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The report is based on a review of both published and unpublished water demand forecasting literature providing an annotated description of each including reference.

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AN ANNOTATED BIBLIOGRAPHY ON TECHNIQUES OF FORECASTING DEMAND FOR WATER

by

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A Report Submitted to the

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PREFACE

The planning and management of urban water resources are increasingly constrained by primarily four major forces. First, there are environmental constraints in the procurement of additional supply. Second, a new set of problems have been created with the passage of recent laws and regulations. Institutional and legal problems of interbasin transfers have proliferated, and public concern for environmental quality has resulted in the new legislation, such as the Federal Water Pollution Control Act Amendments (1972), the Safe Drinking Water Act of 1974, and the Clean Water Act of 1977. Third, the costs of water resource development have been rising rapidly, exacerbated by an increase in energy costs and the costs of money. Fourth, the demand for urban water continues to rise, especially in those urban areas experiencing rapid growth as the southwestern United States.

One consequence of these trends has been the need to develop new techniques of planning and methods of evaluation, such as the formulation and recent revision of the Principles and Standards for Planning Water and Related Land Resources by the U.S. Water Resources Council and the Planning Process: Multiobjective Planning Framework by the U.S. Corps of Engineers. More recently and specifically has been the development of a methodology to evaluate the role of conservation in municipal and industrial water supply planning which has served to broaden the focus from supply-side measures to include the potential opportunities of demand reduction.

The potential savings from precision in estimating future urban water use are obvious. And, because of the need to measure the effectiveness of potential water conservation measures in order to evaluate the role of conservation in the development of an urban water supply plan, new and more responsible approaches of disaggregated demand forecasts are mandatory.

The purpose of this volume is to provide field planners with the currently available and relevant literature on forecasting demand of municipal and industrial water. This volume consists of a detailed abstract of 83 journal articles, books, theses, dissertations, or research reports: only those sources considered meritorious and useful have been selected.

We wish to acknowledge the suggestions and guidance by the members of the OCE Water Conservation Task Force in the preparation of this volume.

TABLE OF CONTENTS

1. Anderson, William B. "An Economic Approach to Water Supply Planning in Southeastern Virginia." Ph.D. dissertation, Virginia Polytechnic Institute and State University, 1978.

The author has performed cost-benefit analyses for the provision of various levels of water supply for 4 Virginia cities. The analyses utilize water-use projections developed by the United States Army Corps of Engineers through the year 2030 and estimates of water-use demand elasticities obtained from the literature.

2. Andrews, R. A., and M. R. Hammond. Characteristics of Household Water Consumption in Three New Hampshire Communities. Durham: Water Resources Research Center, University of New Hampshire, December 1970.

This report presents the results of a residential water-use study based on billing records and interviews of 361 households in Durham, Epping, and Portsmouth, N.H. Average daily per capita water use was found to be 42, 52, and 59 gpcd for these cities, with standard deviations of 22, 26, and 22 gpcd respectively.

3. AWWA Committee on Water Use. "Trends in Water Use." Journal of the American Water Works Association 65, no. 5 (May 1973) :285-99.

This article reports and discusses the results of a survey of water-use data for 94 individual utilities across the United States during the period 1960-70. The purpose of this analysis was to assess current trends in customer (household, business establishment, industry, etc.) water consumption in order to assist in the projection of future water requirements.

The total customer water-use data for each utility were disaggregated by three customer categories, i.e. residential, commercial, and industrial or larger nonindustrial customers. In the next step the data were spatially reaggregated into eastern and southern, central, and western regions of the United States.

Total overall average water use (expressed in gallons per customer per day) for all areas was found to be increased over the period of investigation for all customer categories.

4. AWWA Committee on Water Use. "Review of the Johns Hopkins University Research Project Method for Estimating Residential Water Use." Journal of the American Water Works Association 65, no. 5 (May 1973):300-301.

This article reviews the 1966 John Hopkins University residential water-use research report for possible practical application in estimating average and peak residential water use in individual communities.

The committee's conclusion is that the applicability of this method for estimating total future residential water requirements of a particular city may be subject to question for a number of reasons mostly related to nonavailability of all required data. It recommends further research on its application.

5. AWWA Task Group. "Study of Domestic Water Use." Journal of the American Water Works Association 50, no. 11, (November 1958):1408-18.

This paper presents the results of the study of the AWWA Task Group on the effect of climate and family income on residential water use for the period of 1936-56, based on the data for 113 water systems in the United States.

The authors were primarily concerned with daily variations in peak demands, since these parameters are of basic importance in designing water-supply systems.

6. Batchelor, R. A. "Household Technology and the Domestic Demand for Water." Land Economics 51, no. 3 (August 1975):208-23.

In this paper an analytical model of household water demand is developed which takes account of the accumulation of water using durable goods.

The author proposes a demand function of the form: $x_i = g(W_i, N_i, P_i, b_i) + \sum_{j_i y_i \in y^T} a_{ij} \Delta f_j (W_i N_i, P_i, b_i)$, where x_i = total water use in household i (annual); W_i = wealth of household i; N_i = number of occupants; P_i = price of water; a_{ij} = binary variables indicating the presence of absence of the appliance used in each activity $y_j \in y^T$, where y^T represents the set of activities y_i liable to appliance innovation; b_i = vector of binary variables indicating the presence or absence of certain static technological features (such as existence of inside baths or toilets, etc.). The g and Δf_j stand for functions relating total and incremental water demands to the above listed variables; Δf_j relates to the activities due to the presence of "dynamic" technological features. Both functions are assumed linear and stochastic.

The parameters of the model are estimated based on a random sample of 1,388 households in Malvern, United Kingdom. Of the total number, 698 households provided appropriate data which, among others, included total water consumption in 1968, net annual property value (proxy for real income), the number of occupants, and the number and type of 5 water-using appliances (washing machines, cars, dishwashers, showers, and garden sprinklers). The estimates of domestic water consumption by those appliances, and estimates of basic demand for all other purposes, are compared with those obtained in other studies.

The effect of the accumulation of these consumer durables on the level of water use over time is also discussed, however, without empirical time-series analysis. Noteworthy is the discussion of statistical experimental design for water demand models. Although the purity of the proposed approach has much intellectual merit, its practical usefulness in demand forecasting seems low. This is mainly due to the absence of many important variables in demand function.

7. Baumann, D. D., D. Dworkin, S. Sebastian, B. Andrews, and D. Holtz. Planning Alternatives for Municipal Water Systems. Indianapolis, Ind.: Holcomb Research Institute, Butler University, 1976. 61 pp.

This book presents a valuable summary of current and future planning alternatives for municipal water systems. It discusses the most critical aspects of forecasting water demand and water supply, including the economic and social aspects of balancing supply and demand.

8. Berry, Dale W., and Gilbert W. Bonem. "Predicting the Municipal Demand for Water." Water Resources Research 10, no. 6 (December 1974):1239-42.

This article presents the results of regression analysis relating per daily water use to per capita income. The analysis is based on a mixture of cross-sectional and time-series aggregated data (7 New Mexico cities and 23 separate years) and has yielded the regression equation $q = 25.1 + 0.059_y$ with $R^2 = 0.766$, where q is the municipal water use (gpcd) and y is the annual per capita personal income in 1965 dollars.

In 1974 similar analysis was performed for 1970 data for 16 New Mexico cities and towns, and the regression equation was practically identical to the above. The coefficients of water rate (expressed as the charge per 1,000 gallons in the last applicable block) and the population of the city were not statistically significant with even 90% confidence. Sprinkling requirements were also found to be insignificant.

9. Billings, R. Bruce, and Donald E. Agthe. "Price Elasticities for Water: A Case of Increasing Block Rates." Land Economics 56, no. 1 (February 1980):73-84.

The authors of this paper use 2 price related variables in order to avoid the biased estimates of price elasticity which result when average price is used for block rate schedules. These variables are used together with income and 2 measures of the weather variability to construct the water demand model of the general form: Q = f(P,D,S,Y,W,). The dependent variable Q measures monthly water consumption of the average household (100 cubic feet), while P = marginal price facing the average household (¢/100 cubic feet), Y = personal income per household ($/month), and W = evapotranspiration minus rainfall (inches).

Quantitative relationships of either linear or log-linear form were estimated for monthly data from January 1974 to September 1977 obtained from the Tucson (Ariz.) Department of Water and Sewers.

This is a valuable analysis of residential water demand, since it takes account of marginal prices and it also defines precisely all variables used in the demand model.

10. Bobee, B., P. Boucher, and H. Demard. "A Method for Estimating Peak Water Demand for Multifamily Residences." Water Resources Bulletin 16, no. 4 (August 1980):729-37.

The authors of this article have investigated the relationships between peak water demand and building size (number of apartments), and also available water pressure, for 17 apartment residences in the city of Sainte-Foy.

The main practical result of the study is the dependence of the peak demand on the square root of size (number of apartment units) and the cube root of water pressure. Three simple regressions between characteristics of peak demand, for return periods of T = 1 year, 1 month, and 1 week, and number of apartment units in the building are presented.

11. Bogue, Stuart H. "Trends in Water Use." Journal of the American Water Works Association 55, no. 5 (May 1963):548-54.

In this article the author makes some general comments about the use of municipal water, based on generalized data from the Detroit metropolitan area. The following factors that affect water use were identified: (1) size and type of community, (2) location, (3) water quality, (4) pressure, (5) sewers, (6) metering (7) age of community, (8) lawn sprinkling, (9) cost, and (10) air conditioning. The author has not attempted to analyze these factors in greater detail.

12. Boland, John J. "The Micro Approach--Computerized Models for Municipal Water Requirements." In Treatise on Urban Water Systems, edited by Albertson et al., pp. 295-316. Fort Collins: Colorado State University, 1971.

This article is drawn from a lecture given at the Institute on Urban Water Systems at Colorado State University in June 1970. It consists of a general discussion of water-use forecasting, followed by a detailed exposition of the MAIN II forecasting system, as developed by Hittman Associates, Inc. Since the MAIN II system estimates water use from demographic and socioeconomic data only, it can be used to backcast, where water use estimated for an earlier period is compared to known water use for the same period. Boland presents the results of a number of backcasts, including 1 for Baltimore, Md., 6 for Park Forest, Ill., 1 for Baton Rouge, La., and 1 for a housing development in Anne Arundel County, Md. Errors ranged from 0.4% for Baltimore and 0.8% for Baton Rouge to as much as 16% for one attempt to backcast commercial use in Park Forest. The use of the forecasting system is illustrated for the new town of Columbia, Md. Data requirements are discussed, and forecast results for the year 2000 are presented.

13. Boland, John J. "Forecasting the Demand for Urban Water" In Municipal Water Systems: The Challenge for Urban Resource Management, edited by D. Holtz and S. Sebastian, pp. 91-114. Bloomington: Indiana University Press, 1978.

This paper, like the others in this volume, was first presented at a conference held at French Lick, Ind., in October 1976. It contains a discussion of various approaches to forecasting urban water use and describes criteria for choosing an appropriate forecasting method. Major stress is given to the observation that forecasting error of any kind is likely to lead to excess costs, whether forecasts are too high or too low.

The second part of the paper summarizes some empirical observations of relationships between water use and certain explanatory variables, including population, number of connections, weather, price, and income. An argument is made for replacing population with number of connections (or of households) and for disaggregating water use by customer class as well as by season.

Detailed water-use data obtained for the Washington Suburban Sanitary Commission service area are used to illustrate these points. Boland reaches the following conclusions:

1. Water use is better correlated with number of customer connections than with resident population.

2. Significant differences in the nature of water use exist among the various categories of users.

3. Individual water use within a class is subject to great variability.

4. All classes of water use can be highly seasonal in nature.

5. Economic variables, including water price and water-user income, are important factors in explaining water use.

14. Boland, John J. "The Requirement for Urban Water--A Disaggregate Analysis." In Annual Conference Proceedings, American Water Works Association, 24-29 June, pp. 51-66. San Francisco, Calif., 1979.

This paper describes the need for better understanding of the requirement for urban water. Improved explanation of water use is prerequisite to improved water-use forecasting methods. Forecasting applications are discussed, including conventional long-range forecasts. Boland also describes the use of short-range forecasts (for financial planning, for example) and the application of forecasting techniques to the analysis of specific perturbations in future water use (alternative futures).

Present knowledge of the structure of urban water use is summarized. Improved approaches to estimating and forecasting water use are contrasted to present practices, yielding recommendations on subjects ranging from basic data collection to forecasting methods themselves. An extensive bibliography is provided.

15. Boland, John J., Philip H. Carver, and Charles R. Flynn. "How Much Water Supply Capacity Is Enough?" Journal of the American Water Works Association 72, no. 7 (July 1980):368-74.

This paper discusses the application of risk management techniques to urban water-supply planning. It is argued that, rather than apply standard rules of thumb to obtain supply requirements, water utility managers should attempt to balance the economic, social, and environmental cost of providing increased capacity against the risk and cost of water-use restrictions. In particular, utilities may develop drought management plans which can be used to replace the last, most expensive increments of supply capacity. The paper describes a study performed by the authors for Ecological Analysts, Inc., as a part of a larger investigation for the Washington Suburban Sanitary Commission. In that study, probabilistic forecasts of water-supply deficits were developed from water-use forecasts and statistical analysis of supply data. The water-use forecast methods are not discussed in detail in this article, although several of the demand models are presented. The development of alternative drought management plans is reviewed, and the use of those plans, together with the deficit forecasts, to analyze supply augmentation requirements is discussed in detail.

16. Boland, John J., and Charles W. Mallory. "Comments on 'Residential Water Demand Forecasting' by Peter W. Whitford." Water Resources Research 9, no. 3 (June 1973):768-70.

This comment contains some clarification and expansion of Whitford's review of the Main II forecasting model, developed by Hittman Associates, Inc., as part of a research effort supported by the Office of Water Resources

Research. The authors also present the procedure to be followed in using the MAIN II system. This procedure permits the water-supply planner to perform sensitivity analysis for a given set of assumptions (used in generating a forecast) through repetitive application of the MAIN II algorithm.

17. Boland, John J., Steve H. Hanke, Richard L. Church, and Philip H. Carver. An Examination of Alternate Rate-Making Policies for the Washington Suburban Sanitary Commission. Baltimore, Md.: Rivus, Inc., 1975, 198 pp.

This report describes an analysis, using computer simulation of 3 alternative rate-making policies for the WSSC: a uniform charge, a uniform charge with a summer surcharge, and an increasing-block rate system. The report also discusses means available for compliance with EPA regulations affecting sewer rate structures as they existed in 1975.

The computer simulation incorporated a disaggregate projection of water use, separately considering 5 different user categories as well as sprinkling use in each of 3 different population density zones. Projections were made a function of, among other things, the applicable water price faced by each customer group. When block-type rate structures were considered, customers were further disaggregated by use block. Existing operating and capital costs faced by the WSSC were modeled and forecast. The computer simulation calculated a rate structure at selected intervals, based on the estimated revenues and costs projected by the mode. Results included forecasts of number of customers, average day water use, maximum day water use, contribution to sewer flow, water costs, sewer costs, total revenue, and rate levels. These forecasts were available for each year of the forecast period, and for each of the chosen rate-making policies. Information was also available regarding the incidence of rate changes on customers at various percentile ranks in each category's water-use distribution.

Rate-making policies were compared and evaluated on the basis of their likely impact on future operations, the incidence of rate changes on various customers, their relative ability to track changes in costs, implementation characteristics, and conformance with EPA regulations. Based on this analysis, the consultants recommended that the uniform charge system then employed be retained. The report also contains considerable statistical data on individual water use within the WSSC service area.

18. Browne, David W., Gary Minton, and Clyde Barnhill. "Forecasting Water Demand in the Pacific Northwest." Journal of the American Water Works Association 72, no. 9 (September 1980):506-7.

This short article discusses possible reasons for the apparent leveling off of per capita demand for municipal water. The analysis is based on the aggregated water-use data of several cities in Oregon and Washington for the period of 1970-80.

The authors observe that there actually is a general leveling or even decrease in the average growth rate of per capita consumption. This trend is explained as the result of (1) recent trend away from declining block rate structures toward uniform water rates, (2) saturation of the market for washing machines and dishwashers, while older machines are replaced with more efficient models, (3) increase in the construction of multifamily residences, and (4) increased public awareness of the need to conserve water.

The authors do not discuss the statistical validity of their conclusions.

19. Burke, Thomas R. "A Municipal Water Demand Model for the Counterminous United States." Water Research Bulletin 6, no. 4 (July-August 1970): 661-81.

The purpose of this study was to develop an econometric model for forecasting aggregate requirements for municipal water. The model is to provide rapid determination of the future water requirements of 488 American cities with populations 25,000 or over. The model incorporates 17 explanatory variables reflecting environmental, demographic, economic, and other factors affecting water use. However, price of water is not included.

Separate regression functions have been estimated for 19 regions of the United States, based on statistical analysis of cross-section data derived from 2 published sources: (1) The Public Health Service/FWPCA Inventory of Municipal Water Facilities (1963), and (2) the United States Department of Commerce's County and City Data Book (1963).

This study does not make any forecasts of future water use. There is suggestion made, however, that projections of explanatory variables into the future could be made based on average rates of their growth derived from time-series analysis.

20. Camp, R. C. "The Inelastic Demand for Residential Water; New Findings." Journal of the American Water Works Association 70, no. 8 (August 1978):453-58.

This article presents the results of a multiple regression analysis of 13 variables explaining residential water use. The sample consisted of 288 single family households randomly selected from 10 service areas in Mississippi. Water use was derived from billing data. The price used was taken from the rate schedule at the mean level of consumption for each city. Data for other determinants of water use were obtained by interview or observation of the household characteristics.

The principal determinants of the level of domestic water use (at the 0.05 significance level) were as follows: (1) number of persons by household, (2) number of clothes washers, (3) the education level of the household head, (4) the market value of the residence, (5) the price of water, (6) presence of swimming pool, (7) rainfall, and (8) lawn area. The estimated price elasticity was -0.24 for the linear-functional form and -0.31 for the mixed linear-logarithmic form.

21. Carver, Philip H. "Price as a Water Utility Management Tool Under Stochastic Conditions." Ph.D. dissertation, Johns Hopkins University, 1978. 452 pp.

This dissertation examines a wide range of issues associated with the use of price as a management tool in urban water supply. The nature of water utility cost is reviewed, as is the literature on marginal cost and peak load pricing. Data collected from 13 Washington (D.C.) area water utilities are used to estimate short-run and long-run responses to price changes. The application of an innovative pricing policy (a summer surcharge plan) to the Fairfax County (Va.) Water Authority is analyzed in detail, leading to estimates of its effectiveness in changing both peak and average water-use rates. Water-use forecasting techniques are developed and applied to the Washington Suburban Sanitary Commission. These forecasts are combined with a statistical analysis of river flow to give a probabilistic forecast of water-supply deficit. The deficit forecast then forms the basis of a financial simulation which reveals the consequences of alternative pricing policies. Consumer surplus measures are used to choose among the various policies according to economic efficiency; other criteria include equity, complexity, and revenue erosion. The disseration includes listings of computer programs used and an extensive bibliography.

22. Clark, Robert M. "Cost and Pricing Relationships in Water Supply." Journal of the Environmental Engineering Division of ASCE 102, no. EE2 (April 1976):361-73.

The purpose of this study was to relate the price of water to several characteristics of the water-supply system, as well as to find the relationship between price and per capita water consumption. The study area included 22 districts within a midwestern SMSA (not named). Data presented is from a utility serving this area disaggregated by districts. Cost analysis is based on total revenue producing water pumped by the utility during the calendar year 1964-73.

Based on a stepwise regression analysis, the author concludes that population density and the source of raw water were major price determinants. Total population served and total demand play secondary roles. The regression of per capita water use on price yielded price elasticities in the range of -0.6, varying slightly with functional form.

23. Clouser, Rodney L., and William L. Miller. "Household Water Use: Technological Shifts and Conservation Implications." Water Resources Bulletin 16, no. 3 (June 1980):453-58.

This study investigates the effect of water intensive appliances or activities on household water consumption. The analysis was applied to the results of a questionnaire survey of 406 individual households in 2 Indiana communities and their water utility companies (which provided total water bill and quantity of water used by each household in 1977).

The water demand model included such variables as price paid per 1,000 gallons of water used by the household, number of family members residing in the household, number of bathrooms, the household income, and presence of various water intensive appliances. The demand for water was divided into 3 distinct seasonal periods, and appliances or water intensive practices unique to the various periods were incorporated into the estimation.

In the majority of cases the use of the washing machine, dishwasher, swimming pool, and lawn watering increased per capita consumption and were statistically significant.

The authors also consider the installation of water-saving devices as an alternative method of extending supplies in communities. They conclude that the private economic benefits would be low if water charges were between $1.00 and $3.00 per 1,000 gallons; however, aggregate benefits to the community could be large if the cost of drilling new wells or increasing storage facilities could be avoided.

24. Collins, Michael A., and Alan H. Plummer, Jr. "Industrial Application of Whitford's Demand Forecasting Procedure." Water Resources Research 10, no. 2 (April 1974): 345-7.

The authors of this article discuss application of Whitford's methodology to forecasting basin-wide water demand for steam-electric power generation industry in the Trinity River basin in Texas. Based on 4 different estimates of possible electrical energy production in the basin and *ad hoc* evaluation of water use per unit of power production, the authors have found base line water requirements. In the next step, cumulative probability curves were found through equal weighting of reasonably likely high, medium, and low effects of 3 factors. These were (1) the possible introduction of nuclear-fueled, steam-electric power plants, (2) changes in power plant effciencies, and (3) changes in the basin-wide fractional mix of cooling methods.

It is concluded that Whitford's approach is useful in large-scale, long-range planning.

25. Danielson, Leon E. "An Analysis of Residential Demand for Water Using Micro Time-Series Data." Water Resources Research 15, no. 4 (August 1979): 763-67.

This study estimates the parameters of a residential water demand model based on individually metered water consumption data. A sample of 261 households in Raleigh, North Carolina was observed cross-sectionally over 68 time periods of approximately 30 days each. The period covered by the data was May 1969 through December 1974.

Separate water demand models were constructed for total residential, sprinkling, and winter demands. These dependent variables were estimated as a function of temperature, rainfall, house value, water price, and household size. Water price in this study, which included 50% sewerage charge, was interpreted as marginal charge, since nearly all households fell within the first block rate. For total residential demand, price elasticity (in logarithmic demand equation) was estimated to be -0.27. The coefficients for household size, which consistently explained the largest percentage of variation, was estimated to be 0.740. The remaining variables had coefficients of -0.018 for rainfall, 0.316 for average temperature, and 0.334 for house value.

For winter demand price elasticity was -0.305, coefficients for house value and household size were 0.342 and 0.689 respectively. Price elasticity for sprinkling demand was estimated to be -1.38, while the coefficients for rainfall, average temperature, and house value were -0.206, 5.141 and 0.363 respectively.

26. Darr, P., S. L. Feldman, and C. S. Kamen. "Socioeconomic Factors Affecting Domestic Water Demand in Israel." Water Resources Research 11, no. 6 (December 1975):805-9.

This paper presents an analysis of residential water-use data with respect to such explanatory variables as income, number of persons per family, cultural origin of customer, education and age of the head of the household, and number of rooms per household. The analysis is based on a questionnaire survey of 1,892 households in 4 urban areas of Israel. The survey provided disaggregated data on many variables and water-use data (in cubic meter per capita per dwelling unit, annually) for the 1970-71 fiscal year.

The authors have estimated the parameters of separate water demand functions (log-linear) for metered or unmetered residences and for indoor or outdoor uses. Income, or its surrogate, was found an important predictor of residential water use.

27. Darr, P., S. L. Feldman, and C. S. Kamen, "A Reconsideration of the 'Requirement Approach' to Residential Water-Use Forecasting." Water Resources Research 11, no. 6 (December 1975):1019-20.

This short article reports an in-depth study of residential water use in the desert town of Eliat, Israel. The analysis of residential water use per capita was conducted with respect to income per capita, number of persons per dwelling unit, country of origin, and age and education of the respondent. The analysis was based on the interview of 104 households in July 1973. The results of the regression showed that none of the above variables explained variations in water consumption. In further analysis only technical water-using specifications were found to be correlates.

The authors' conclusion is that "the tool more apt to be of aid in forecasting water use in such an extreme environment is the requirement approach" based on noneconomic engineering parameters.

28. De Rooy, Jacob. "Price Responsiveness of the Industrial Demand for Water." Water Resources Research 10, no. 3 (June 1974):403-6.

This article presents an analysis of water use of 30 large chemical manufacturing plants in northern New Jersey. The author reports the price elasticities of water used for cooling, processing, and steam generation of -0.894, -0.745, and -0.741 respectively. However, the reliability of these numbers is disputable due to the fact that average price and mixed cross-sectional and time-series data were used in the calculations.

29. Domokos, J., J. Weber, and L. Duckstein. "Problems in Forecasting Water Requirements." Water Resources Bulletin 12, no. 2 (April 1976):263-75.

This paper examines the methodological problems associated with forecasting water requirements by use of regression analysis. Both linear and nonlinear simple time-series extrapolations are discussed with respect to long-range forecasting.

The authors conclude that problems arising in forecasting based on multiple regression models are likely to involve serially dependent errors, multilinear explanatory variables, and difficulties inherent in the presence of explanatory variables that must themselves be predicted.

30. Ecological Analysts, Inc. Water Supply Study for Montgomery and Prince George's Counties, Maryland. Towson, MD., 1977. 364 pp. plus app.

This study, undertaken for the Washington Suburban Sanitary Commission (WSSC), assessed the adequacy of the existing supply system, determined the requirement for future supply augmentation, and analyzed the trade-off between supply augmentation and demand reduction with a view to determining more satisfactory supply planning criteria. The latter effort is of particular interest not only because of the innovative methods used but because of the broad implications of the resultant recommendations.

A water-use forecasting model was developed for use in the study, based on statistical analysis of water-use data collected for the WSSC service area and for the service area of a neighboring utility, the Fairfax County Water Authority. Multivariate economic demand models were developed for single-family residential and apartment residential use, separating seasonal and nonseasonal use. Because the available data observations covered a period of little or no change in the price of water, the price coefficient could not be estimated. Price was omitted from the models, therefore, and forecasts were conditioned by the assumption of constant real price. Income elasticities of 0.3 and 0.8 were obtained for nonseasonal use by single-family homes and apartments respectively. The income elasticity for seasonal use by single family homes was found to be 0.7. Single coefficient requirements models were used for 14 other user classes. The forecast was geographically disaggregated, utilizing separate data for each of 63 planning sectors. Alternate forecasts of population and housing characteristics were provided by county planning agencies, yielding alternate water-use forecasts.

A probabilistic analysis of streamflow was undertaken which, when combined with the water-use forecasts, provided a probabilistic forecast of water-supply deficits. Explicit drought management plans were drafted, including various measures designed to reduce water use in the event of threatened water-supply deficit. These plans were reviewed by political officeholders and recast, by them, into three alternative drought management scenarios, each specifying the frequency with which individual drought management measures would be implemented. Combination of the deficit forecast with a particular drought management scenario gives the supply capacity augmentation which will be required if deficits are to be avoided without exceeding the allowed frequency of implementation of the drought management measures. It was found that the conventional supply planning criteria previously employed would have required raw water storage of 3.4 billion gallons by the year 2005; a drought management scenario considered acceptable by political officeholders would require storage of only 1.32 billion gallons by the same date. In the latter case, no drought management measure, even appeals for voluntary reductions, would be implemented more often than once in 12 years. By increasing the permissible frequency to once in 5 years the storage requirement is further reduced to 0.74 billion gallons.

31. Foster, Henry S., Jr., and Bruce R. Beattie. "Urban Residential Demand for Water in the United States." Land Economics 55, no. 1 (February 1979): 43-58.

The purpose of this study was to specify and estimate parameters for a single equation economic model for urban residential water demand. Price, income, rainfall, and number of residents per water meter were chosen as explanatory variables. The model adopted for this study includes price in exponential form and all other variables in power form. Three variations of this model were developed by incorporating dummy variables. This was done for statistical tests of regional and size-of-city differences. The regional breakdown employed in this study divides the United States into 6 regions in terms of drought potential, agricultural production patterns, manufacturing, and monthly precipitation.

Data on water quality, price, and number of residents per meter for 218 cities come from A Survey of Operating Data for Water Utilities in 1960 by the American Water Works Association, Income data were taken from the 1960 Census of Population; rainfall and average temperature, Climatological Data for the United States, 1960-61.

The resulting estimated equation for the aggregate model was

$$Q = .2492e^{-.1278P}Y^{.4619}R^{-.1679}N^{.4345}$$

where Q = quantity of water demanded by household, i.e., per meter (1,000 cubic feet per year); P = average water price (dollars per 1,000 cubic feet); Y = median household income (dollars per year); R = precipitation (inches) during the defined growing season; and N = average number of residents per meter. This model is intended to permit any city to forecast residential water use, given its values of explanatory variables.

Tests performed with the disaggregate models showed that city size has an insignificant effect on per household residential water use, whereas regional differences have been found more significant. The demand curves were estimated for each region using regional mean values of income, precipitation, and number of residents per meter.

32. Frnka, Robert L. Forecasting the Need for Surface Water Use Conjunctive with Ground Water. Mississippi State: Water Resources Research Institute, Mississippi State University, September 1979. 91 pp.

The objective of this study was to provide a planning model for integrating surface and ground water supplies in the major municipalities of Mississippi. In order to perform such analyses, the author had to prepare forecasts for municipal water demands in Mississippi for over 40 areas for the years 1980, 1990, and 2000.

Aggregated water requirement models used by the author were log-linear equations derived from other studies which used average annual water use (mgd) and per capita use as dependent variables and population, industrialization index, per capita income, mean temperature, and average rainfall as independent variables, which had to be determined for the future years. The parameters of these equations were estimated based on 82 observations of cross-sectional data in all counties in Mississippi. The author found that based on the available data the intercorrelations between population and per capita income and between mean temperature and rainfall were fairly high. Income and temperature were excluded as redundant factors, therefore. In equations expressing per capita water use the mean temperature was also excluded.

33. Frye, Richard, and James W. McFarland. "A Municipal Water Supply Investment Problem in Rhode Island." Water Resources Bulletin 16, no. 1 (February 1980):31-5.

This article discusses deficiencies of presently available water demand models, which are price-sensitive, in a decision-making framework dealing with future water-supply investment. Based on the comparison of the benefit-maximization economic model with a "requirement" approach, the authors conclude that the former is as arbitrary as the later.

34. Gallagher, David R., and Raymond W. Robinson. Influence of Metering, Pricing Policies and Incentives on Water-Use Efficiency. Australian Water Resources Council Technical Paper, no. 10. Canberra, A.C.T., Australia: Australian Government Publishing Service, 1977. 137 pp.

The authors hypothesize that pricing is an effective tool in managing urban water supplies. Their investigation covers all aspects of this hypothesis, including description of recent trends in water use, a review of the urban water demand literature, several empirical studies, and analyses of water-supply costs and of pricing policies in Australia.

Water-use trends are presented for major Australian cities for 10-to-15 year period ending in the mid-1970s. These trends are normalized for population, households or other measures and transformed in various ways to illustrate the difficulty of projecting future water use from trend analysis alone. The economic theory of demand is reviewed in some detail, with application to the urban water sector. The water demand literature is reviewed; many of the empirical findings presented in the literature are reproduced here. Urban water use in Australia is analyzed against this theoretical and empirical background, including some attention to the economic characteristics of the "allotment and excess use" rate structures common in Australia.

Two empirical studies are reported. The first took place in Nowra, New South Wales, a coastal town of 16,000 population. Twenty households chosen at random were interviewed regarding socioeconomic and water use characteristics. Five of these households were segregated as a control group while the remaining respondents participated in a pricing experiment. The results were used to estimate a demand function for household water use in winter. The function explained 65% of the observed variance in water use and included an estimate of price elasticity equal to 0.283.

The second empirical test took place in summer in Wollongong, New South Wales, a coastal city of 200,000 population. An initial sample of 19 households was drawn and a procedure similar to that employed at Nowra was used. Separate per capita demand functions were estimated for in-house water use and for outside (garden) use. The former explained 29% of observed variance and revealed a price elasticity of -0.288, very close to the winter elasticity in Nowra. The outside per capita demand function explained 45% of observed variance but failed to include price as a significant variable.

The remaining sections of the report analyze metering and pricing policies from a welfare economics point of view, arguing for the introduction of marginal cost pricing on the basis of economic efficiency. The characteristics of water-supply costs in Australian cities are also described and compared to those reported in studies of United States water utilities. An extensive bibliography is included.

35. Gallagher, David R., John J. Boland, Barry J. LePlastrier, and David T. Howell. Methods for Forecasting Urban Water Demands. Australian Water Resources Council Technical Paper. Canberra, A.C.T., Australia: Australian Government Publishing Service, 1980. 93 pp.

This report addresses the methods used to forecast water use in the urban areas of Australia. The world literature on factors affecting urban water use is surveyed, and those findings most likely to apply to Australia are summarized. A field survey of the forecasting techniques actually used by the major water utilities of Australia is reported, and the techniques described are contrasted to methods in use elsewhere. It is concluded that improvements in forecasting techniques are warranted and can be readily made. An approach to forecasting is developed, based on disaggregate demand models.

This approach is made flexible by incorporating a range of techniques which can be selected according to data availability. In this way, practice can be steadily improved as better data become available in the future. The derivation of demand models is illustrated using data collected for selected residential areas in New South Wales. It is recommended that water utilities begin collecting data which would support the development of disaggregate demand models in the future.

36. Gottlieb, M. "Urban Domestic Demand for Water: A Kansas Case Study." Land Economics 39, no. 2 (May 1963):204-10.

This paper presents the economic analysis of municipal water demand based on aggregated water works data. The authors purpose was to isolate the effect of price and income on water consumption in small Kansas towns during the 1950s. The analysis was based on area-wide averages, total consumption divided by either population or the number of customers, and community-wide average household income. The price of water was derived by dividing total water revenue by the total amount of water used.

The author used an estimating function of the form: log y = log a + log xb + log zc, where y = consumption in 1,000 gallons annually; x = average household income, dollars; and z = price in cents per 1,000 gallons. The results of multiple regressions of rate and income levels, from cross-sectional data, on per customer water consumption show price elasticities of -0.68 and -1.23 and income elasticities of 0.45 and 0.58 for years 1952 and 1957 respectively.

Two measures of consumption were also correlated, i.e., per capita versus per customer consumption. For 24 cities in 1957 and 20 cities in 1952 the author has obtained the estimating equations: $Y_c = 8.21211 + .25165X$;

(R = .9115), and $Y_c = -1.056 + .3165X$; (R = .9663) respectively. Where Y_c is a per capita consumption and X is consumption per connection.

37. Grima, Angelo P. Residential Water Demand: Alternative Choices for Management. Toronto University of Toronto Press, 1972. 211 pp.

This book presents an extensive study, from both theoretical and empirical standpoints, of residential water demand in the Toronto metropolitan area. The water consumption data used in this study are based on 91 individual observations from metered single unit households for 1967. These water-use data were averaged over a year, the summer period and the winter period, thus producing average water use in gallons per day in a dwelling unit over each period.

These 3 dependent variables were estimated using log-linear equations with 4 independent variables: (1) the assessed value of the residence (a proxy for income), (2) the number of persons per dwelling unit, (3) marginal charge in cents per 1,000 gallons to the consumer beyond the quantity allowed with the minimum bill, and (4) the fixed bill for 1 billing period.

The elasticities of demand with respect to the price were found to be -0.93, -1.07, and -0.75, with income elasticities of 0.56, and 0.48 for average annual, summer, and winter water use respectively.

38. Hansen, R. D., H. H. Fullerton, A. B. Bishop, and T. C. Hughes. Historical and Projected Municipal and Industrial Water Usage in Utah 1960/2020. Logan: Utah Water Research Laboratory, Utah State University, February 1979. 59 pp.

This report presents the results of a municipal and industrial water-use inventory for 50 Utah municipalities and for each of Utah's 29 counties.

Municipal and industrial water-use data from 1960 to 1976 are presented at four levels of disaggregation, i.e., statewide, multicounty district, county, and major city. The data are analyzed to produce annual per capita withdrawal rates for municipalities and major industries.

In discussing future water needs, the authors suggest 262 gpcd as an appropriate water-use rate for statewide planning, and 100 gpcd for municipal indoor water use.

The publication cites some simple demand or requirements models obtained in other studies; however, the authors do not say explicitly how these models should be used to calculate future water use.

39. Headley, T. Charles. "The Relation of Family Income and Use of Water for Residential and Commercial Purposes in the San Francisco-Oakland Metropolitan Area." Land Economics 39, no. 4 (November 1963):441-49.

The author has analyzed the impact of income levels on water consumption by regression analysis using both cross-sectional and time-series data obtained from utility records and Census of Population, 1950 and 1959. The regressions were performed for 14 cities of varying population (from 3,000 to 775,000) assuming that price, temperature, precipitation, and other socioeconomic variables are constant. Separate consideration is given to commercial and residential use categories, although criteria for disaggregation are not specified.

Cross-sectional estimates of residential water-use elasticity with respect to median family income, using a linear demand equation, were 1.49 in 1950 and 1.24 in 1959. In log-linear forms the income elasticities were 1.63 and 1.37 respectively. Time-series analysis yielded an average elasticity for the 14 cities of 0.25. Average elasticity of combined residential-commercial per capita use was 1.09 according to the 1950 cross-sectional regression.

Although this study uses simplified modeling techniques as compared to most recent research, it does give an interesting consideration of economic issues in municipal water supply.

40. Herrington, Paul. "The Economics of Water Supply and Demand," Economics 12, Part 2 (Summer 1976):67-84.

This article provides an excellent discussion of the theoretical, empirical, and policy aspects of the economics at public water supply, mostly related to the United Kingdom. The author considers, in turn, demand analysis and forecasting, investment decisions and pricing questions, meanwhile intelligently summarizing the current state of economics of water supply and demand. It is concluded that Britain's growing water problems can only be solved satisfactorily by application of well-tried economic principles.

This paper probably constitutes one of the best economic treatments of water supply problems and other related issues.

41. Hittman Associates, Inc. Forecasting Municipal Water Requirements. Vol. 1, The MAIN II System. Columbia, Md., 1969. PB 190275. 208 pp.

This report describes the development of improved methods for forecasting municipal water requirements which led to the elaboration of one of the more successful computer based forecasting models presently available--the MAIN II system. The authors have determined and analyzed the economic and demographic variables of municipal water use (including their future growth based on the data from 50 metropolitan areas throughout the United States.

The model calculates the values of residential, industrial, commercial, and other water uses for a selected future year. It incorporates several categories of residential water use (metered/unmetered, sewered/septic tanks, houses/apartments), and for each category water use is calculated by a regression equation that uses economic (home value, price of water), weather, and demographic factors (mostly Census Bureau data) as independent variables. Projections are made of these factors rather than the resultant water use. The forecasting system is able to perform detailed estimates for up to 200 water-use categories.

The report also contains 3 case studies (Baltimore, Md; Baton Rouge, La., and Columbia, Md.) in which forecasts of water use were prepared using MAIN II system.

42. Hittman Associates, Inc. Price, Demand, Costs, and Revenue in Urban Water Utilities. Columbia, Md., 1970. 106 pp.

This publication constitutes an excellent study of the municipal water industry based on data collected directly from 46 urban water utilities. The primary purpose of this study, sponsored by the United States Department of the Interior, Office of Water Resources Research, was to develop improved rate-making policies for local utilities that would take account of effects of these policies, including relationships between price, demand, cost, and revenue. The findings of other investigations were reviewed and analyzed, particularly estimates of the price elasticity of municipal water demands.

The authors developed a general economic model of urban water utilities based on the functional expressions for mean, maximum day, and peak hour demand; operating cost; and various classes of revenue which were derived from the data base. The economic model was tested using 2 case studies of Detroit and Roseville, Mich., to illustrate the effects of a postulated rate increase on water demand, cost, and revenue. The distribution of demand, cost, and revenue among various classes of water users under alternate pricing strategies was also investiqated.

The following water demand functions are reported:

1) Average municipal demand

$$\bar{Q}_{mr} = 0.0042\ N_d^{.9223}{}_{(.0507)} D_p^{-1.389}{}_{(.371)};\ R^2 = 0.935,\quad n = 35$$

where

$\bar{Q}_{mr}$ = average municipal retail demand (mgd)

N_d = dwelling units in retail service area (number)

D_p = median number persons per occupied unit (number).

2) Maximum day municipal demand

$$Q_{mx} = 1.55\bar{Q}_m^{1.012}{}_{(0.04)};\quad R^2 = 0.947,\quad n = 38$$

where

Q_{mx} = maximum day municipal demand (mgd)

Q_m = average municipal demand (mgd)

3) Peak hour municipal demand

$$Q_{mp} = 1.27\ Q_{mx}^{1.039}{}_{(0.28)};\ R^2 = 0.981,\quad n = 28$$

where

Q_{mp} = peak hour municipal demand (mgd)

Separate functions for residential and commercial/institutional user categories were developed to express unit water uses (per connection) in terms of such variables as residential marginal price, moisture deficit, and total retail population.

43. Houthakker, H. S., and Lester D. Taylor. Consumer Demand in the United States, 1929-1970: Analyses and Projections. Cambridge, Mass: Harvard University Press, 1966. 214 pp.

The authors of this book have performed an econometric analysis of consumer demand for 83 different commodities based on historical records for the period of 1929-62. For each commodity (including water) demand functions (expressed as expenditure) are evaluated and several sets of projections for personal consumption expenditures in the year 1970 are estimated.

The following dynamic model based on 3-pass least squares method was found to determine per capita personal consumption expenditure of water in year t (q_t) in 1954 dollars (with intercept equal to 2.8775):

$$q_t = \underset{(.5261)}{1.0240} + \underset{(.2275)}{.5427q_{t-1}} + \underset{(.0009)}{.0024\Delta x_t} + \underset{(.0005)}{.009x_{t-1}} + \underset{(.2694)}{.1771z_t}$$

where

q_{t-1} = per capita personal consumption expenditure in year (t-1)

x_t = total per capita personal consumption expenditure in year t

$\Delta x_t = x_t - x_{t-1}$

z_t = 3-pass variable (-1.31 for 1962 and -1.24 as historical mean).

The linear version of the static model includes the percentages of the population living in the South and West and the own-price elasticity, as these variables were found to be significant. Total expenditure was found to be insignificant. This model is given below:

$$q_t = \underset{(11.280)}{-26.263} - \underset{(.4939)}{.6821 \ln p_t} + \underset{(3.0010)}{6.2061 \ln (\text{\% pop. in South})_t}$$

$$\underset{(.6724)}{+5.1595} (\text{\% pop. in West})_t - \underset{(.3429)}{.8965\, d_t}$$

where

p_t = relative price of water in year t (1954 = 100)

d_t = dummy variable used to separate the pre-World War II years from those following; takes the value 0 for 1929-41 and 1 for 1946-61.

The authors also give economic background for econometric analysis and discuss the problems of estimation and projection.

44. Howe, Charles, W. "Municipal Water Demands." In W. R. D. Sewell, B. T. Bower, et al., Forecasting the Demands for Water, Ottawa, Canada: Policy and Planning Branch, Department of Energy, Mines and Resources, 1968. 43-79.

The author of this article proposes an approach for forecasting water demand which is based on the premise that, given economic and technological forecasts, water demand forecasts must be made in conjunction with an analysis of the costs of water supply and water pricing policies. Thus, water demand forecasting should constitute a sequence of the following steps: (1) an economic base study with forecasts of activity levels; (2) a preliminary estimate of water demands using historical coefficients of water use; (3) preliminary water system design and costing; (4) determination of financial and pricing policies for the urban utility; (5) detailed forecasts of demands in the residential, commercial, industrial, and public sectors, based on estimated demand functions and approximate water price structures.

This article discusses the economic base study and the detailed forecasts of demands in the 4 water-use sectors in greater detail. The latter topic is based on the water demand functions developed by the Johns Hopkins University Study.

45. Howe, Charles W., and F. P. Linaweaver, Jr. "The Impact of Price and Residential Water Demand and Its Relation tc System Design and Price Structure." Water Resources Research 3, no. 1 (First Quarter 1967): 12-32.

This article presents one of the most extensive and reliable cross-sectional studies of residential water demand, using data collected by the Residential Water Use Research Project at Johns Hopkins University. The authors analyzed 39 master-metered residential areas in the United States. Continuous recordings of water use were taken for 2-and 3-year periods during the 1960s and aggregated to hourly, daily, seasonal and annual figures. Indoor and outdoor uses were separated, with the latter divided into eastern and western regions of the nation.

Indoor demand was estimated using a linear equation with the following independent variables: market value and the age of the dwelling unit; number of residents; average water pressure; and the sum of water and sewer charges that vary with water use, evaluated at the block rate applicable to the average domestic use in each study area. The resulting price and income elasticities were -0.231 and 0.319 respectively.

Outdoor use for sprinkling purposes was estimated using a log-linear functional form with irrigable area per dwelling unit, summer potential evapotranspiration, summer precipitation, and marginal price applicable to average summer total rates of use, as explanatory variables. The results showed a price elasticity of -1.12 for all metered areas and price elasticites of -0.70 for the western region and -1.57 for the eastern region. Maximum day sprinkling demand functions were developed for 3 types of residential areas, i.e., metered with public sewer (east), metered with public sewer (west), and flat rate with public sewers. The maximum day demands were

were found inelastic with respect to price in the west, but relatively elastic in the east.

46. Hughes, Trevor C., and Robert Gross. Domestic Water Demand in Utah. Logan: Utah Water Research Laboratory, College of Engineering, Utah State University, May 1979. 61 pp.

The overall objective of this study was to develop Utah residential water demand functions for average month, peak month, and peak day per capita or per connection water use. These dependent variables are defined using multiple regression cross-sectional analysis performed on pumping records for 14 metered supply systems of varying size. Price of water, outdoor use index, size of supply system, and number of persons per connection were examined as explanatory variables. The demand functions using price and outdoor use index (integer on 1 to 9 scale) and functions relating one type of demand to another are presented, together with recommended design levels for the same time durations. The design levels were calculated by adding to expected values an increment which was based upon standard deviation of the sample.

The study also develops design criteria for the capacity of those water-supply components which are related to very short term flows. This analysis is based on flow measurements (1- to 5-minute-duration flow rates) during the summers of 1977 and 1978 at master meters on three Utah systems. The results were analyzed by a frequency analysis approach. It was found that instantaneous demand peaks which can be expected once in about 30 years in Utah are under 2 gpm per connection for lines serving 10 families, and 5 gpm per connection for lines serving 4 connections.

This report contains very useful data for engineering design of water-supply systems. Demand projections may suffer from difficulties with assigning an appropriate outdoor water use for a given city, and also from the fact that average price was used as independent variable.

47. Kim, Joe R., and Richard H. McCuen. "Factors for Predicting Commercial Water Use." Water Resources Bulletin 15, no. 4 (August 1979):1073-80.

Of interest in this article is the empirical analysis of urban commercial water use. It is based on data from 64 suburban mall shops in the Washington (D.C.) area. Water use, (in gallons per working day), for each shop was provided by the Washington Suburban Sanitary Commission. Temporal variation in water use is not considered, assuming that this use category is not characterized by large daily and seasonal variation.

The results of a multiple correlation analysis and a principal components analysis suggest the water consumption is a function of the following primary factors: an employee water-use factor, a customer layout factor, and a customer water facility factor. Gross shop area, number of average daily employees, number of average daily man-hours, number of faucets, number of mop sinks, number of toilets, and number of drinking fountains were rejected due either to high intercorrelation or to low correlation with water use.

The following linear model was calibrated using a numerical optimization technique:

$$Q = 15.5F + 0.0147A + 0.945L$$

where Q = number of gallons of water consumed per work day, F = the number of drinking fountains, A = gross area in square feet, and L = the length of the display window in feet. This relationship is characterized by a correlation coefficient of 0.883 and a standard error of estimate of 35.6 gpd.

Good presentation of data analysis techniques adds to the value of this work.

48. Klimek, John C. "Forecasting Industrial Water Requirements in Manufacturing." Water Resources Bulletin 8, no. 3 (June 1972):561-70.

This paper presents the procedures used to obtain estimates of 1964 for water withdrawals for manufacturing and 1990 and 2000 requirements for the Oswego River Basin of New York State, including counties and subareas of 10,000 or more population.

The following equation was used to develop estimates of daily manufacturing group withdrawal in each period of forecast:

$$F(I) = INT(A(I) \times B(I) \times D(I) \times (W(I) - W(I) \times P(I)) + (W(I) \times P(I)/Q(I)))$$

where

F(I) = daily withdrawal by industry group

A(I) = base period employment

B(I) = employment change

D(I) = change in productivity by employee

W(I) = weighted intake per employee

P(I) = percentage of intake subject to reuse

Q(I) = weighted reuse rate.

Estimates of intake per employee, manufacturing activity, and water reuse were developed through surveying a selected number (unspecified) of industrial establishments in the region. The survey was designed to obtain information on present and future water-use practices as well as information on existing employment, present rate of operation and expectation in regard to employment, output, and employee productivity trends.

49. Larson, Brent O., and H. E. Hudson, Jr. "Residential Water Use and Family Income." Journal of the American Water Works Association 43, no. 7 (August 1951):603-11.

This paper presents an analysis of residential water use with respect to income for 13 Illinois communities based on pumpage and billing records. The author has found that the residential per capita use was poorly correlated with the population of the community served, while a good correlation existed between water use and net effective buying income (averaged for each community).

50. McCuen, R. H., R. C. Sutherland, and J. R. Kim. "Forecasting Urban Water Use: Commercial Establishments." Journal of the American Water Works Association 67, no. 5 (May 1975):239-44.

This paper analyzes water-use data for 7 department stores and 140 mall shops in 4 shopping centers located in Washington, D.C.; Greendale, Wis.; and Baltimore, Md.

The authors have found that water consumption at shopping centers is price inelastic and that the number of employees per shift and the gross store area are the best explanatory variables. Because of high intercorrelation between them, the later variable was used to derive water-use model of the form: $W = i + sA$, where i= the intercept coefficient in gallons per working day and s = the slope coefficient expressed in gallons per working day per square foot of gross area.

It is also concluded that the water-use relationship should be derived based on a disaggregation level equivalent to the 4 digit Standard Industrial Classification category.

51. Maddaus, William O., and Donald L. Feuerstein. "Effect of Water Conservation on Water Demands." Journal of the Water Resources Planning and Management Division of ASCE 105, no. WR2 (September 1979):343-51.

This article presents the study of municipal water use and alternative supply for the 9-county San Francisco Bay Area. The authors applied a "requirements" forecasting model disaggregated by spatial location and user class. Average annual water-use projections were developed for 440 zones within the Bay Area (each zone is 1 or more census tracts, using 1975 as the base year.)

Water use in each zone was related to 4 explanatory variables; namely, population, housing density, employment, and the type of land use. Water uses in 5 different categories--(1) inside residential, (2) outside residential, (3) commercial-industrial, (4) public authority, and (5) unaccounted for use--were used as independent variables. The relationships between dwelling unit density and inside residential water use (gpcd), or residential outside unit water use (gpdud), and between employment density and commercial-industrial unit use (gped) were first determined based on actual water-use data in 1975 obtained from the East Bay Municipal Utility District and applied for the 104 of the 440 zones. The obtained relationships were adjusted for each of the remaining 440 zones according to the actual water-use data from those areas. These relationships are not treated statistically or expressed by mathematical equations; however, graphed data points are indicative of very high correlation. Public authority and unaccounted for water uses were determined as percentage of appropriate subtotals.

The above relationships were assumed to hold in the future providing that no conservation program is instituted. The water-use projection model considered projected increases in population, dwelling units, employment, and developed acreage in each of 440 zones during 5-year increments.

Once the base projection was developed, appropriate modifications were made to account for each of 2 water conservation plans, disaggregated according to the same plan. As a result, the total water requirements in the year 2000 were produced. The base requirements of 1,404 mgd was reduced to 1,281 mgd at a unit cost of conservation of $37 per 1 million gallons (.98¢/m^3) saved, and to 1,245 mgd at a unit cost of $300 per 1 million gallons (7.9¢/m^3). The development of new water supply sources could provide up to 525 mgd of water at an average unit cost of $208 per 1 million gallons (5.5¢/m^3).

The major shortcoming of this study is the fact that the authors made no effort to treat seasonal variation in water use and water supply, and they do not mention the problem of reliability of supply.

52. Maidment, David R. "Annotated Bibliography on Water Demands." Water Supply and Management 3 (1979):117-29.

A brief introduction describes both the dependence of water-use forecasts on accurate knowledge of the nature of water demands and the factors which determine them. Brief annotations are provided for 67 articles and technical reports analyzing the demand for water in municipalities, agriculture, and industry. These articles and reports represent the work of more than 100 authors in 15 countries.

53. Mitchell, Bruce, and Paul H. Heighton. "A Comparison of Multivariate and Trend Forecasting Estimates with Actual Water Use." Water Resources Bulletin 13, no. 4 (August 1977):817-24.

This paper presents a disaggregated requirements approach to water demand forecasting for a proposed 427-acre subdivision of Barrie, Ont. The estimation is based on number of housing units, number of different housing types, lot size, and population size. Average water requirements for particular uses were estimated at a very high level of detail, including a small-sclae survey of water-use behavior and analysis of actual water use for given purposes.

According to the results presented by the authors, conventional trend extrapolation was sufficiently accurate for this small area.

54. Morgan, W. Douglas, and Jonathan C. Smolen. "Climatic Indicators in the Estimation of Municipal Water Demand." Water Resources Bulletin 12, no. 3, (June 1976):511-18.

The purpose of this paper was to determine the regression estimator most representative of climatic variation in one common data set of monthly aggregated municipal water use for 33 cities in southern California. A total of 396 cross-sectional observations of average price and income for each water district in 1970 were analyzed. Three alternative climatic indicators were tested: (1) temperature and precipitation, (2) potential evapotranspiration minus precipitation, and (3) monthly binary seasonal variables.

The results of the analysis have shown that both the first and the second models perform much better than the model using seasonal binary variables. In terms of economic responses, the study confirmed that the price elasticity of seasonal water use is higher than other municipal water demand elasticities.

55. Morris, John R., and Clive V. Jones. Water for Denver: An Analysis of the Alternatives. Environmental Defense Fund, Inc., 1980. 159 pp.

This report contains the results of the Denver Water Conservation Study performed by the University of Colorado, Denver. The study is based on questionnaire data from bill and tax assessment of 889 single-family residential customers served by 14 water districts in the Denver metropolitan area. Information was collected on over 100 variables for the base year 1976.

Two econometric demand models were developed. The first model developed for 384 households (excluding households from flat-rate districts) is:

$$\bar{Q} = \underset{(2.1)}{68.7} - \underset{(-2.3)}{.96}\ PRICE + \underset{(3.7)}{.43}\ \overline{INCOME} + \underset{(2.8)}{.59}\ \overline{LSPACE} \qquad \text{(t-statistic)}$$

where

$\bar{Q}$ = average annual household water consumption (thousands of gallons)

$\overline{INCOME}$ = average family income (hundreds of dollars)

$\overline{LSPACE}$ = average residential lot size (hundreds of square feet)

PRICE = price given in ¢/1,000 gallons determined in each district as the cost charged for the final 1,000 gallons consumed each billing period during the irrigation season.

The coefficient of variation for the equation, R^2 is 0.65, and F statistic 10.55 with 17 degrees of freedom indicated that independent variables of the equation are related to $\bar{Q}$ with a probability exceeding .99.

A second model was specified based on data for each individual household within the sample of metered single family residences. This model included 11 explanatory variables.

Further information on the structure of demand is provided by 2 additional regressions estimating indoor and outdoor uses specified on a sample of district wide averages. In these estimations price variable was found virtually insignificant for indoor consumption and significant for outdoor use (elasticity equaled -0.73).

56. National Water Commission. "Forecast and the Role of Alternative Futures." Journal of the Water Resources Planning and Management Division of ASCE 102, no. WR2 (November 1976):365-83.

This staff paper contains a general discussion of forecasting future use and supply of water on the nationwide scale. A review of previous water resource forecasts by the Kerr Commission, the Water Resources Council, and the USGS is presented. Those forecasts have generated widely ranging figures depending on the underlying assumptions.

According to the existing need for forecasts useful in policy making, the commission has rejected a single "most likely" forecast in favor of separate "alternative futures." This concept recognizes that the amount of water used as well as supply availability is dependent upon policies adopted, future socioeconomic phenomena, etc.

The procedure proposed in this article involves 2 steps. First, 3 to 5 "alternative futures" are developed, each of which is described by the set of assumptions encompassing population growth and distribution, food and fiber production, income distribution, national economic efficiency, life-style changes, and various means of developing, using, and conserving water resources. In the second step, forecasts of water use for each future are made. This forecasting approach was expected to provide the commission with a tool for making sensitivity tests of a variety of assumptions.

57. Primeaux, Walter J., and Kenneth W. Hollman. "Factors Affecting Residential Water Consumption: The Managerial Viewpoint." Water and Sewage Works (1974):R138-44.

This article presents the analysis of residential household water use based on cross-sectional data obtained through surveying 402 single-family households distributed evenly among each of 14 Mississippi cities in 1971. The price charged per gallon and the monthly consumption per each household were obtained from municipal water meter records in each city.

The household water demand model utilizes 13 independent variables. These are number of persons, number of bathrooms, dishwashers, washing machines, existence of swimming pool, irrigable areas, market value of residence, average maximum temperature, annual precipitation, education, age of head of household, race, and price. The latest variable is taken as the price of 1,000 gallons of water at the mean level of consumption in each municipality.

The authors obtained a R^2 of 0.56 for a linear equation when all variables were included; withdrawing the variables of race and age had no significant effect on R^2. The demand model utilizing only 3 independent variables (number of residents, market value, and price) explained 47% of the variance independent variable.

58. Rees, Judith A. Industrial Demand for Water: A Study of South East England. London School of Economics and Political Science. London: Weidenfeld and Nicolson, 1969. 194 pp.

This book contains an analysis of industrial water use in South East England based on a questionnaire survey of a random sample of 253 manufacturers in the area administered during the spring and summer of 1966.

The author has analyzed the uses to which manufacturing industry puts water, the sources from which the demand for water is satisfied, the factors which determine the quantity of water taken by firms in the various industry groups, and also the effect of water availability on industrial location. The results of this analysis were used to analyze possible future trends in industrial demands for water.

The following table summarizes the author's findings concerning estimates of the minimum water requirements of firms (only water purchased from the water supply industry) in various industry groups:

Industry	Best-fit explanatory equation	Explanatory variable(s)	Level of explanation (R^2)
Chemicals	$Q^2 = a+bT$	tonage of raw materials	97.3%
Food	$Q^2 = a+bT$	as above	86.7%
Metal and metal products	$Q^2 = a+bE^2$	number of persons employed	96.0%
Other (leather & fur clothing & textiles timber & furniture, printing)	$Q^2 = a+bE$	number of persons employed	87.0%

Lower levels of explanation for explanatory equations for purchased water were found for

a) drink industry, $Q = a+b \log P_m$, $R^2 = 36.3\%$, P_m = price paid for gallons for metered supplies of water

b) plastics and rubber, $Q^2 = a+bE+cT$, $R^2 = 41.5\%$

c) paper and products, $\log Q = a+b \log P + c \log QA$, $R^2 = 55.3\%$

P = price paid for all purchased supplies per 1,000 gallons

QA = quantity of water privately abstracted by firms

d) nonmetallic minerals, $Q = a+bE$, $R^2 = 67.2\%$

e) engineering (precision plus mechanicals), $\log Q = a+b \log P + c \log QA$, $R^2 = 44.1\%$.

The author has found that over the past 10 years manufacturers in the study area have expanded their water usage by approximately 2% annually, but many plant managers expected this rate to decrease down to 0.8% during the next 10 years. She also concludes that little evidence exists to suggest that the availability of water facilities will increase in importance in the locational decision of firms.

59. Reid, George W. "Multistructured Municipal Water Demand Model." Water Resources Bulletin 7, no. 6 (December 1971):1238-45.

The theoretical forecasting approach proposed by the author of this article is based on the application of econometric techniques which would predict the values of explanatory variables required by any demand requirement model. The model is composed of economic, population, reconciliation, and life-style submodels and it is goal oriented. The forecasting process begins with the determination of "people needs" which, in turn, are placed in the context of the management of critical resources for beneficial use.

The author admits that the model is determinative in some aspects and probabilistic or stochastic in others. This must be so, it is stated, since the accuracy of water demand forecast cannot be better than the present predicting power of macroeconomic theory. There is hope that new computer capabilities and econometric techniques will significantly improve in the near future.

This article contains valuable theoretical considerations which may contribute to general forecasting techniques.

60. Roberts, W. J., S. C. Csallany, and N.G. Towery. "Forecasting Water Demands and System Capabilities." Journal of the Sanitary Engineering Division Of ASCE 96, no. 3A6 (December 1970):1349-60.

This study contains an empirical analysis of municipal water requirements, and projections of demands and deficits for the years 1980 and 2020 for 1,200 Illinois community water supplies. The projections are based primarily on population estimates furnished by Illinois government. Based on the examination of water pumpage data the authors have developed nomograms that permit easy determination of future water use (including determination of average daily and maximum daily pumpage).

61. Romm, Jerri K. "Water Supply, Land Use, and Urban Growth" Journal of the Water Resources Management Division of ASCE 103, no. WR2 (November 1977):271-84.

The general thesis of this article is that land-use projections are more reliable than population projections for the determination of future water requirements. This approach is adopted to water-supply planning by the Santa Clara Valley Water District in California. It is suggested that the analysis of residential, industrial, and agricultural land-use combinations possible with available water supply be first performed, and next, a set of community goals be established to best fit available supply.

Although the above implies that water supply is the primary determinant of growth, a highly controversial proposition, the program designed by the district to project future water use seems to be of real value. It projects spatial distribution of annual water demand for a 25-year period in Santa Clara Valley County. The forecasting process consists of 2 components: (1) taking stock of all anticipated land-use changes for each year to the year 2000, based on parcel-by-parcel inventory by water service area, and (2) assessment of unit water uses associated with each new land use. There are 13 categories of possible land use with further disaggregation of residential use into 5 density classes. The model uses a density-consumption relationship for residential water-use projections and water use per employee in the case of commercial consumption. Agricultural use is projected on the basis of water use per acre for individual crops.

The article does not contain any of the functional forms or coefficients of the proposed model. These data are reported to be included in "Master Plan: Expansion of In-County Water Distribution System" prepared by the district in the December of 1975.

62. Schaake, John C., Jr., and David C. Major. "Model for Estimating Regional Water Needs." Water Resources Research 8, no. 3 (June 1972):755-59.

This article describes, (in general terms), a Fortran IV computer program used for estimating future demands or requirements for water in the 50 subbasins of the North Atlantic Region of the United States. The water flow requirements (water demands) are disintegrated by geographic area, economic sector, and water quality type. There are also 9 categories of water use, including totals and some intentionally overlapping classes. The model utilizes projections of regional product, population, personal income, and water withdrawal coefficients within each region, and it produces estimates, by bench mark years, of water demands disaggregated by the above categories.

One of the 6 subroutines of the program generates estimates of future municipal and industrial water demands based on population served and per capita income for each subbasin. It uses a regression equation derived from a time-series analysis of the data for Connecticut. Explanatory variables are population served and per capita income (the measures of these variables are not specified).

Another subroutine estimates future total gross water use by economic sector through multiplying the dollar gross output estimates by the appropriate water-use coefficients. The dollar output is derived from an input-output table for the NAR.

A detailed description of the model and data requirements can be found in appendix T of the United States Army Corps of Engineers North Atlantic Region Study Report.

63. Sewell, W. R. Derrick, and Leonard Boueche. "Peak Load Pricing and Urban Water Management: Victoria, B. C., A Case Study." Natural Resources Journal 14, no. 2 (July 1974): 384-400.

This article presents a brief discussion of the theory of marginal cost pricing which is next applied to peak load pricing in municipal water supply. The authors illustrate these pricing rules based on a simulation program developed for the Great Victoria Water District, Victoria, B.C. Prior to this, they develop separate demand functions for average annual, peak (June-August), off-peak, and mid-peak (May and September) water uses. Prices, income, average summer temperature, and average summer rainfall are used as independent variables. Mid-peak and peak prices for water were obtained by allocating the capacity costs between mid-peak and a peak period according to their relative contribution to the total period (30% for mid-peak and 70% for peak demand).

The demand model is defined quantitatively on time-series data for the years 1954-70. The results show that the demand for water for residential purposes is moderately inelastic (elasticities from -.318 to -.568) when considered on an overall annual basis. The simulation analysis showed that the application of seasonal prices over the period 1967-70 would stimulate a reduction in peak demands ranging from -7.3 to -5.4 percent, and in an 18% increase in off-peak demand.

The article also contains a summary review of 12 urban water demand studies carried out before 1974.

64. Sonnen, Michael B., and Donald E. Evenson. "Demand Projections Considering Conservation." Water Resources Bulletin 15, no. 2 (April 1979):447-60.

This article describes a water demand model which is disaggregated to 40 land-use categories in any of 35 census tracts in each of 10 larger areas of the Island of Oahu, Hawaii. The model was developed by Water Resources Engineers, Inc., for the United States Army Corps of Engineers, Pacific Ocean Division, in 1977.

The model calculates a total average monthly water use using the following functional form:

$$Q = [UI \times WR \times UF \times (1-CI) + 27{,}152.4(UO-G) \times A \times EA \times (1-CO)] \times \frac{PR+OP+E(PR-OP)}{PR+OP-E(PR-OP)} (1-SL)$$

where UI = the number of units using water in a given land-use category (homes, people, 1,000s of square feet, hotel rooms, or acres), UF = the average use rate (gpd per dwelling unit), WR = seasonality factor for indoor usage (ratio of water use in each month to water use in average month), CI = anticipated average annual indoor conservation fraction in future year. In the second part of the equation describing outdoor use, the expression (UO-G) measures monthly requirement for irrigation water in inches (total requirement minus precipitation) in each month, A = the gross area in acres, EA = the fraction of irrigable acreage, and CO = the outdoor conservation percentage in future years. The third expression; takes account of price effect on water use, where PR = current price of water, OP = an older price of water, in a previous year in the stimulated prediction period, and E = the elasticity of demand with respect to price. Finally, the last expression excludes the fraction of total water demanded that is supplied locally.

Although this model seems to be straightfoward, it requires an unusually large amount of data, including price elasticities for each land-use category. The authors admit the difficulty and argue that choosing the numerical conservation target to be achieved is more meaningful and yields more predictable results than price or price elasticity manipulations.

65. Sonnen, Michael B., and Donald E. Evenson. A Model for Estimating Water Demands. Walnut Creek, Calif.: Water Resources Engineers, Inc., May 1977. 52 pp.

This report describes an application of computer program developed by Water Resources Engineers, Inc., for predicting urban and agricultural water demands. The model is based on a number of usage, geographic, weather and economic variables. It is described in greater detail in the publication "Demand Projections Considering Conservation" (Water Resources Bulletin 15, no. 2 (April 1979)).

This publication contains an actual computer output of the program when applied to forecast water demand for the Kaneohe Bay (Hawaii) area. Based on population and land-use information for the base year 1976 and the projected values of these variables for the year 2000, water demands for these 2 years and for 5 intervening years (1978, 1980, 1985, 1990, and 1995) were calculated. Water demands for each month by land-use category for the years 1976 and 2000 in 3 sectors of the Kaneohe Bay were also calculated.

The authors have also performed simple sensitivity analyses of the basic demand function by differentiating it with respect to each variable and showing how to convert the results to the units of percentage change in total demand for 1% change in the value of each input variable.

66. Sterling, M. J. H., and D. J. Antcliffe. "A Technique for the Prediction of Water Demand from Past Consumption Data." Journal of the Institution of Water Engineers 28, no. 8 (November 1974):413-20.

This article presents a mathematical description of time-series data on water consumption; utilizing it to predict the average monthly consumption of water in a mixed rural and industrial water-use area. Actual consumption data, used to illustrate the methodology, consist of total daily water consumption averaged over each month from 1963-1968. The authors applied both linear regression analysis and spectral expansion by orthogonal functions as prediction methods. (The latter estimator is capable of following seasonal variation in water use).

Comparison of projected and actual total water-use patterns by month in 1968, based on the 1963-67 data, revealed a mean error of ±1.2% (averaged over 12 months with a maximum of 3.3%) for 1 month ahead rising to approximately ±1.8% for 12 months ahead.

67. Stevens, Thomas H., and Robert J. Kalter. "Forecasting Industrial Water Utilization in the Petroleum Refining Sector: An Overview." Water Resources Bulletin 11, no. 1 (February 1975):155-63.

In this paper various factors affecting water use in the petroleum refining industry are investigated. Included among these are the price of water, environmental quality legislation, and technological factors. These factors are also used to determine their impact on water recirculation within the industry.

Based on these analyses, 2 alternative water utilization forecasts for the domestic petroleum refining sector are developed for the years 1980 and 1985. The first forecast assumed that average water withdrawals per barrel of crude oil will remain at the current level of 378 gallons per barrel. The second alternative assumed that cooling towers are utilized by all refineries, with a 95% recirculation ratio, reducing water use to only 88 gallons per barrel of crude.

68. Tate, Donald M. Water Demand Forecasting in A Regional Context: Theory and Practice. Canada: Department of Fisheries and the Environment, Inland Water Directorate, Water Planning and Management Branch, 1977(?).

This paper discusses a case study of the Great Lakes as an example of water demand forecasting in regional context.

Water-use forecasts for the 42 counties in the area are based on a per capita requirements approach, using a previous survey of municipal water use to calculate the coefficients of water withdrawal per capita for individual municipalities. The domestic and commercial water withdrawals were computed separately. Losses were estimated at 10% of domestic plus commercial and institutional withdrawals. Consumptive use was taken at 15% of withdrawal.

The author demonstrates the difficulties in obtaining all input data required by more sophisticated forecasting techniques; he also emphasizes the role of assumptions concerning economic activity and technology of water use.

69. Tate, Donald M. Water Use and Demand Forecasting in Canada: A Review. Ottawa, Canada: Department of Fisheries and the Environment, Inland Water Directorate, 1977.

This paper reviews the state of the art of water demand forecasting and water-use studies in Canada. The author provides an outline of the concepts in forecasting which include (1) the alternative futures framework, (2) the spatial disaggregation of forecasts, and (3) the usefulness of the system approach to the subject. Some general points concerning these procedures, such as the need for practicality in formulating new methods, the role of water pricing, economic interrelationships, and the role of technological change, are also considered.

The review of several water management projects in Canada has shown that the most frequent approach was based on per capita water-use coefficients (requirements approach). The use of input-output methods or the alternative futures approach has been attempted; however, these methods are not widely accepted.

The author concludes that the newest approach being taken to water demand forecasting in Canada is based on systems analysis. It analyzes basic data on population and industrial production under alternative growth assumptions and disaggregates these data to river basins and further to local regions. Next, these data are used as inputs to detailed sector-by-sector forecasts at the local level including municipal, industrial (manufacturing, mining, agriculture, energy generation, and navigation), and recreational water demands.

The last part of the paper outlines models proposed for general use in Canada. Municipal water demand for all Canadian municipalities over 1,000 persons is to be analyzed by separate consideration of residential, commercial, industrial, and institutional sectors. Municipalities under 1,000 persons are to be dealt with using coefficients of total water pumped per capita. Inputs to the individual community models will be derived from the population/agriculture component of the national/regional model and other data reqnired only for the municipal mode.

The extensive analysis of water demand forecasting in this paper was dictated by the fact that it was prepared as part of a multicountry review of this subject by the International Institute for Applied Systems Analysis.

70. Thompson, A. G., V. E. Smith, and W. R. Colvin. Development of Commercial Institutional Parameter Units for the Main II System of Water Demand Forecasting. Laramie: Water Resources Research Institute, University of Wyoming, November 1976. PB 263 493. 55 pp.

The primary objective of this report was to provide a method of estimating commercial/institutional parameters for the MAIN II (Municipal And Industrial Needs) water forecasting computer model where data are not available. This modification was based on data collected from 20 cities west of the Mississippi River ranging in size from 2,500 to 300,000 in population. Data on commercial/institutional water use included 28 categories and their associated parameter units.

The authors incorporated a subroutine in the MAIN II model which estimates missing data on commercial/institutional values using linear relationships between population and category parameter units. The modified program was applied to three test cities (Billings, Mont.; Twin Falls, Idaho; and Kimball, Nebr.), and it gavc estimates of 1975 water use within 10% of the actual usage.

71. Thompson, R. G., M. L. Hyatt, J. W. McFarland, and H. P. Young. Forecasting Water Demands. Arlington Va.: National Water Commission, November 1971. PB 206 491. 377 pp.

This report describes models for forecasting water demands for agriculture, steam-electric power generation, petroleum refining, and residential use. Emphasis is on rationale and technology of forecasting rather than on absolute numerical values. The report shows how forecasts vary according to the directions that may be taken by policy, technology, population, the economy, and other basic variables. These different possible directions are termed "alternative futures."

Through use of a model developed by Wollman and Bonem alternative national forecasts of withdrawals and losses of water in agriculture, mining, manufacturing, power plant cooling, and municipal purposes, as well as use of water for waste disposal, are presented for the year 1980, 2000, and 2020.

72. Thompson, Russell G., and H. Peyton Young. "Forecasting Water Use for Policy Making: A Review." Water Resources Research 9, no. 4 (August 1973): 792-99.

This article presents a linear method of approximating derived demand functions for water in agricultural and industrial production. The authors review the basis for estimating withdrawal, consumptive, and disposal demand functions which relate water use to its price and to prices of all other inputs. Demand functions are sighted from other studies which indicate that, for example, withdrawals by electric generating stations for once-through cooling would be lowered 98% if a price of 0.5¢/1,000 gallons were imposed. This use accounts for nearly 25% of all freshwater withdrawals in the U.S.

Two important applications of these demand functions are (1) alternative projections of water use, and (2) a basis for evaluting proposed investments in water resource development which should be justified by the economical value of the water provided.

73. Turnovsky, Stephen J. "The Demand for Water: Some Empirical Evidence on Consumers Response to a Commodity Uncertain in Supply." Water Resources Research 5, no. 2 (April 1969):350-361.

This paper estimates some demand functions for domestic and industrial water based on cross-sectional data from 19 Massachusetts towns for the years 1962 and 1965. These years mark the beginning and the end respectively of the 1960s New England drought. The author attempted to take account of the uncertainty of water supply present during the drought period.

It was found that per capita domestic consumption (actual and planned) was significantly dependent on price (elasticities from -0.049 to -0.406), average housing space in a town, and supply uncertainty as measured by supply variance. For industrial demand only price and "uncertainty" were significant (price elasticities: -0.473 to 0-839).

74. United Nations. The Demand for Water: Procedures and Methodologies for Projecting Water Demands in the Context of Regional and National Planning New York: Department of Economics and Social Affairs, United Nations, 1976. 240 pp.

This report was prepared by an Ad Hoc Group of Experts on Water Requirements Forecasting convened to suggest principles and approaches by which current practices of projecting the demands for water could be advanced to meet more closely the increasing need for efficient use and protection of the available freshwater resources.

The following are the scope and objectives of the report: (1) to outline the conceptual and procedural frameworks for water demand forecasting, (2) to review basic methodological approaches and techniques applicable for forecasting the various categories of water demands, (3) to review and disseminate indicative data on specific water uses and demands to facilitate tentative projections, and (4) to assist national and regional Governments in establishing institutional frameworks and the data base for projecting the demands for water.

The major conclusion of this analysis relates to the role of projections in policy formulation. It recommends that the basic aim of projections should be to outline the consequences of various assumed development patterns and alternative policies rather than to predict or predetermine a single most likely or most desirable course for the future.

75. United Nations Conference Secretariat. "Resources and Needs: Assessment of the World Water Situation." In Water Supply and Management 1, pp. 273-311.

This publication contains an overview of the world water situation including assessment of freshwater supplies, assessment of water use and demand, and discussion of demand/supply relationships.

Under the demand section, the report summarizes what is known about total water uses for several components of demand and evaluates the applicability of this knowledge for assessing global water demand.

76. Weeks, C. R. and T. A. McMahon, "Urban Water Use in Australia," Civil Engineering Transactions Australia: The Institution of Engineers (1974): 58-66.

This paper presents results of a survey of urban water use in Australia, based on data collected during the late 1960s. Factors influencing per capita municipal use are examined, including population size, presence of metering, water quality, and climate. Forecasts are prepared for 11 Australian cities using a simple trend extrapolation approach. Monthly water use is forecast from multi-variate regression models which include monthly rainfall, mean maximum monthly temperature, number of raindays, and pan evaporation as explanatory factors.

An investigation of household water use is reported, based on data collected for five small study areas in Victoria. Per capita use is expressed as a function of number of persons per housing unit, and both seasonal variations and peak day use levels are investigated. A survey of water use by major industrial firms in Melbourne is also reported. Water use coefficients, based on units of production, are calculated for 29 industrial categories. Australian results are contrasted to corresponding data reported for the United States and the United Kingdom.

77. Whitford, Peter W. Forecasting Demand for Urban Water. Stanford, Calif.: Stanford University Report EEP-36, September 1970. 221 pp.

The author's purpose is to develop and demonstrate a model for forecasting residential water use. The model incorporates an uncertainty factor that takes account of various future water management policies that could be adopted. Four case studies (Baltimore, Kansas City, Phoenix, and Seattle) are used to illustrate the model application in forecasting water use in the year 2000.

The reported alternative forecasts of future water use result from various assumptions concerning the outcomes of the following six factors that may affect water use: (1) regulations on the water use of appliances; (2) the type of pricing policy that is adopted; (3) policy on public education (water conservation); (4) the housing patterns in the future; (5) the cost of supply; and (6) changes in the technology of use. Two or 3 outcomes are considered for each of these factors, and probabilities of occurrence are subjectively assigned to each outcome, allowing a probability distribution of a given future water use to be drawn. This is done by multiplying conditional probabilities assigned to each policy outcome and ascribing it to an appropriate level of water use.

For each case study the cumulative probability distribution curves describe the probability of any given per capita water demand in the year 2000. A "base" line estimate is determined by such water utility data as population served, the average annual and seasonal consumption of water (disaggregated into residential, commercial, industrial, and other), and the water rates.

78. Whitford, Peter W. "Residential Water Demand Forecasting." <u>Water Resources Research</u> 8, no. 4 (August 1972):829-39.

This article provides an excellent discussion of the water demand forecasting problem, and it describes a methodology for forecasting urban residential water use which incorporates the development of "alternative futures." The "futures" are projected based on the 2 or 3 outcomes of each of the following factors that may influence future water use: (1) regulations on the water use by appliances, (2) types of policy pricing adapted, (3) policy on public education (4) future housing patterns, (5) cost of supply, and (6) changes in the technology of use. Thus, the forecasting method incorporates potential water conservation programs into estimates.

It should be noted that the author is primarily concerned with factors or variables which are not significant or which do not exist at present. The proposed model may be treated as a tool for generating a probability distribution of the future water demand, once a single-number base line forecast is found by using standard methods.

The proposed model is demonstrated by forecasting water demand for the cities of Phoenix and Baltimore for the year 2000. Data on present water use, obtained from water utilities, included such items as population served, the average annual and seasonal consumption of water (disaggregated into residential, commercial, industrial, public and other), and the water rates. The base line estimate for Baltimore was obtained by projecting the 1985 forecast of Hittman Associates (using MAIN II system) to the year 2000. The base line forecast for Phoenix was estimated by comparing the rate of growth of per capita residential demand with that of Baltimore.

Whitford's model should prove very useful for policy making purposes since it incorporates the concept of alternative futures.

79. Willsie, Roger H.. and Harry L. Pratt. "Water Use Relationships and Projection Corresponding with Regional Growth, Seattle Region." Water Resources Bulletin 10, no. 2 (April 1974):360-71.

This article briefly outlines both the methods used and the results obtained in a study of water-use relationships and future demand for water for the Seattle region. Water-use analysis is based on billing information which was disaggregated into 6 customer classes (single-family residential, multifamily residential, industrial, commercial, public, and miscellaneous) and 14 water-use subdivisions. Only residential water use was analyzed intensively.

A cross-sectional regression analysis of residential water use was performed for the 1972 time period, using water use per person by type of residence and by season as dependent variables for each subdivision. The independent variables were average income per person per year f each water-use area and average lot size per person (for single-family residences). Only the single-family regressions were found statistically significant. Income elasticity was estimated to be approximately equal to 1. Use of water by multifamily residents was found to be unresponsive to changes in income.

Industrial and commercial water billing information was compared with employment to yield the coefficients of water use per employee. Public and miscellaneous categories were identified with residual water use (23%) and assumed to be in the same proportion in the future.

Time-series analysis of total annual water consumption in Seattle for the years 1950-72 was also performed, using population, summer temperatures, and summer precipitation as explanatory variables.

Based on the results of these water-use analyses together with projected future levels of population, employment, income, and lot size, future disaggregated water demands were estimated through the year 2000. Water demands were also estimated under alternative regional growth assumptions.

80. Wolff, Jerome B., F. P. Linaweaver, Jr., and John C. Geyer, Commercial Water Use, Technical Memorandum No. 27, New York: ASCE Urban Water Resources Research Program, American Society of Civil Engineers: 67 pp. (reprint of 1966 report by Dept. of Environmental Engineering Science, The Johns Hopkins University)

This report presents the results of an intensive study of water use for 186 commercial and institutional establishments in the Baltimore (Maryland) metropolitan area. Water use data were obtained from quarterly meter readings, from more frequent special readings, and from recorders attached to water meters. Data were collected for various periods in 1964 and 1965. Both average water use levels and peak use rates were investigated, including the development of water use hydrographs for selected establishments.

A major contribution of this study is the development of unit use coefficients suitable for estimating average day water use for 18 categories of commercial and institutional users, ranging from primary and secondary schools to department stores. In each case, water use is expressed as a function of some appropriate parameter, such as number of students in the case of schools, or square feet of sales area in the case of department stores. Coefficients are also presented for maximum day water use and peak hour water use (on a non-coincident basis) for each category.

81. Wong, S. T. "A Model on Municipal Water Demand: A Case Study on Northeastern Illinois. Land Economics 48, no. 1 (February 1972):34-44.

This article presents regressions of municipal residential water consumption on price, income, and average summer temperature for Chicago and outside communities. The analysis is performed on data obtained from the Department of Water and Sewers, City of Chicago, and other local agencies. The data characteristics are not discussed in detail.

The results of time-series regressions (1951-61) on the Chicago area showed partial R's of income and average summer temperature of 0.74 and 0.77 respectively. Price was found insignificant (elasticity -0.02) for Chicago, whereas, it was significant at the 5% level for the outside communities (elasticity -0.28). For those communities, average summer temperature had the most significant effect. The author suggests that a partial flat-rate pricing policy and otherwise very low price of water were responsible for the insignificant effect of price on water use in Chicago. A log-linear functional form was used.

Four cross-sectional regressions of residential per capita water use on price and income were performed for 103 communities (stratified into 4 community site groups), giving price elasticities ranging from -0.82 to -0.26 and income elasticities of 0.48 and 1.03. These values are compared with the results of 17 previous studies of these variables.

82. Yamauchi, Hiroshi, and Wen-yuan Huang. "Alternative Models for Estimating the Time Series Components of Water Consumption Data." Water Resources Bulletin 13, no. 3 (June 1977):599-610.

The authors of this article demonstrate the application of various statistical techniques to the analysis of water consumption data. The step-wise regression method was applied to 187 data points (January 1960 to July 1975) representing average daily water consumption within the service area of the Honolulu Board of Water Supply.

The authors use both additive and multiplicative models to analyze the trend, cyclical, seasonal, and irregular components of the aggregated demand.

83. Yarborough, Keith A. "Analysis of Seasonal Water Consumption in Danville, Ill." Journal of the American Water Works Association 48, no. 5 (May 1956):479-84.

The author's purpose was to determine seasonal water consumption in Danville based on house meter records for the summer quarter (June 15-September 15) and winter quarter (December 15-March 15) for the period 1950-55.

Although the conclusions of this study are very general, it is important to note that the author attempted to take account of potentially important variables explaining water use. Climatological factors (or weather conditions) and assessed-property evaluation are considered for each of 5 water-use zones.

AUTHOR INDEX

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CROSS-REFERENCE TABLE OF FORECASTING METHODS
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Method / Content		Single Coefficient			Multiple Coefficient		Probabilistic
	Simple Time Extrapolation	Per Capita	Per Customer	Unit Use Coefficient	Requirements	Demand	Contingency
Provides General Discussion	7,13,14,34,53, 66,76	7,13,14,18, 35,36,38	7,13,14,35, 36,46,60,62, 69	13,14,35, 46,61,67, 70	7,11,12,13, 14,27,29,33, 35	1,6,7,9,11, 13,14,17,21, 22,27,31,33, 34,35,36,37, 39,40,44,59, 83	7,13,14,15, 21,24,56,59, 69,71,77,78
Provides Empirical Data (Coef- ficients)	53,58,76	2,13,18,36, 38,39,46, 49,60,68	3,13,36,42, 46	24,50,58, 67,70,76, 79,80	10,12,13,19, 27,30,42,47, 48,51,53,76, 79	5,6,8,9,13, 20,21,22,25, 26,27,28,30, 31,32,34,36, 37,39,41,42, 43,45,49,55, 57,79,81	21
Describes Application				30,61	12,16,51,76, 77,79	1,9	16,21,24,30, 72,77
Presents Model(s)	66	38,60,62	26	27,50,58, 62,70	12,19,27,42, 47,48,51,76	6,8,9,20,23, 25,26,27,31, 34,35,36,37, 41,42,43,55, 57,63,64,65, 69,70,72,73, 79,81	15,21,30,77
Evaluates Model(s)					4,12,16,27, 29,54	27,32,54	
Presents Forecast Results	53,66,76	38,60		61,70	12,30,48,51, 77	17,30,32,41, 63,65	15,30,71,77

Comments: 1. Although some studies are not listed here, they contain valuable information pertaining to water demand forecasting.

2. The above classification is designed to help in using the annotated bibliography and it may contain certain categorizing simplifications.

Dziegielewski, Benedyki.

An annotated bibliography on techniques of forecasting demand for water / by Benedyki Dziegielewski, John J. Boland, Duane D. Baumann.--Fort Belvoir, Va. : U.S. Army Engineer Institute for Water Resources, 1981.

[76]p. ; 27 cm.--(IWR contract report ; 81-C03) (DACW ; 72-80-C-0028)

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1. Water-supply--Bibliography. 2. Water resources development--Planning--Bibliography. I. Title. II. Boland, John J. III. Baumann, Duane D. IV. United States. Army. Institute for Water Resources. V. Planning & Management Consultants. VI. Series. VII. Series: DACW ; 72-80-C-0028

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