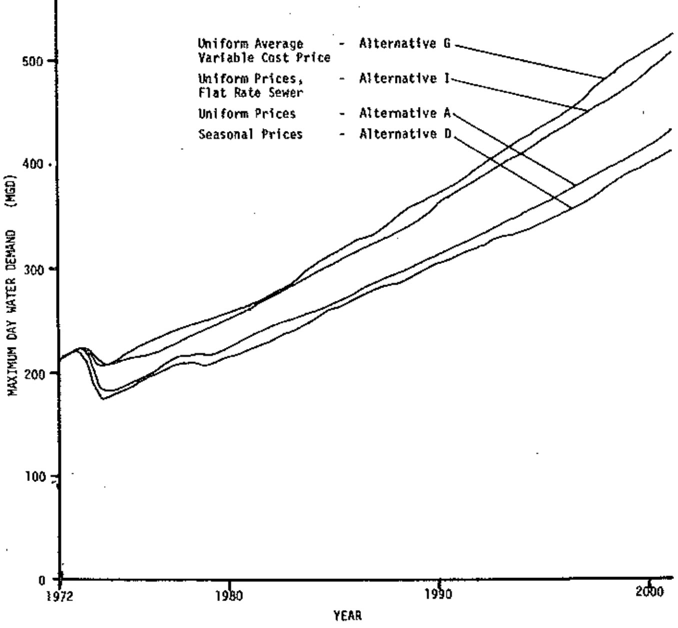
Seasonal pricing policies were tested for the total service area, for Montgomery and Prince Georges counties separately, and for the eight districts individually. Figure IV-7 illustrates the impact of the policy on average day water demands when applied on a total area basis. The water demand associated with seasonal pricing (Alternative D) remained very close to that associated with uniform pricing (Alternative A), tending to be slightly higher during the last fifteen years of the simulation. In the case of maximum day water demands, shown on Figure IV-8, seasonal pricing produced noticeably lower demand levels. After the first five years, maximum day demands were generally about five percent lower for seasonal pricing, implying lower capital costs for the water supply system.

Figure IV-7
Average Day Water Demand for Rate-Making Policy Alternatives



The result described above may be contrasted to the impact of the winter contribution to sewer flow. In this case, due to the lower winter prices, sewer flows increased as much as ten

Figure IV-8
Maximum Day Water Demand for Rate-Making Policy Alternatives



percent, as shown on Figure IV-9. This implies higher sewer capital costs, which may offset the savings indicated for the water supply system. Table IV-1 indicates that this is true. The present value of the capital cost stream for seasonal prices applied to the total area (Alternative D) is more than $8 million higher than that associated with the comparable uniform pricing policy. Similar relationships appear to hold for the two levels of spatial disaggregation tested. The price levels forecast on the assumption of a seasonal pricing rule are shown on Figure IV-10. They are generally symmetrical around the comparable uniform pricing levels with the summer price remaining about $0.30 per 1000 gallons higher and the winter price $0.30 per 1000 gallons lower.

Figure IV-9
Average Winter Contribution to Sewer Flow for Rate-Making Policy Alternatives

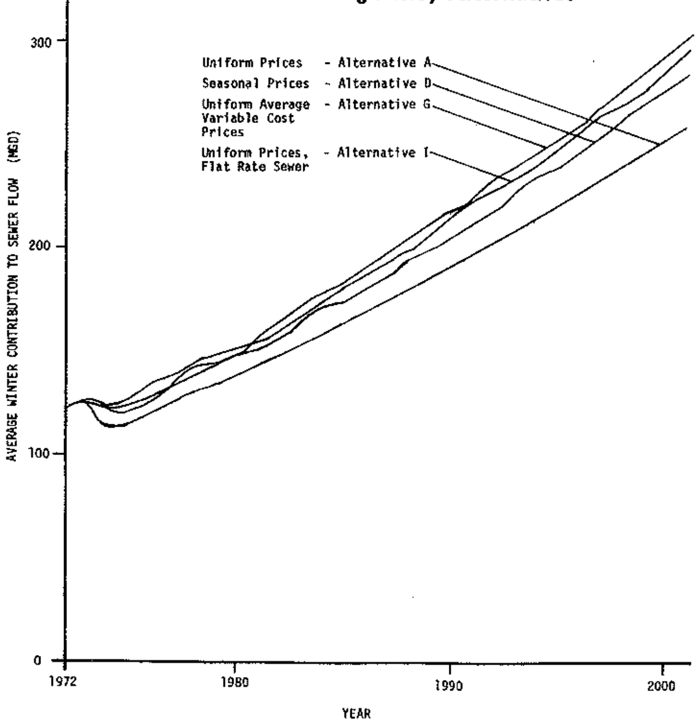
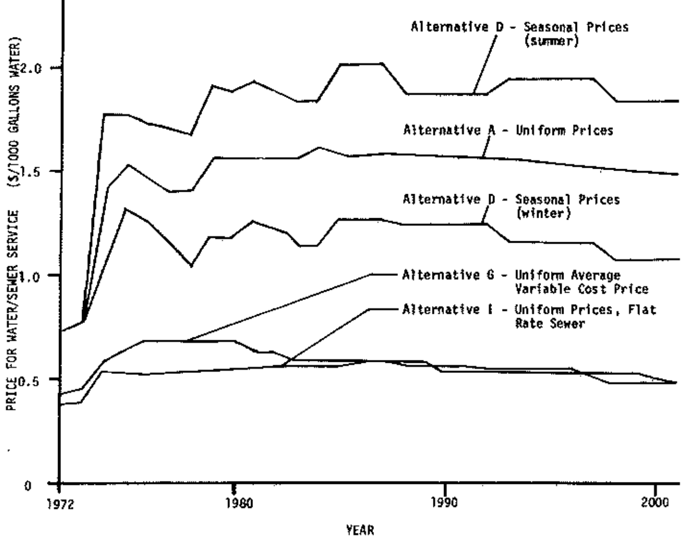


Figure IV-10
Price Forecasts for Rate-Making Policy Alternatives



Seasonal prices, when applied in the generally recommended manner, offer lower maximum water demands at the expense of higher maximum sewer flows. In the case of the WSSC, the net effect was increased capital costs with little change in the average price of water/sewer service to the average customer. Individuals who have very low seasonal demands (little need of water for sprinkling, etc.) will experience a reduced average price; those who have relatively larger seasonal demands will pay a higher price. The overall quantity of water used is affected only slightly by this policy.

The impact of seasonal prices upon individual residential customers is partially illustrated by Table IV-2 which lists the expected annual water bills for "average" residential consumers in 1977 under four different rate-making policies. It can be seen that seasonal prices affect the total bill only slightly, causing a small reduction in the total quantity of water used. This results in an increase in the average unit cost of water purchased, yet little change in the household budget. As noted above, individual customers' demands and costs may differ significantly from this "average" consumer.

The present investigation has highlighted a result of seasonal prices which has apparently escaped notice in the literature on this subject to date: seasonal prices create seasonality in sewer flows. Since the higher flows occur in the winter, which is often the time of the highest levels of infiltration from ground and surface water, they almost certainly increase the hydraulic capacity requirement of the sewerage system. This leads to higher capital costs which may, as in the WSSC simulation, more than offset the savings in water system costs.

Peak-load pricing theory offers a solution to this problem, once it has been identified. Since sewer flows are now seasonal, the capital cost of the sewerage system must be treated separately, and in the same manner as, the capital cost of the water system. Summer prices should include, in addition to average variable cost of water/sewer service, the full capital cost of the water supply system. Winter prices are based on average variable cost of water/sewer service plus the full capital cost of the sewerage system. The result of this computation would evidently be a set of prices which are almost uniform, thus explaining the generally superior performance of uniform pricing. Since proper application of peak-load pricing principles offers real advantages in terms of efficiency and equity, this subject seems worthy of further investigation. The simulation exercise performed in this study merely suggests that these principles have been proposed without full understanding of the behavior of public sewerage systems and its implications for pricing policy. It is also apparent that the existing uniform pricing policy is a reasonable approximation of an efficient policy.

INCREASING-BLOCK PRICES

Another approach to reducing summertime water demands is the use of increasing-block rate structures. In its simplest form, each customer is faced with two price levels for water/sewer service. The first, the lower level, applies to all quantities of water used during a billing period up to some specified level. All water used beyond this level is billed at the second, higher price level. The effect of this two-block arrangement is a uniform low price for water up to the limit of the first block, followed by rising average price as usage expands beyond that point. If the limit of the first block corresponds to normal

Table IV-2
Expected Annual Water/Sewer Bills for Typical Residential Customers — 1977

Charge Description	Unit	Rate-Making Policy Alternatives**			
		A	D	G	I
Total Quantity of Water Billed	(gal/year)	94,000	92,000	100,000	109,000
Annual Cost: Commodity Charges	($/year)	131.60	132.36	69.30	56.83
Fixed Charges ***	($/year)	11.20	11.27	81.38	100.62
Total	($/year)	142.80	143.63	150.68	157.45
Average Unit Cost of Water	($/1000 gal)	1.52	1.56	1.51	1.44

---

*Typical residential customers are those individual households whose water use pattern corresponds exactly to the average behavior of the residential sectors.

**Alternative A = Uniform Prices
Alternative D = Seasonal Prices
Alternative G = Average Variable Cost Prices
Alternative I = Flat Rate Sewer

***Fixed charges shown are proportionate shares of total fixed charges--the exact amount levied on any residential customer depends on the particular fixed charge structure chosen. At the present time residential customers pay no fixed charges, they are levied entirely on commercial, industrial and institutional accounts. Alternatives G and I, however, would almost certainly require residential fixed charges in amounts close to those shown.

winter water usage, the increasing-block rate structure tends to discourage seasonal uses.

The Water/Sewer Utility Simulation Model, as presently conceived, is not capable of analyzing this policy alternative. Within any demand sector, there exists a wide range of individual demands. Each customer will respond to the increasing-block rates in accordance with his individual level of usage: some will never exceed the first block; some will exceed it only in the summer season; others will always exceed it. The response to price change depends upon the price level associated with each customer's marginal unit of demand; no general relationships can be formulated for an entire sector. The best approximation which can be devised to represent this behavior is based upon subdividing each sector into a number of customer classes, assumed homogeneous, then treating each class separately. Such a change would require a complete revision of the simulation model used in this study.

Although the increasing-block policy was not simulated, its general characteristics can be predicted with the aid of the results already obtained. Since the objective of the policy is to discourage summer sprinkling demands associated with single-family residences, the rate structure can be simplified greatly by using uniform prices for all sectors except single-family residences. These uniform prices could be the same as those calculated for the uniform pricing policy, Alternative A, and the contributions of apartment, commercial, industrial and institutional users to water and sewer demands would remain unchanged.

The first block size for the affected customers (single-family residential customers) should approximate the normal winter usage for that class of customers. For example, the winter residential demand in 1977, under a uniform price of $1.40 per 1000 gallons, is forecast at 235 gallons per day per connection, or about 43,000 gallons per six-month billing period. If the first-block price is less than the uniform price, for example, $1.30 per 1000 gallons, the winter demand would rise slightly to about 240 gallons per day per connection, or almost 44,000 gallons per a six-month period. The second-block price can then be set at a level which will provide the desired incentive for water-saving. A second-block price of $2.00 per 1000 gallons would reduce sprinkling usage from 8400 gallons per year to 4700 gallons, and would reduce the average residential water bill by about $6.00 per year. The overall impact of this arrangement, again based on the year 1977, is a 1.9 percent decrease in summer usage and in maximum day demand, and a 0.8 percent increase in the winter contribution to sewer flow. Total water usage is reduced approximately 1.3 percent.

This analysis refers only to customers who purchase water and sewer services at levels very close to the average for the sector. Those who use less water will be affected only slightly, if at all, by the block rate structure described. Customers who use large quantities of sprinkling water will be faced with large increases in their total bills unless they reduce consumption significantly.

It is impossible to trace the total impact of such a policy without detailed simulation of the type described above. The only conclusion which can be drawn in the absence of such an analysis is that the effect of an increasing-block rate structure applied to residential customers is similar to that of seasonal pricing, with two exceptions: (1) the impact of winter contributions to sewer flow is less marked since only the residential sector of customers is involved, and (2) the impact on maximum day demands can be increased without encountering serious equity problems because of the specificity of the higher rate (i.e., it affects only the upper fraction of residential use). An overall assessment of this alternative indicates that, pending further investigation, it appears to retain the claimed advantages of seasonal pricing (lower water capital costs), while avoiding a portion of the disadvantages noted in the previous section (higher sewer capital costs). The increasing-block policy has the further advantage of avoiding major implementation costs, such as those associated with seasonal pricing.

AVERAGE VARIABLE COST PRICING

The rate-making policy now used by the WSSC provides for the recovery of most costs associated with "basic main facilities" through the commodity charge, or price. This cost category makes up more than one-third of the revenue requirement now met through commodity charges. An alternative policy, one used by many utilities, is to base the commodity charge on the variable costs of providing water and sewer service (operating and maintenance costs) and recover capital costs through higher fixed service charges or assessments. The implementation of such a policy would result in substantially lower price levels, and corresponding higher demands.

Figures IV-7, IV-8 and IV-9 demonstrate the effect of average variable cost pricing on water demands and sewer flows. In the first two cases, average variable cost pricing (Alternative G) substantially increases average day water demands and maximum day demands. The average winter contribution to sewer flow is also markedly increased. These effects result in a large increase in capital costs, shown in Table IV-1 as a $118 million increase in present value over that associated with the existing policy. The price levels required by this policy are plotted on Figure IV-10 where they remain much below those forecast on the basis of existing policy.

The overall impact of average variable cost pricing can best be illustrated in Table IV-2. Average residential customers will, under average variable cost pricing in year 1977, tend to use about 6.5 percent more water and will pay a total water bill (for the year) which is 5.5 percent higher. This result is accompanied by higher water demands, higher sewer flows, and substantially increased investment requirements.

FLAT-RATE SEWER SERVICE CHARGES

Another rate-making policy in common use throughout the United States is the practice of recovering all costs associated with sewerage service through a fixed charge. The commodity charge, under this scheme, would be used to recover the operating and maintenance costs of the water supply system, as well as the major share of water capital costs. As in the case of the average variable cost pricing alternative, this policy results in substantially lower commodity charges and higher fixed charges.

Figures IV-7, IV-8 and IV-9 illustrate the increased average day water demands, maximum day water demands, and average winter contributions to sewer flow which result from a system of flat-rate sewer service charges (Alternative I). These increases are generally slightly less than those associated with the average variable cost pricing alternative. The price level, as shown on Figure IV-10, remains somewhat less, or approximately equal to that required for average variable cost pricing. The present value of the capital investment stream required by this policy rises more than $114 million over the value associated with the existing rate-making policy (see Table IV-1).

Table IV-2 illustrates the effect of flat-rate sewer charges on the individual "average" residential customer. The cost each year of the quantity of water purchased falls from $131.60 to $56.83, although the quantity rises from 94,000 gallons to 109,000 gallons. The average fixed charge, however, rises from $11.20 per year to $100.62 per year. This results in a total annual water bill which is almost ten percent higher than that expected under existing policy.

APPENDIX A

PREPARATION OF BASE FORCASTS OF POPULATION AND HOUSING STOCK

INTRODUCTION

Chapter III of the accompanying report describes the data and assumptions required to operate the Water/Sewer Utility Simulation Model. Among these requirements are base forecasts of population and of customer connections. The connection forecast must be disaggregated by the type of customer: single-family residential, garden apartment, high-rise apartment, commercial/industrial, and institutional. The connection forecast is combined with a forecast of water use per connection to prepare a base forecast of water demand, given a static rate schedule. Since the preparation of detailed forecasts of the number of residential connections is not usually a step in the conventional development of demand forecasts, this Appendix has been prepared to outline the methodology employed.

Briefly, a method was developed for estimating the number of residents per housing unit in single-family dwellings and in apartments. Forecasts were prepared of future population and of the proportionate mix of housing stock. These were combined with the resident-per-dwelling estimates to produce forecasts of housing units, which were then converted to base forecasts of residential connections.

RESIDENTS PER HOUSING UNIT

Residents of the portions of Montgomery and Prince Georges counties served by the WSSC live in at least four types of housing units: single-family dwellings (detached, semi-detached and row-type); multiple-family dwellings smaller than garden apartments (converted single-family dwellings, flats, etc.); garden apartments (walk-up apartment buildings of not more than three floors); high-rise apartments (apartment buildings of more than three floors, usually elevator-equipped).

The second type of housing unit, multiple-family dwellings, is difficult to define precisely; available data suggest that at this time it represents an insignificant fraction of the housing stock of the WSSC service area. The classification, for purposes of preparing base forecasts, was, therefore, reduced to three main types: the single-family residence, the garden apartment, and the high-rise apartment. In the analysis of population per dwelling unit, no distinction was made between the types of apartments, resulting in two categories of dwelling units to be analyzed: single-family residences and apartments in the general sense.

The only source of detailed housing data for the study area is the U.S. Census of Housing, conducted decenially. Data on total population figures, total number of housing units, and fraction of total housing units which are apartments, are available for many of the population centers within the study area for the years 1940, 1950, 1960 and 1970 (in part). Tables A-1 and A-2 list these data according to service area district. The

Table A-1
Average Population per Dwelling Unit – 1940-1970

Area	1940	1950	1960	1970
District 10	4.0	3.0	2.7	n.a.
District 50	n.a.**	n.a.	3.5	3.4
District 60	4.0	n.a.	3.5	3.2
Prince Georges County	4.2	3.6	3.7	n.a.
District 20	3.6	3.2	3.0	2.6
District 30	n.a.	n.a.	3.3	2.7
District 40	n.a.	n.a.	3.5	3.1
District 70	n.a.	n.a.	n.a.	3.1
District 80	n.a.	n.a.	3.4	n.a.
Montgomery County	3.9	3.5	3.6	n.a.
TOTAL SERVICE AREA	4.0	3.6	3.6	3.3

---

*Data were obtained by dividing appropriate U. S. Census count of resident population by total number of dwelling units in area.

**n.a. = Population, housing count, or both, were unavailable for consistent areas.

Table A-2
Fraction of Total Housing Units Which Are Apartments – 1940-1970

Area	1940	1950	1960	1970
District 10	.47	.33	.75	n.a.
District 50	n.a.**	.36	.37	.43
District 60	.21	.31	.28	.44
Prince Georges County	.16	.36	.35	.43
District 20	.40	.43	.52	.59
District 30	n.a.	n.a.	.30	.45
District 40	n.a.	n.a.	.21	.24
District 70	n.a.	n.a.	n.a.	.43
District 80	n.a.	n.a.	.37	.30
Montgomery County	.14	.20	.20	.30

---

*Data were obtained by dividing appropriate U. S. Census count of number of apartment units by total number of housing units for each area.

**n.a. = Data unavailable for same area.

count for each district was obtained by combining data for all population centers listed in the Census which fall in that district. In some cases no census data were available for particular districts. The county data, where used, refer to the entire counties.

A linear regression model provided estimates of the average number of persons per dwelling unit, by type of unit, for each of the districts and counties. Reliable estimates were obtained for both counties and for one district (District 20). These are given in Table A-3. Further testing revealed that the average number of persons residing in each category of dwelling unit has evidently not changed significantly in the thirty-year period analyzed. The falling overall average number of persons per dwelling unit shown on Table A-1 is fully accounted for by the rise in the fraction of total units which are apartments, shown on Table A-2. The estimates presented in Table A-3, then, appear suitable for projections of these parameters, since they have not changed noticeably during the last three decades.

Table A-3
Estimates of Population per Housing Unit By Type of Unit

Area	Population per Single-family unit	Population per Apartment unit
Prince Georges County	4.80	1.64
Montgomery County, except District 20 (Takoma Park)	4.44	1.05
District 20 (Takoma Park)	4.87	1.47

POPULATION FORECASTS

Population forecasts for each of the study areas were obtained in the following way. WSSC records were used to estimate the total number of residential connections for 1970 and U.S. Census Bureau data to estimate: (1) the fraction of these connections that are single-family residential, and (2) the average size of the apartment complexes (units per complex) connected. This produced estimates of single-family units and apartment units. The unit population figures given in Table A-3 were then used to estimate the 1970 population for each area.

U.S. Census Bureau data provided the total population figures for Montgomery and Prince Georges counties for the years 1940, 1950, 1960 and 1970. These data were employed to prepare growth rate forecasts for each of the areas under study. These growth rates were applied to the 1970 estimates described above in order to obtain population forecasts for each area (see Table III-13 in the main text of this report). In the case of the smaller districts, the allocation of growth among districts was relatively arbitrary. The larger districts were assumed to follow the growth patterns of the county.

HOUSING MIX

Based on the historical growth trends in single-family/apartment mix, as shown in Table A-2, these fractions were projected into the future. The current mix of high-rise/garden apartments was estimated from WSSC billing records, and assumptions were made concerning the trend of this ratio into the future. In general, denser areas are assumed to have relatively high growth rates for high-rise apartments, while less dense areas are expected to maintain high growth rates for garden apartments.

These two forecasts were combined to develop a forecast of the fraction of all housing units that will fall into each of the three categories. The population forecasts and unit population estimates (Table A-3) were the base for preparing forecasts of the number of housing units expected within each category for each area each year.

RESIDENTIAL CONNECTION FORECASTS

The final step in the forecasting procedure is to prepare assumptions regarding the average number of units in each type of apartment complex. As larger and more modern complexes gradually replace older, smaller facilities, this average size can be expected to rise. In a few cases, a district is already dominated by some very large complexes; future average size may be approximately constant, or may decrease. Separate assumptions were made for each type of apartment and for each area, then combined with the forecast number of housing units by type of housing to create a base forecast of residential connections by area and by type of dwelling unit (see Table III-7 in the main text).

APPENDIX B

A WATER/SEWER UTILITY SIMULATION MODEL

STATEMENT OF THE PROBLEM

The development of an appropriate rate-making policy for a public water/sewer utility is a complex task. An effective policy must assure that costs will be recovered in the long run, without excessive short-run surpluses or deficits, and it must be relatively straightforward in implementation. The prices determined under such a policy must not appear arbitrary or capricious, and price differentials existing between various groups of consumers must, in general, appear reasonable to members of those groups. Beyond these requirements for feasibility, it might be hoped that the rate-making policy be one which produces the "right" prices– those which result in efficient utilization of the water resource. Policy development techniques and criteria currently in use do not permit full assessment of the economic implications of alternative rate-making policies, so whether or not one produces a "better" price than another cannot be known in advance. This Appendix describes a method of evaluating rate-making policies, using computer simulation, which yields quantitative comparisons of a variety of price-related effects.

A rate-making policy consists, in its simplest form, of that set of criteria, conventions, or guidelines which are used by a utility to decide when rates are to be changed and what the structure and level of the new rates will be. In most cases, existing policy includes provision for a two-part rate structure (usually made up of a variety of fixed charges, assessments, taxes, etc., and a commodity charge), a set of conventions which determine those portions of the total cost to be recovered through fixed charges and through commodity charges, specific criteria which trigger a rate review, and a standard calculus for setting new rates.

Alternative rate-making policies may be constructed by altering these considerations in several ways. Fixed charges may be eliminated entirely, or the fraction of total cost recovered through them can be changed. Decreasing-block, increasing-block, or uniform rate structures may be used. Rate reviews can be initiated at more or less frequent intervals. The rate-setting calculus can be modified to provide for average cost pricing, marginal cost pricing, zoned prices, or seasonal prices. Each of these possibilities can be implemented in various ways. Any complete set of such options comprises a distinct rate-making policy, which can be expected to produce effects on demand, cost, and revenue unique to that policy.

THE SIMULATION MODEL

The operation of the simulation model can be illustrated with the aid of Figure B-1, a simplified flow diagram. Starting with the present time, water demands, costs and revenues are forecast for each year, based on the rate structures now in effect. Simulated rate reviews are conducted as required, and the rate structure is recalculated in accordance with the rate-making policy assumed to be in use. The actual operation of the model rests on a number of structural and behavioral assumptions concerning water/sewer utilities and their customers. The principal assumptions are reviewed here. Variable names used in this discussion are generally the same as those actually used in the computer program, but occasionally they differ in the interest of clarity.

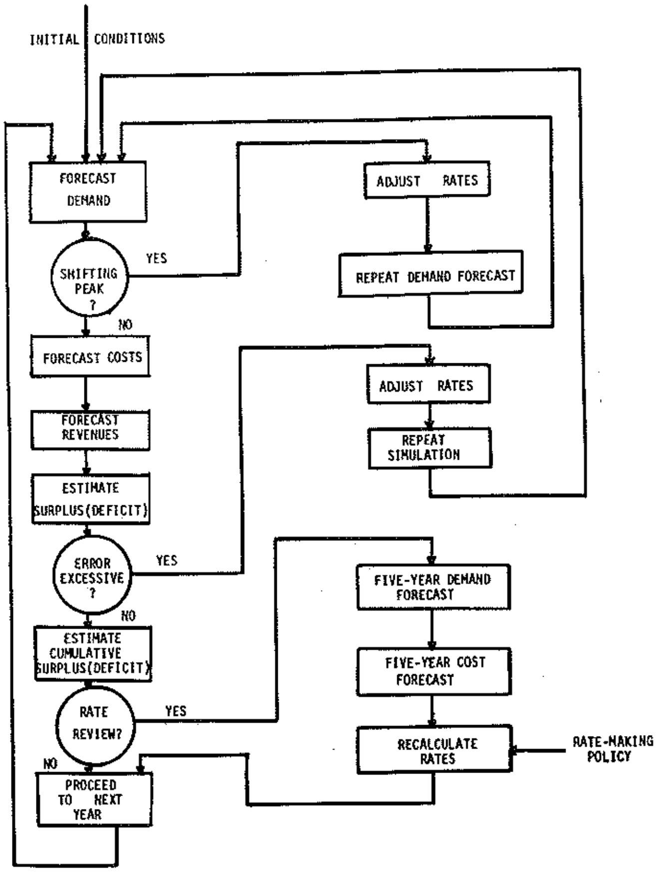


Figure B-1
Flow Chart of Simulation Model

Demand Forecasts

The simulation model begins with a base forecast of average and maximum day water demands. Average demands are disaggregated into seven sectors: single-family residential sprinkling, single-family residential domestic, garden apartments, high-rise apartments, commercial/industrial, institutional, and public/unaccounted; as well as two seasons: winter and summer. These base forecasts reflect increasing population growth and changing tastes, but not price change. The current rate structure is implicit throughout the forecast period. So long as the rate structure is unchanged, the base forecast is taken as the final forecast.

After the first price change occurs, the following method is used to adjust average water demands:

$$QA(i,j) = \left[\frac{PM(i,j)}{PM(i,j)}\right]^{EL(i,j)} \star QT(i,j) \qquad \text{(B-1)}$$

where: $QA(i,j)$ = forecast average water demand for season i, sector j (MGD)
$QT(i,j)$ = base forecast of average water demand for season i, sector j (MGD)
$PM(i,j)$ = price in effect for water and sewer in season i, sector j ($/1000 gal.)
$PM(i,j)$ = price implicit in base forecast for season i, sector j ($/1000 gal.)
$EL(i,j)$ = price elasticity of demand assumption for season i, sector j

Maximum day water demands are calculated for each year as follows:

$$QM(k) = 1.55 \star QC(k)^{1.012} \qquad \text{(B-2)}$$

where: $QM(k)$ = forecast maximum day demand for year k (MGD)
$QC(k)$ = sum of forecast average demands for year k (MGD)

The expected contribution to sewer flows can be estimated from the disaggregated water demand forecasts. This is done by making appropriate assumptions regarding the fraction of each sector and seasonal water use which is returned to the sewer.

Cost Forecasts

Costs are estimated separately in two categories: operation, maintenance and administration costs, also known as variable costs; and capital, or capacity costs. Operation, maintenance and administration costs include all those cost items which vary with the quantity of water actually sold, the quantity of sewage removed, or the number of customers actually serviced. Capital costs, on the other hand, are related to the capability to provide water and sewer service, and are treated as fixed costs in the short run. They consist almost entirely of the cost of physical plant.

Variable costs are estimated each year as a function of the average and maximum day demands experienced that year, as well as the population served and the average number of persons served per customer account. The following estimating model is used:

$$CV(k) = 1.267 \star \overset{CF \star}{QD(k)^{-1.112}} \star QM(k)^{.3489} \star 6\ SP(k)^{.614} \star SC^{-.4233} \qquad \text{(B-3)}$$

where: $CV(k)$ = operation, maintenance and administration costs for year k ($/MG)
CF = Conservation factor to adjust cost model to local conditions
Conversion
$QD(k)$ = sum of forecast average demands for year k (MGD)
$SP(k)$ = Service area population in year k
SC = average number of persons per service connection

Capital costs are derived from base forecasts prepared of anticipated capital expenditures for water and sewer facilities. These forecasts are converted to annual charges by estimating a nominal life for each facility and amortizing the investment over that period. One method of accomplishing this would be to use the mean service life of the facility, taking the opportunity cost of capital to the utility as a discount rate. In order to conform more closely to actual rate-setting practices, data used in a simulation might be based on time horizons and discount rates implicit in municipal bonding practices. This overstates somewhat the magnitude of the capital charges during period of growth. Since this treatment is uniform for all policy alternatives analyzed, it should not affect the results in any substantive way.

The amortization procedure results in separate time streams of annual capital charges for the water and sewer facilities, respectively. These base forecasts are assumed to be implicitly related to the base forecasts of maximum day water demand, in the case of water costs; and of average day water demand in the case of sewer costs. As the base forecasts of demand are altered, the table of capital charges is interpolated to obtain revised capital costs appropriate to the new demands. Capital investment is assumed to be sufficiently divisible at this level of aggregation to permit such a procedure. One constraint placed on the interpolation is that annual capital charges are never permitted to fall below the level of the most recent year. This condition follows from the long-run nature of these costs.

Total costs for each year can be derived as follows:

$$CX(k) = CC(k) + [CV(k) \star \overset{BC\ \$}{QD(k)} \star 0.36525] \qquad \text{(B-4)}$$

where: $CX(k)$ = Total costs for year k ($1000)
$CC(k)$ = annual capital charges for water plus annual capital charges for sewer, both for year k ($1000)

Revenue Forecasts

Two categories of revenues are employed: fixed revenues (derived from all non-commodity charges) and variable revenues. Variable revenues are those obtained from commodity charges levied on each unit of water sold or sewage collected. The method of calculating revenues is as follows:

$$RF(k) = FF \star CC(k) \qquad \text{(B-5)}$$

where: $RF(k)$ = estimated fixed revenue for year k ($1000)
FF = fraction of fixed costs recovered through fixed charges of all types

$$RV(i,j) = PM(i,j) \star QA(i,j) \star 182.625 \qquad \text{(B-6)}$$

where: $RV(i,j)$ = variable revenue for season i, sector j ($1000)

$$RX(k) = RF(k) + \sum_i \sum_j RV(i,j) \qquad \text{(B-7)}$$

where: $RX(k)$ = total revenue for year k ($1000)

The use of a fixed factor for estimating fixed revenues reflects the customary practice of levying fixed charges to fully

NOT ALL FIXED REV. COMES FROM CUSTOMERS

recover specific categories of capital cost, such as distribution water mains, collecting sewers, and individual connections. An implicit assumption is that these categories remain an essentially constant fraction of total capital cost. It should be noted that FF = 0.0 corresponds to long-run marginal cost (LRMC), or average long-run cost pricing, and that FF = 1.0 is equivalent to average variable cost pricing. Jurisdictions which extract a surplus from utility operations may have $FF<0.0$, and in certain heavily subsidized operations, it is possible that $FF>1.0$. Proper choice of this variable appears to be an adequate means of describing a utility's policy toward cost recovery, even if in a relatively simplistic manner.

Surplus (Deficit) Estimates

The calculation of surplus for each year is straightforward:

$$SX(k) = RX(k) - CX(k) \qquad (B\text{-}8)$$

where: SX(k) = surplus (deficit is negative) for year k ($1000)

It should be noted that this definition of surplus does not include any surplus or deficit considered a normal part of the cost recovery policy by the utility. Situations of this kind sometimes arise where local governments operate the water/sewer utility and either subsidize them from general tax revenues or expect them to return surpluses to the general fund. In these cases, the desired performance is simulated by proper choice of the variable FF, described above, and the surpluses obtained by Equation B-8 are excess quantities beyond those considered normal.

A cumulative surplus is also computed, beginning with the base year, adding all surpluses and subtracting all deficits as they appear. This quantity is used to determine trigger points for rate review.

Rate Adjustments

The simulation model provides for two types of rate adjustment outside the normal rate review procedure. These adjustments are related to shifting peak demands and to excessive errors in calculated rates. The first case arises when seasonal prices are employed: the normal rate review process produces a relatively large change in price. Under some conditions, the summer price may be sufficiently high, and the winter price sufficiently low; the forecast demands, then, exhibit a shifting peak with winter demands exceeding summer demands. In such a case, peak-load pricing theory requires that summer prices be reduced and winter prices increased until seasonal demands are equal, or summer demands just exceed winter demands. In the simulation model, prices are adjusted by a small increment until this condition is obtained. Such an adjustment can ordinarily be expected to occur in the first year following a major adjustment of seasonal rates.

RE-WORD

The second type of adjustment is employed whenever the surplus or deficit generated in a single year exceeds some pre-set limit. In the present formulation, the surplus (deficit) is not permitted to exceed 15 percent of the annual capital cost in any given year. This constraint is imposed to reflect the heuristic nature of actual rate-setting processes—utility managers can be expected to exercise sufficient judgment to avoid gross errors in rates, even when strict application of rate-setting formulae might lead to such errors. Should the simulation program produce a rate structure which causes surplus (deficit) to exceed the limit, the rate is adjusted iteratively, by small increments, until the constraint is no longer violated. The simulation then proceeds using the adjusted price rather than the one originally calculated.

These adjustment procedures are not intended to be essential components of the model, but merely to help avoid specific circumstances leading to unrealistic results. In practice, they seldom are required in the absence of large and abrupt changes in costs or demands, or other conditions which contribute to model instability.

Rate Review Trigger Points

Two criteria are used to determine whether or not rates will be reviewed before the next year's operation is simulated. Rates are reviewed when:

a. five years have elapsed since the last review; and
b. the cumulative surplus or deficit exceeds levels set by the model user.

The second criterion (b) recognizes that, although most utilities are reluctant to adjust rates frequently because of adverse customer reaction, they will feel obliged to do so when an imbalance of costs and revenues reaches a certain size.

When one of these two conditions is satisfied, the simulation program branches into a rate review procedure. This results in the new rates being calculated, replacing those previously in use. The main simulation program then proceeds to the next year, computing demands and revenues on the basis of the new rates.

Rate Review Procedure

Two major components are used in the rate review process: five-year forecasts of demands and costs; and a rate-making rule. The five-year forecasts are obtained by a curve-fitting technique applied to the original base projection of average demand. Beginning with the current forecast water demand (forecast on the basis of current prices), the exponential growth rate implied by the next five years of the base projection is used to generate a five-year forecast. This procedure ignores price elasticity of demand, a customary simplification in such forecasts.

The five-year forecast of average water demand is used to prepare similar forecasts of costs, using the techniques outlined above. These estimates are represented by:

(QAVT-WV6) = current five-year forecast of average water demand (MGD) (Net of public/unaccounted uses)
CFYV = current five-year forecast of variable costs ($1000)
CFYC = current five-year forecast of capital costs ($1000)

[illegible]

Two rate-making rules are contained in the model: uniform pricing and seasonal pricing. The uniform rule operates as follows:

$$PREQ = \frac{CFYV + (1.0 - FF) \star CFYC - CS}{(QAVT\text{-}WV6) \star 365.25} \qquad (B\text{-}9)$$

where: PREQ = revised average rate ($/1000 gal.)
CS = cumulative surplus (deficit) ($1000)

$$\text{PAVE} = \frac{(\text{WV2} + \text{WV3})}{(\text{WV4} + \text{WV5}) \star 182.625} \qquad \text{(B-10)}$$

where: PAVE = actual average rate in year ($/1000 gal.)

(WV4 + WV5) = summer plus winter water demands less public/unaccounted uses (MGD)

(WV2 + WV3) = total revenue received from commodity charges

Now:

$$\text{P(i,j)} = \frac{\text{PREQ}}{\text{PAVE}} \star \text{P(i,j)} \qquad \text{(B-11)}$$

P(i,j)?

In this manner, rates are set to approximately break even over the next five years, given the forecasts of demands and costs employed. Furthermore, any cumulative surplus or deficit that may exist is included in the calculus, so that it may be netted out within the same time period.

The seasonal rate-making rule operates in a similar manner, except that costs are distributed in a different manner between seasons. All relevant capacity costs are allocated to the summer demands, with variable costs spread over both seasons. The winter seasonal rate is determined as follows:

$$\text{PRQW} = \frac{\text{CFYV} - \text{CS}}{365.25 \star (\text{QAVT} - \text{WV6})} \qquad \text{(B-12)}$$

where: PRQW = revised average winter rate ($/1000 gal.)

The summer rate requirement is obtained from:

$$\text{PRQS} = \text{PRQW} + \frac{(1.0 - \text{FF}) \star \text{CFYC}}{182.625 \star (\text{QSMT} - \text{WV8})} \qquad \text{(B-13)}$$

where: PRQS = revised average summer rate ($/1000 gal.)

(QSMT-WV8) = forecast of average summer water demand for year (net of public/unaccounted uses) (MGD)

Current average rates are calculated by dividing winter and summer revenues by winter and summer revenue-producing demands, respectively. The ratios of PRAW and PRAS to the winter and summer average rates currently in effect produce new rates for each season and sector, as shown by Equation B-11.

The most obvious deficiency of these rate-setting rules is the simplistic manner in which they estimate future demands and costs. The technique selected was not intended to produce especially accurate results, but to approximate the results obtained by the application of conventional rate-setting procedures. These procedures frequently omit explicit consideration of price elasticity and employ forecasts of demands and costs which may prove to be rather inaccurate. Conventional practice possesses the advantages, however, of relative ease of application in a variety of circumstances and of avoiding any appearance of arbitrariness or obscurity, an essential virtue if the resulting rates are to find public acceptance. If more sophisticated rate-setting techniques could be devised which would retain these advantages, they could easily replace those given above, and the simulation model could be used to determine whether any real advantage could be expected from their use.

STRUCTURE OF THE SIMULATION MODEL PROGRAM

It is not necessary, in order to use the model, to understand the details of the program, nor the theory of its operation. However, a minimal understanding of the general flow of logic within the programs will aid in intelligent use of the model.

Two separate computer programs are required to use the simulation model. The first program should be designed to receive data from the user and record it in a disk file. The second program, called "SIMUL," reads the data from the disk file and solves the simulation problem. The only communication between the two programs is by means of the disk file written by the first program and read in by "SIMUL."

The data handling program is designed for each application to take data from a tape or on-line mode and store it in the designated disk file. Eash data array (e.g., QP) may be accepted separately by the program. After each array has been accepted, the program should print the data array and allow the user to re-enter the array for corrections if necessary. This option is useful if the user finds he has made a typing error or that there has been a data tape transmission error. After all the data arrays are accepted, the program stores them on the designated disk files. The dimensions in this program must be compatible with the dimentions in "SIMUL," which is currently dimensioned for a simulation study period of 30 years; with simple manipulations of the dimension statements, wide flexibility in the time horizons being considered is allowed.

"SIMUL" performs the simulation on the problem specified by the data in the disk file and certain control variables added by the user during operation. Table B-2 is a list of the principal variables and arrays used in this program. The last section of this Appendix is a complete listing of the program.

The initial values needed for the simulation program are as follows:

PM(1,1), PM(1,2), PM(1,3), PM(1,4)
PM(2,1), PM(2,2), PM(2,3), PM(2,4)
QP array
CZ array
CY array
SP array
QT array
CON array
SM
SN
FF
CF
EL array

Table B-2
List of Variables

VARIABLE	DEFINITION
QA(i,j)	Average daily water demand for each season i and sector j (MGD)
QM(k)	Forecast maximum day water demand for year k (MGD)
EL(i,j)	Price elasticity of demand assumption for season i and sector j
PM(i.j)	Price in effect in season i, sector j ($/1000 gal.)
QT(i,j)	Base forecast of average water demand for season i, sector j (MGD)
CV(k)	Operation, maintenance, and administrative costs for year k ($/MG)
CF	Conversion factor to adjust to local conditions
SP(k)	Service area population in year k
SC(k)	Mean population per service connection in year k
CC(k)	Annual capital charges for water plus annual capital charges for sewer, both for year k ($1000)
FF	Fraction of fixed costs recovered through charges of all types
RF(k)	Estimated fixed revenue for year k ($1000)
RX(k)	Total revenue for each year ($/year)
CX(k)	Total costs for year k ($1000)
SX(k)	Surplus (deficit) for year k ($/year)
SM	Maximum size of cumulative surplus permitted without rate revision ($)
SN	Maximum size of cumulative deficit permitted without rate revision (-$)
CS	Cumulative surplus
CY(k)	Initial projection of water capital costs for year k ($/year)
CZ(k)	Initial projection of sewer capital costs for year k ($/year)
QP(k)	Initial projection of maximum day demand for year k (MGD)
QAVE(M)	Average daily water demand for all sectors for each year M used in setting rates, temporary working array (MGD)
CFYC	Aggregate capital costs for temporary five-year forecast - working variable
CFYV	Aggregate variable costs for temporary five-year forecast - working variable
QAVT	Aggregate average demand for temporary five-year forecast - working variable
QSMT	Aggregate summer demand for temporary five-year forecast - working variable

VARIABLE	DESCRIPTION
RFYV	Aggregate variable revenue requirement for temporary five-year forecast - working variable
QTS(k)	Total average water demand in all sectors except public unaccounted for year k
SWR(n)	Working variable
WTR(n)	Working variable
QAS(k)	Total average water demand in all sectors for year k
CON(q)	Total number of service connections in year (5 * (q-1))
WTQ(j)	Temporary forecast of winter water demand for sector j - working variable
STQ(j)	Temporary forecast of summer water demand for sector j - working variable

NOTE: The simulation program uses a two-season year (summer and winter).

Seasons are numbered sequentially, two for each year. For example, the QT matrix is dimensioned as QT(60,4), which means that season 9 and 10 represent year 5.

PROGRAM LISTINGS

```
%USE-SIMUL
10 DIMENSIØN CC(30)
20 DIMENSIØN CV(30)
30 DIMENSIØN CX(30)
40 DIMENSIØN CY(31)
50 DIMENSIØN CZ(31)
60 DIMENSIØN EL(2,7)
70 DIMENSIØN QTS(35)
80 DIMENSIØN PM(62,6)
90 DIMENSIØN QA(70,7)
100 DIMENSIØN QAVE(5)
110 DIMENSIØN QM(35)
120 DIMENSIØN QP(35)
130 DIMENSIØN QAS(30)
140 DIMENSIØN QT(70,7)
150 DIMENSIØN RF(30)
160 DIMENSIØN RX(30)
170 DIMENSIØN SP(35)
180 DIMENSIØN SX(30)
190 DIMENSIØN SWR(5)
200 DIMENSIØN WTR(5)
210 DIMENSIØN CØN(8)
220 DIMENSIØN SC(40)
230 DIMENSIØN WTQ(7),STQ(7)
240 EQUIVALENCE (QA(1,1),QT(1,1))
250 WRITE (0,901)
```

```
260 901 FØRMAT(1X,"FIRST FILE NAME")
270 READ (0,903)AA
280 903 FØRMAT(A6)
290 902 FØRMAT(1X,"SECØND FILE NAME")
300 WRITE (0,902)
310 READ (0,903)BB
320 ØPEN 10,FILE=AA
330 READ (10)SP,CY,CZ,EL,((PM(I,J),J=1,6),I=1,2),IND1,JJ1
340 CLØSE 10
350 ØPEN 11,FILE=BB
360 READ (11)QT,QP,CØN,PUR,IND2,JJ2
370 CLØSE 11
380 DØ 10 IYEAR=1,35
390 J=(IYEAR+4)/5
400 ZK=IYEAR-1-(J-1)*5
410 SC(IYEAR)=ZK*0.2*(CØN(J+1)-CØN(J))+CØN(J)
420 10 SC(IYEAR)=SP(IYEAR)/SC(IYEAR)
430 830 FØRMAT(1X,"MAX. CS PERMITTED")
440 WRITE (0,830)
450 ACCEPT SM
460 860 FØRMAT(1X,"MIN. CS PERMITTED")
470 WRITE (0,860)
480 ACCEPT SN
490 890 FØRMAT(1X,"FF")
500 WRITE (0,890)
510 ACCEPT FF
520 920 FØRMAT(1X,"CF")
530 930 FØRMAT(1X,"CFF")
540 WRITE (0,920)
550 ACCEPT CF
560 WRITE (0,930)
570 ACCEPT CFF
580 950 FØRMAT(1X,"INDICATØR")
590 WRITE (0,950)
600 ACCEPT IND
610 CYT1=0.0
615 LL=0
620 CS=0.0
630 CZT1=0.0
640 DØ 80 I=1,35
650 DØ 79 K=1,6
660 79 QTS(I)=(QT(2*I-1,K)+QT(2*I,K))/2.+QTS(I)
670 80 QTS(I)=QTS(I)/(1.-PUR)
680 CØRR=0.0
690 DØ 999 L=1,30
700 ZZ=0.0
710 IF (L.GE.3)CF=CFF
720 IF (L.GE.4)ZZ=2.5
730 IS1=2*L-1
740 IS2=2*L
750 110 DØ 115 K=1,6
760 WTQ(K)=((PM(IS1,K)/PM(1,K))**EL(1,K))*QT(IS1,K)
770 STQ(K)=((PM(IS2,K)/PM(2,K))**EL(2,K))*QT(IS2,K)
780 115 CØNTINUE
790 STQ(7)=((PM(IS2,1)/PM(2,1))**EL(2,7))*QT(IS2,1)
800 WV1=0.0
810 WV2=0.0
```

```
820 WV3=0.0
830 DØ 120 K=1,6
840 WV1=WV1+WTQ(K)
850 WV2=WV2+STQ(K)
860 120 WV3=WV3+STQ(K+1)
861 IF (LL.EQ.L)GØ TØ 130
870 IF (WV2.GE.WV1)GØ TØ 130
880 CØRR=CØRR+(0.5*CC(L-1))
890 L=L-1
900 IS1=IS1-2.
910 IS2=IS2-2.
920 GØ TØ 337
930 130 CØRR=0.0
931 LL=L
970 QAS(L)=(WV1+WV2)/(2.*(1.-PUR))
980 WV=(WV1+WV3)/(2.*(1.-PUR))
990 QM(L)=1.5*(WV**1.012)
1000 CV(L)=(1.267*(QM(L)**0.3489)*(SP(L)**0.614)*CF)/((SC(L)**0.4233&
)*(QAS(L)**1.112))
1010 DØ 135 I=1,30
1020 IF (QP(I).GT.QM(L))GØ TØ 140
1030 135 CØNTINUE
1040 140 IF (I-1)145,145,150
1050 145 CYT=CY(1)
1060 GØ TØ 155
1070 150 CYT=CY(I-1)+(CY(I)-CY(I-1))*(QM(L)-QP(I-1))/(QP(I)-QP(&
I-1))
1080 155 CØNTINUE
1090 DØ 165 I=1,30
1100 IF (QTS(I).GT.QAS(L))GØ TØ 170
1110 165 CØNTINUE
1120 170 IF (I-1)175,175,180
1130 175 CZT=CZ(1)
1140 GØ TØ 185
1150 180 CZT=CZ(I-1)+(CZ(I)-CZ(I-1))*(QAS(L)-QTS(I-1))/(QTS(I)-&
QTS(I-1))
1160 185 IF (L.EQ.3)CZT=CZ(3)
1170 IF (L.EQ.4)CZT=CZ(4)
1180 IF (CYT.LT.CYT1)CYT=CYT1
1190 IF (CZT.LT.CZT1)CZT=CZT1
1200 CC(L)=CYT+CZT
1230 CX(L)=CC(L)+0.36525*WV*CV(L)
1240 RV1=0.0
1250 RV2=0.0
1260 DØ 190 K=1,6
1270 RV1=RV1+PM(IS1,K)*WTQ(K)*182.625
1280 190 RV2=RV2+PM(IS2,K)*STQ(K)*182.625
1290 RF(L)=FF*CC(L)
1310 WV=RV1+RV2
1320 RX(L)=WV+RF(L)
1329 DISPLAY L
1330 SX(L)=RX(L)-CX(L)
1331 PP=SX(L)/CC(L)
1332 IF (PP.GT.0.15)GØ TØ 191
1333 IF (PP.LT.-0.15)GØ TØ 192
1334 GØ TØ 199
1335 191 PF=-0.05
```

```
1336 GØ TØ 193
1337 192 PF=0.05
1338 193 DØ 195 K=1,6
1339 PM(IS1,K)=PM(IS1,K)+PF
1340 195 PM(IS2,K)=PM(IS2,K)+PF
1341 L=L-1
1343 GØ TØ 215
1344 199 CS=CS+SX(L)
1345 DØ 132 K=1,7
1346 QA(IS1,K)=WTQ(K)
1347 132 QA(IS2,K)=STQ(K)
1348 CYT1=CYT
1349 CZT1=CZT
1350 IF (CS.GT.SM)GØ TØ 220
1360 IF (L.LE.4)GØ TØ 220
1370 IF (SN.GT.CS)GØ TØ 220
1380 IF (IS1-8)205,205,200
1390 200 IF (PM(IS1,1).EQ.PM(IS1-8,1))GØ TØ 220
1400 IF (PM(IS2,1).EQ.PM(IS2-8,1))GØ TØ 220
1410 205 DØ 210 K=1,6
1420 PM(IS1+2,K)=PM(IS1,K)
1430 210 PM(IS2+2,K)=PM(IS2,K)
1440 215 CØNTINUE
1450 999 CØNTINUE
1460 GØ TØ 350
1470 220 Y=0.0
1480 IF (L.EQ.2)CF=CFF
1490 DØ 225 M=L,L+5,1
1500 225 Y=Y+LØG10(QTS(M))
1510 XY=0.0
1520 DØ 230 M=L+1,L+5
1530 230 XY=XY+LØG10(QTS(M))*LØG10(M-L+1)
1540 B=(2.4142*XY)-1.1497*Y
1550 DØ 240 M=1,5
1560 QAVE(M)=QAS(L)*((FLØAT(M+1))**B)
1570 240 CØNTINUE
1580 WV=0.0
1590 DØ 245 M=1,5
1600 245 WV=WV+(QAVE(M)**0.2411)*(SP(L+M)**0.614)
1610 CFYV=0.54305*(SC(L)**(-0.4233))*CF*WV
1620 CFYC=0.0
1630 DØ 300 M=1,5
1640 DØ 250 I=1,30
1650 IF (QAVE(M)-QTS(I))255,250,250
1660 250 CØNTINUE
1670 255 IF (I-1)260,260,265
1680 260 SWR(M)=CZ(1)
1690 GØ TØ 270
1700 265 SWR(M)=CZ(I-1)+(CZ(I)-CZ(I-1))*(QAVE(M)-QTS(I-1))/(QTS&
(I)-QTS(I-1))
1710 270 WV=(QM(L)/QAS(L))*QAVE(M)
1720 DØ 275 I=1,30
1730 IF (WV-QP(I))280,275,275
1740 275 CØNTINUE
1750 280 IF (I-1)285,285,290
1760 285 WTR(M)=CY(1)
1770 GØ TØ 300
1780 290 WTR(M)=CY(I-1)+(CY(I)-CY(I-1))*(WV-QP(I-1))/(QP(I)-QP(&
```

```
I-1))
1790 300 CFYC=WTR(M)+SWR(M)+CFYC
1800 QAVT=0.0
1810 WV6=0.0
1820 WV8=0.0
1830 DO 305 M=1,5
1840 305 QAVT=QAVT+QAVE(M)
1850 WV4=0.0
1860 WV5=0.0
1870 DO 70 K=1,6
1880 WV4=WV4+QA(IS1,K)
1890 70 WV5=WV5+QA(IS2,K)
1900 DO 306 K=L+1,L+5
1910 WV6=WV6+(QTS(K)*PUR)
1920 306 CONTINUE
1930 IF (IND)205,310,325
1940 310 RFYV=CFYV+(1.-FF)*CFYC-ZZ*CS
1950 PAVE=(RV1+RV2)/((WV4+WV5)*182.625)
1960 PREQ=RFYV/((QAVT-WV6)*365.25)
1970 WV7=PREQ/PAVE
1980 IF (L.EQ.1)WV7=1.4285
1990 DO 320 K=1,6
2000 PM(IS1+2,K)=PM(IS1,K)*WV7
2010 PM(IS2+2,K)=PM(IS2,K)*WV7
2020 320 CONTINUE
2030 GO TO 215
2040 325 WV=0.0
2050 DO 330 M=L+1,L+5
2060 DO 330 K=1,6
2070 330 WV=WV+QT(2*M,K)
2080 WV=WV/(1.-PUR)
2090 WV8=PUR*WV
2100 WV1=0.0
2110 DO 335 N=L+1,L+5
2120 335 WV1=WV1+QTS(N)
2130 QSMT=(WV/WV1)*QAVT
2140 PAVW=RV1/(WV4*182.625)
2150 PAVS=RV2/(WV5*182.625)
2160 337 CONTINUE
2170 PRQW=(CFYV-ZZ*CS+CORR)/((QAVT-WV6)*365.25)
2180 PRQS=PRQW+(((1.-FF)*CFYC)-CORR)/((QSMT-WV8)*182.625)
2190 WV9=PRQW/PAVW
2200 WV10=PRQS/PAVS
2210 IF (L.EQ.1)WV9=1.4285
2220 IF (L.EQ.1)WV10=1.4285
2230 DO 340 K=1,6
2240 PM(IS1+2,K)=PM(IS1,K)*WV9
2250 340 PM(IS2+2,K)=PM(IS2,K)*WV10
2260 GO TO 215
2270 350 CONTINUE
```

```
2410 625 WRITE (0,606)FF,SM,SN,CF
2420 606 FØRMAT(1X,"FF=",F4.2,2X,"SM=",F8.2,2X,"SN=",F8.2,2X,"CF=",F&
6.2)
2430 WRITE (0,607)
2440 607 FØRMAT(1X,"YR",2X,"QA(1)",4X,"QA(2)",4X,"QA(3)",4X,"QA(4)",&
4X,"QA(5)",4X,"QA(6)",4X,"QA(SN)")
2450 DØ 650 I=1,30
2460 WVB=0.0
2470 WVA=0.0
2480 J=2*I-1
2490 JK=2*I
2500 DØ 640 K=1,6
2510 WVB=WVB+QA(JK,K)
2520 640 WVA=WVA+QA(J,K)
2530 WVB=WVB/(1.-PUR)
2540 WVA=WVA/(1.-PUR)
2550 WRITE (0,908)I,(QA(J,K),K=1,6),WVA
2560 WRITE (0,909)(QA(JK,K),K=1,6),WVB
2570 908 FØRMAT(1X,I2,1X,7(1X,F8.3))
2580 909 FØRMAT(4X,7(1X,F8.3))
2590 650 CØNTINUE
2600 652 FØRMAT(1X,"YR",4X,"CV",8X,"CC",8X,"CX",8X,"QM")
2610 653 FØRMAT(1X,I2,4(F9.2,1X),F6.3)
2620 654 FØRMAT(1X,"YR",4X,"RV",8X,"RF",8X,"RX",8X,"SX")
2630 WRITE (0,652)
2640 DØ 670 I=1,30
2650 670 WRITE (0,653)I,CV(I),CC(I),CX(I),QM(I)
2660 WRITE (0,654)
2670 DØ 675 I=1,30
2680 WVA=RX(I)-RF(I)
2685 PP=SX(I)/CC(I)
2690 675 WRITE (0,653)I,WVA,RF(I),RX(I),SX(I),PP
2700 WRITE (0,677)
2710 677 FØRMAT(1X,"YR",6X,"1",9X,"2",9X,"3",9X,"4",9X,"5",9X,"6")
2720 678 FØRMAT(1X,I2,6(1X,F9.3))
2730 679 FØRMAT(3X,6(1X,F9.3))
2750 750 DØ 760 I=1,30
2760 WRITE (0,678)I,PM(2*I-1,1)
2770 760 WRITE (0,679)PM(2*I,1)
2780 DISPLAY CS
9999 END
%KEY
```

APPENDIX C

THE WATER/SEWER UTILITY SIMULATION MODEL AS A PLANNING TOOL

THE PLANNING PROBLEM

Planning is an important function in any well-managed organization. In a water/sewer utility which serves a growing service area, it is particularly important since water/sewer utilities comprise the most capital intensive major industry in the United States; i.e., the utilities require the highest capital investment per employee. Total investment typically exceeds annual revenues by more than five times, and the investment commitments must often precede actual needs by many years. The planning of future additions to system capacity (facility planning) must be accurate and thorough if the system is to be engineered soundly and be efficient in operation, in order to meet adequately all demands on that system. At the same time, the planning of rate-making policy, funding sources, operations, etc. (financial planning), cannot be neglected if the utility is to retain the ability to construct needed facilities and to operate existing facilities in the most efficient manner.

Although these two planning activities--facilities and financial--are often conducted separately, they are of course closely inter-related. The estimates of future system demands, the most important aspect of facilities planning, are influenced by the rate-making policy and price levels determined in the financial planning process. The financial planners, in turn, must base much of their work upon the capital improvements program developed by facilities planners. Less obvious, but perhaps more important, are the many linkages between individual planning activities: operating cost forecasts require assumptions regarding the design of future treatment plants; programming major improvements requires some knowledge of capital fund availability, etc. Effective planning, from the utility's point of view, requires a high level of communication between individuals engaged in these two types of planning.

The Water/Sewer Utility Simulation Model has been designed to trace the effects of any change in rate-making policy throughout all aspects of utility operation: systems demands, investment requirements, funding requirements, revenue availability, etc. It requires many highly explicit assumptions regarding the characteristics of the utility service area and the utility itself. For this reason, the same model can be used to estimate the effect of changing any of the assumptions. This capability suggests an additional application of the model as a planning tool, where it can serve as a communication link between facility and financial planners. Changes in the programming of capital improvements, when inserted into the model in the form of revised estimates of capital costs, result in changes in total costs, in the prices of water/sewer service, in the demands for that service, and in facility requirements. This provides the financial planners with a preliminary estimate of the impact of a new improvement program on existing financial plans. At the same time, it informs facility planners of the feasibility of the program revisions. Changes in financial operations may be related to shifting requirements for system capacity as well. The following sections describe in more detail several specific uses of the simulation model as a planning tool.

FACILITY PLANNING APPLICATIONS

The planning of physical facilities in water and sewerage systems is related to two types of requirements: (l) the expected levels of water usage and sewer flow which determine the capacity of major treatment and transmission facilities; and (2) the spatial pattern of system development which determines the design of distribution and collection systems. Forecasts of water and sewage flows are customarily obtained from predictions of service area population, which are combined with assumptions regarding per capita water demand or per capita sewage generation, producing forecasts of aggregate water use and sewage flow. Distribution and collection system additions are normally analyzed on an individual basis, and are not the subject of generalized forecasting procedures.

The Water/Sewer Utility Simulation Model requires individual forecasts of customer connections, disaggregated by demand sector and by geographical location (where possible), and of expected water use per each type of connection. Appendix A describes a technique for developing connection forecasts from population forecasts. The detailed nature of these forecasts require the planner to answer many questions that are normally embedded in the forecasting process. He must predict the fraction of the population which resides in single-family dwellings, in garden apartments, and in high-rise apartments; he must make separate estimates of the number of commercial/industrial and institutional establishments to be served. In this way, areas having rapidly changing land-use patterns will be associated with water and sewer flow forecasts which reflect these changes. The specification of water use per connection for each demand sector and at five-year intervals allows consideration of trends in unit water use, either upward or downward. Each of these parameters may be investigated by making several alternate assumptions and noting the overall impact of each.

Whatever set of assumptions may be employed, it is possible for the planner to determine the full range of implications (including facility and investment requirements, resulting price levels, maximum day water demand and sewer flow estimates, etc.) over a thirty-year period. Since this can be done for as many subdivisions of the service area as required, the future behavior of the system can be modeled in considerable detail.

FINANCIAL PLANNING APPLICATIONS

A major application of the Water/Sewer Utility Simulation Model in the financial planning sphere is that described in the body of the report--rate-making policy evaluation. Other potential applications can be described which are of comparable importance. Two of these are well illustrated by the current financial planning of the WSSC. The simulations described in this report were based on an assumption of sharply increasing capital and operating costs, especially those associated with the sewerage system, during the next several years. The abrupt change assumed in these simulations created a number of instability problems, as seen in the figures in Chapter IV, which affect the period 1972-1977 inclusive. The behavior predicted by the simulation model for these years would not be tolerable in practice; it would be the function of financial planners to spread the impact of predicted cost increases so that large shifts in demand or customer behavior would be avoided.

To solve such a problem, planners might re-examine construction schedules which would result in more accurate estimates of the rate of increase of capital cost. The timing of rate changes could be altered to provide for more gradual transitions to higher levels. Initial assumptions of instantaneous changes in operating costs are not usually borne out in practice; more careful study of start-up schedules might result in modified assumptions. All of these factors can be reflected in the data provided to the simulation model, and the simulation repeated until the desired system behavior is obtained. Such methods have many advantages over conventional approaches that depend heavily on experience and intuition, one advantage being the direct and quantitative nature of the assumptions. As new information becomes available or as operating experience is accumulated, it can be factored into the planning process directly without loss of content.

Another application of the simulation model for financial planning concerns the availability of Federal grants for facility construction. Most utility planners have struggled with the fluctuating availability of Federal funds for such purposes as sewage treatment plant construction. Forecasts and rate-making policy based on the availability of such funds often leave the utility in a difficult position if their availability suddenly becomes restricted. On the other hand, if all planning is based on the assumption that no funds will be forthcoming, rates would be set too high and fiscal policy would be unnecessarily conservative. The simulation model permits the development of contingency plans, or financial plans, based on various possible levels of Federal aid; the utility can adjust rapidly and smoothly from one level to another, without foreclosing options prematurely.

CONCLUSIONS

As familiarity with the operation and capability of the simulation model is obtained, many other applications may suggest themselves. A general word of caution must be added regarding the use of models in planning, however. The results of a simulation of the type described here must never be regarded as *answers;* they are merely *estimates* which, when interpreted properly, may provide insight into the nature of the answers to the problem posed. In this sense, a simulation model is no different from any other computational aid available to the planner. In the final analysis, the experience and judgment of the planner, drawing on all readily obtainable information, must provide the answers. The simulation model has the capability to organize the data in such a way as to extend greatly the planner's ability to utilize the information in his deliberations.

APPENDIX D

RESIDENTIAL WATER-SAVINGS MEASURES AND THEIR EFFECT ON RATE-MAKING POLICY

THE POTENTIAL FOR WATER SAVINGS

In October 1971 the Washington Suburban Sanitary Commission published an official statement of policy calling for a coordinated, aggressive effort to promote water conservation throughout the Commission's sanitary district (WSSC, 1971). Three major reasons have been cited for this action: limited fresh-water resources; rising cost of water supply and wastewater disposal services; and the need to minimize wastewater quantities (WSSC, 1972). An important part of the WSSC's water conservation program is the proposed use of the Suburban Maryland Plumbing Code, enforced by the WSSC, to promote the installation of water-saving plumbing fixtures. Furthermore, a recent publication of the WSSC, "A Customer Handbook on Water-Saving and Wastewater-Reduction," lists many currently available techniques for reducing water use within an average home (WSSC, 1972).

The purpose of this brief discussion is to review the literature on the effectiveness of water-saving measures and the relationship of their use to rate-making policy formulation. Information on the impact of in-house water-saving devices and techniques is sparse and highly variable in quality. The most comprehensive and carefully researched study to date is that recently completed for the National Water Commission by Charles W. Howe (Howe, 1970). A related report appeared this year in the Journal of the American Water Works Association (Howe and Vaughan, 1972). A systems study of water conservation measures performed for the Office of Water Resources Research by Hittman Associates, Inc., also contains some useful data on the function of specific water-saving devices (Hittman Associates, 1969).

A major deficiency in the data reported by all investigators to date is that it refers to isolated uses of specific appliances and fixtures, but does not reflect actual use conditions. For example, reducing the water requirement of a toilet from 5 to 3 gallons per flush may be assumed to produce a corresponding decrease in water demand for that particular use. If the modification required to accomplish this reduction, however, interferes with the flushing action of the toilet, then the result may be an increased number of flushes which partially or completely nullifies the expected savings.

The true effect of fixture innovations related to water-saving can only be determined by metering individual fixture units in representative residences as part of a planned research study on a large-scale. Since no such study has been reported to have been undertaken, any claims regarding water savings for specific fixtures must be regarded as only approximate; estimates of overall water savings utilizing such approximations should be made conservatively.

Examination of fixture specifications reveals a wide range of water requirements. Toilets currently on the market require between 3.2 and 8 gallons per flush, as received from the manufacturer. Automatic clothes washers use between 32 and 59 gallons per 8-pound load. Automatic dishwashers may require as little as 6 gallons, and as much as 12.9 gallons, per load, according to some studies. During a review of appliance specifications in the preparation of the Hittman report (Hittman Associates, 1969), it was noted that the water requirements of automatic clothes washers and dishwashers have tended to rise over the years, as performance standards have become more stringent and wash cycles more complex.

Howe (Howe, 1970) has suggested that installation of all currently available water-saving devices might reduce domestic water use by approximately 32 percent. Such a result implies, of course, no reduction in the actual or perceived efficiency of operation of any of the appliances or fixtures. In the latter instance, the net reduction in water use is more difficult to predict; however, it should be somewhat less than 32 percent.

WATER SAVINGS AND RATE-MAKING POLICY

Domestic water use reductions of 20 to 30 percent are most significant to a water/sewer utility which serves a predominantly residential area. Table D-1 lists the present water use and sewer flow contribution in the WSSC service area. It can be verified that a 20 percent reduction in water use--when applied to domestic residential, garden apartment and high-rise customers--would result in a 13 percent reduction in water use and a 15 percent reduction in the contribution made by those same customers to sewer flow. [The "Residential, domestic," "Apartment, garden," and "Apartment, high-rise" categories total 86.3 MGD water use and 83.4 MGD sewer flow. A 20 percent saving in each of these totals is 17.3 MGD and 16.7 MGD, or 13 percent of total water use and 15 percent total sewer flow.]

Table D-1
Water Use and Sewer Flow Contribution by Use Sector, Washington Suburban Sanitary Commission, Fiscal Year 1972

Water Use Sector	WATER USE*	% TOTAL USE	CONTRIBUTION TO SEWER FLOW*	% TOTAL CONTRIBUTION
Single-Family Residential:				
DOMESTIC	55.9	41	55.9	51
SPRINKLING	15.4	11	-0-	-0-
Apartments, GARDEN	22.9	17	21.6	20
Apartments, HIGH-RISE	7.5	6	6.9	6
Commercial/ Industrial	12.0	9	10.7	10
Institutional	8.8	6	8.2	7
Public/Unaccounted**	13.6	10	6.8	6
TOTALS	136.1	100	110.1	100

NOTES: * Millions of gallons per day; on a 12 month average.
** Assumed to be 10% of total water use.

Such major changes in water use and sewer flow result through shifts in demand curves for water and sewer services. Figure D-1 illustrates, in greatly simplified form, such a shift. Curve A-A' represents the demand curve for water use prior to the installation of water-saving fixtures. When the price is set at Level P, the quantity demanded is equal to Q_a. It can be noted that if the price rises, the quantity demanded falls, as predicted by the "law of demand." Changes in water price cause changes in the quantity demanded through the movement along A-A', but not in the demand function itself.

Following the installation of water-saving devices, however, water users find that they can obtain the same service with the use of a smaller quantity of water. For any given price, users will now demand a smaller quantity of water. On Figure D-1, this phenomenon is represented by a shift from demand curve A-A' to demand curve B-B'.

The role of water-saving measures in rate-making policy formulation can be simply illustrated by the following example: in Figure D-2, where demand curve A-A' is in effect, price P_1 will lead a quantity Q_1 being demanded. Should the water utility increase the price to level P_2, the quantity demanded will fall to Q_2, in accordance with the demand curve A-A'. This reduction may be the result of water-saving measures voluntarily implemented by customers to avoid the effect of higher prices. However, an alternative strategy might be to require the installation of these devices without increasing the price. Should such regulation succeed in shifting the demand curve to position B-B', it can be seen that the effect of the regulation is to produce a demand for quantity Q_2 at the original price, P_1.

In cases where the quantity demanded is quite unresponsive to price (e.g., institutional uses), the demand curves are nearly vertical on plots similar to D-1 and D-2. In such cases, a shift in the demand curve through regulation is likely to produce larger reductions in quantity demanded than would normal changes in price. Water uses with a more horizontal demand curve (e.g., residential, sprinkling) might respond more readily to a pricing policy than to regulation.

The computer simulation program described in this report offers a convenient technique for evaluating proposed water-saving regulations. The impact of the regulations must be estimated in terms of a shift in the base forecast of demand employed by the simulation program. Once this is done, a simulation can be made and compared to a similar one which used the original base forecast. Regulations directed specifically at areas known to be insensitive to price incentives (e.g., rental housing, apartments, institutional uses) can be expected--after all factors have been considered--to produce the most favorable results. Differences in the fiscal position of the utility resulting from the shift in the base forecast can be compared to the cost of implementation of the proposed regulations, resulting in useful criteria for selecting or rejecting specific proposals.

The use of the simulation model permits the simultaneous consideration of changes in the investment stream, in revenues, in operating costs, and in the impact on specific groups of water customers. All of these factors, together with the cost of implementation of the water-saving proposal and the expected changes in water use and sewer flow, permit a comprehensive evaluation of specific water-saving measures which is fully consistent with the rate-making policy of the utility.

Figure D-1
Shifting Demand Curves

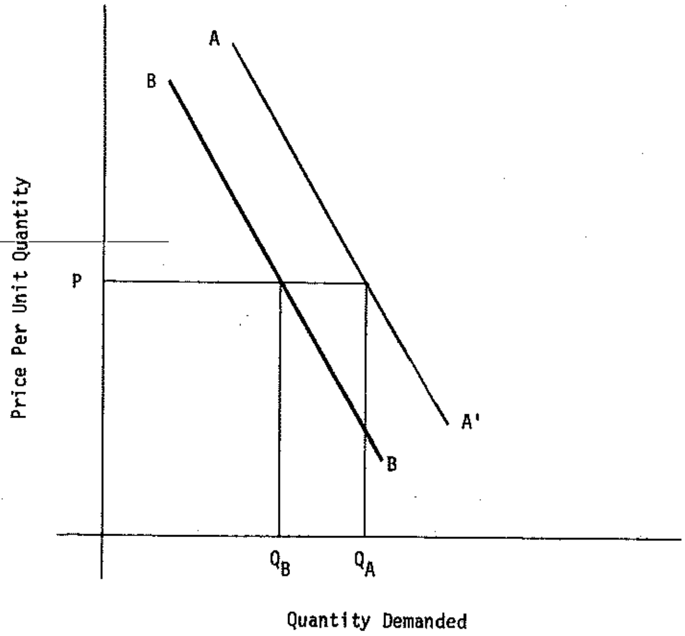
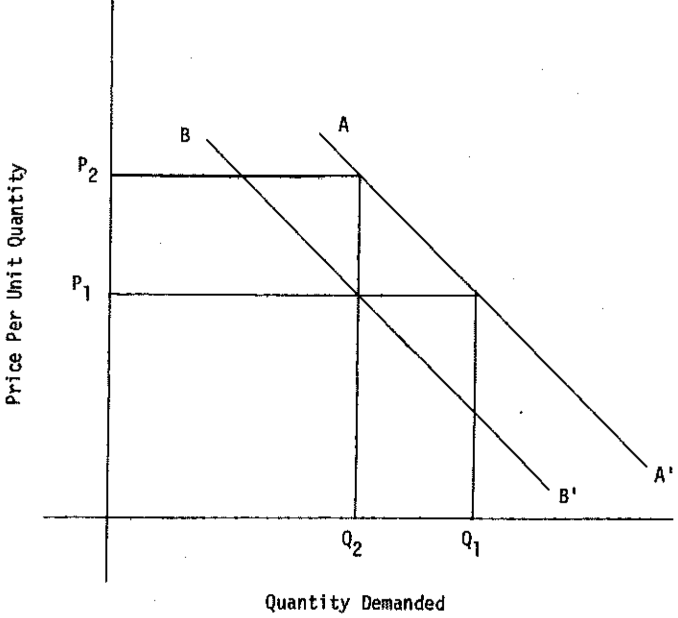


Figure D-2
Quantity Reduction Alternatives



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