

DESIGN OF A STATE-LEVEL WATER USE FORECASTING MODEL

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ABSTRACT

The selection criteria, design, and data for use in a water resources forecasting model for a state (Massachusetts) in which modeling techniques have not been used for water resource planning on a large scale are described. The recommended model, a requirements forecasting model based on employment and population growth, was selected to meet criteria of: compatibility between data availability and the requirements of the model; ease of understanding and use; compatibility with existing planning systems; usefulness at various levels of planning; and flexibility for further development and integration with other models. It can be viewed as the first step toward the development of an integrated long-term water resources planning system for a state.

INTRODUCTION

This article describes the selection criteria, design and data for a water resources forecasting model recommended for use in a state (Massachusetts) in which modeling techniques have not been used for water resources planning on a large scale.

The contributions of the article are intended to be twofold. First, while mathematical models have often been recommended for environmental and water planning without careful reference to the context in which they are to be used, this article describes an attempt to design a model for a particular context. As environmental planning methods become more diverse, it will be desirable to have available articles and examples like the present one so that practitioners can look not only to the abstract virtues of modeling methods, from simple to

highly complex, but can also consider their suitability in different contexts. The selection criteria, design, and data for the proposed model will be of special interest to those contemplating the introduction of mathematical modeling techniques, simple or complex, into planning environments where these have not been used on a regular basis. Second, the relatively straightforward forecasting model recommended for use in Massachusetts will be of interest to state and regional planners, particularly with respect to such issues as the availability of relevant data on the state level and the choice of planning regions.

The working hypothesis of the study described here was that, to be effective in practice, a planning model should be selected on the basis of the following criteria: compatibility between data availability and the requirements of the model; ease of understanding and use; compatibility with existing planning systems; usefulness at various levels of planning; and flexibility for further development and integration with other models. The model recommended for use in the Commonwealth of Massachusetts is an analytically straightforward water use forecasting model using available data on a town-by-town basis. (For an analysis of the role of models in planning and for one of the few available detailed descriptions of the process of model choice and development in a case study, see Major and Lenton [1, Ch. 3; pp. 226-227 and Appendix A]. The Major and Lenton study describes what is perhaps one of the most sophisticated river basin planning efforts ever done using mathematical models, where the planning environment was quite different from that described in this study. For an examination of whether more complex or sophisticated models are better than simpler models see Rogers [2]).

MODEL DESIGN

The system selected for recommendation to the Commonwealth is a requirements forecasting system based on information that is available or is likely to become available at the state level. The water uses for which forecasts are made can be both for withdrawal and for consumptive uses of fresh water and other types of water as appropriate. A program for the system was designed to provide printouts of results, in easily used form, at the town or more highly aggregated level up to the state level. The town is the basic forecasting unit except that there is provision for dividing towns into hydrologic regions where this is required.

A distinguishing feature of the system in terms of forecasting is that base year municipal water use by town, which is not directly available from the data, is estimated by subtracting base year publicly supplied industrial water use for major water using industries from total base year municipal use. (An override feature permits the use of other estimates of municipal use when this estimating

procedure does not give adequate results.) Total water use is then forecast as the sum of two components: industrial use based on employment growth, and municipal use based on population growth.

The system is designed to interface easily between those elements of the system which are processed by the computer and those which are produced as inputs or received as outputs by users of the model. A program such as that developed for the NAR demand model [3, Appendix T] can be included in the system so that each input parameter including population and employment forecasts by town and coefficients for domestic and industrial water use can be easily changed by the user to study the sensitivity of forecasts produced by the system. Altering parameters for sensitivity analysis or using feedback from the outputs produced to change the inputs are examples of the points in the system which require judgment. The user/computer interface allows users to bring to bear their expertise on the quality of the data that are used in the system and thus to affect the quality of the outputs which are produced (see Major [4] for a discussion of the relationship between planning expertise and computer models).

The basic steps of the model are described here and illustrated in the center portion of Figure 1. Base year publicly supplied industrial water use by town is estimated from industrial employment data and state-wide industrial water use coefficients. It is then subtracted from base year public water use to yield municipal water use as a residual in the base year. Per capita municipal water use is calculated from this residual and forecast for the target years using an input coefficient for increase in per capita water use. Because, using this procedure, per capita municipal water use is calculated from input data that varies in quality from town to town, results may not always be of adequate quality. To account for this possibility the model is designed to include an override option. With such an option, per capita municipal use for each town can be set exogenously; or a minimum use figure can be included such that this figure is used whenever the model estimation yields a lower figure. Upper bounds are also possible. Target year industrial water use is calculated from employment projections and water use per employee coefficients, which account for technological changes influencing the rate of water use in production. Publicly and self supplied industrial water use totals (determined using state-wide coefficients) are estimated first by industry type (using Standard Industrial Classification categories) and are later aggregated by town. A detailed listing of the algebraic steps in the computer program is given in Wineman, Major, and Kuusinen [5].

The right-hand portion of Figure 1 illustrates how output can be displayed for users. Municipal and industrial water use projections can be combined in alternative ways to produce total municipal use, total industrial use, total publicly supplied use or total self-supplied use.

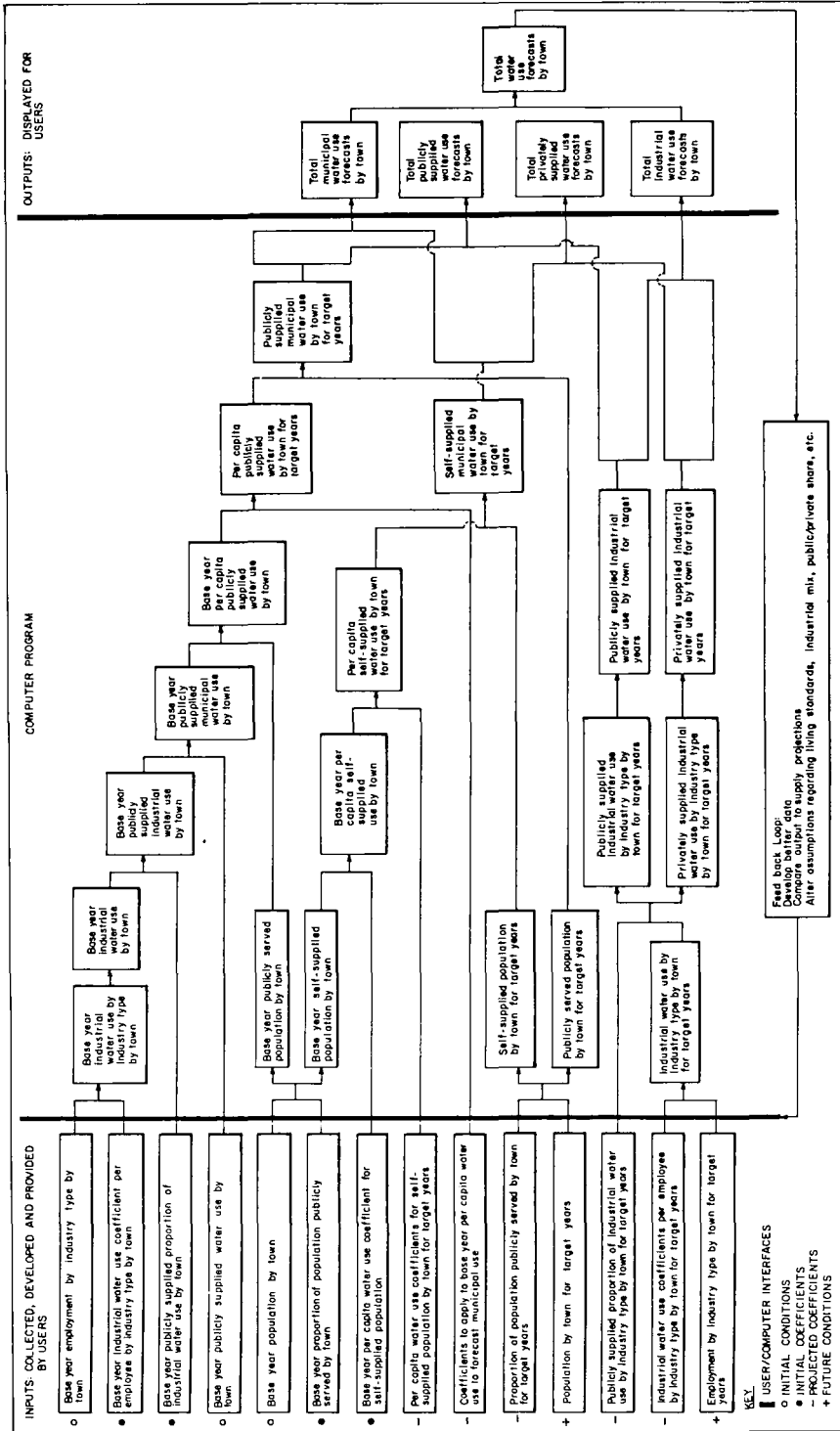


Figure 1. Flow chart for water use requirements forecasting model.

MODEL CHOICE

An examination of available water resources models was made for use in developing a long-term water supply and demand forecasting system to be recommended for use in Massachusetts. It was decided to focus initially on the forecasting side, the aspect described in this paper, inasmuch as certain supply information was available in traditional form and it was felt that this would be adequate for integration with a forecasting model for an intermediate period prior to the development of an appropriate supply model (perhaps a supply optimization model, for example, de Lucia and Rogers [6]). The available techniques for water use forecasting ranged from such complex systems as those used in the North Atlantic Regional (NAR) Water Resources Study [3, Appendix T; 7], a fairly sophisticated and relatively mechanized requirements system using a regionalized input-output model, to traditional handcrafted methods for forecasting demand. The data available upon which models could be based was surveyed through discussions with agency personnel and examination of available Federal, State, and local documents.

Based on this investigation, an "intermediate" level of technology, as described in this paper, was selected. It was felt that this would permit rapid sensitivity analysis, make good use of existing data and indicate where further data should be systematically collected. At the same time, it was thought to be suitable for widespread use within the water resources related agencies in the Commonwealth since it was not overly complex, that is, it would fit within the matrix of use. Also, development time and total staff resources were constrained, and it was felt that the greatest net benefits given these constraints could be achieved through such an intermediate approach.

MODEL ISSUES

One of the first choices that has to be made in a forecasting model is the selection of planning regions. Some agencies use more than one set of regions, depending upon particular objectives of the agency at the time of planning. Because of this need for flexibility it was decided that the model should be based on small geographic units, and if at all possible, on city and town level data. Such units can in turn be aggregated in a way suitable to the purposes of the user. For example, data and forecasts can be aggregated to regional planning agency regions, counties or water use areas.

A disadvantage of choosing city and town units as the regions defined for the model is that they follow political rather than hydrologic boundaries. It should be kept in mind, however, that the forecasts produced by the model will, in almost all cases, be used for studies relating water supply to water demand and will not be used simply for water supply investigations. Therefore, some approximation of hydrologic boundaries by political boundaries will have to be made (as was done in the NAR study and in the Second National Water

Assessment [8]). In cases where this is a significant concern, the model can accommodate data inputs that correspond to town subdivisions needed to define hydrologic units. A similar modification also could be made to accommodate water supply districts smaller than a single city or town.

A second issue requiring attention is the time span over which forecasts will be made. Of prime importance here is the need for long lead time for planning and constructing water supply projects; in the water resources field, forecasts need to be available for periods far in the future. The model is designed to account in part for the great difficulty in making accurate long-term projections by allowing for a range of forecasts to be produced in accordance with various assumptions. Policies based on these forecasts can therefore be shaped to accommodate alternative futures.

A third issue is the choice of demand sectors to be forecast separately from the population-based municipal water use forecasts. Industrial water use, for example, is affected by variables not directly related to population growth in the local area, and therefore it can be forecast separately from population growth. For this reason, the model was designed to consider industrial water use separately from municipal water use, but it is also structured so that, should detailed data for commercial or institutional use become available, they could be entered in the model in the same manner as the industrial data and these uses could then be projected independently. This same technique could also be used to forecast, for example, agricultural water use. The general approach used is not tied to the particular sectors chosen to be forecast separately. The model is flexible enough to accommodate other combinations of sectors; or other techniques may be substituted for forecasting certain sectors and combined with the output generated by the model.

After it was determined that it was appropriate to structure the model to consider industrial water use separately from population-based water use, it became necessary to consider three other questions. First, a decision was made to focus on those industries that are heavy users of water. Minor water using industries could be accounted for either in population-based water use forecasts or in industrial use forecasts by including an allowance factor. After a review of the heavy water using industries as defined in NAR, NEWS [9] and EMMA [10], six two-digit Standard Industrial Classification (SIC) groupings were selected: 20, Food and Kindred Products; 22, Textile Mill Products; 26, Paper and Allied Products; 28, Chemical and Allied Products; 30, Rubber and Miscellaneous Plastics Products; 33, Primary Metal Industries. To increase the level of detail of the forecast three or four digit classification groupings could be selected.

Second, it was necessary to draw a distinction between publicly and privately supplied water because many industries supply their own water. In such cases industrial water use might impact the public water supply by depleting a common source. For this reason, it was necessary to design the model to forecast both self-supplied and publicly supplied industrial water.

The final issue concerned which types of water use (fresh, brackish, and/or salt) should be forecast. Although drinking water and water for health and safety purposes are naturally of primary importance for state level policymaking, use of other types of water should be forecast because of their potential substitutability for fresh water in certain industrial uses. Thus, the model was designed to allow for the inclusion of these types.

DATA

Following the principle that a model should not be built without an understanding of the empirical context within which it will be used, an inventory was undertaken of data available in agencies carrying out water resources and related planning. This inventory yielded a rich array of relevant data sources produced and/or used by seven state agencies and three federal agencies, including such information as: state, regional and municipal level population and employment projections; water use forecasts for sub-regions of the state and for sub-national regions that included Massachusetts, water supply survey questionnaires; and current employment levels by industry type by town.

These types of data sources are generally available at the state level now or will be in the near future. Some examples of information that are readily available to many states are data collected by the New England River Basins Commission and other federally funded river basin commissions for the Second National Water Assessment; U.S. Department of Commerce, Bureau of the Census data; OBERS projections (U.S. Depts. of Commerce and Agriculture for U.S. Water Resources Council) and information generated from federal water quality programs such as the 208 Areawide Waste Treatment Management Program.

Because a reasonable set of data was obtainable without a great deal of effort, it was felt that it would be efficient to start the iterative process of model use for trial runs with that set rather than to spend a long period of time collecting a set of data which would in any case be subject to change. Usefulness should not be sacrificed for speed, however: the initial data should produce a fairly accurate forecast to be used as a basis for sensitivity analysis. It is believed that the initial set of data recommended for use meets this criterion. One example of the kind of data that might be obtained for the initial model runs and later modified to reflect the availability of improved data sets is county or regional planning area level employment forecasts; these can be used to begin with and then municipal level projections can be substituted for them when these latter become available.

A recommended data set for use with the system developed for Massachusetts follows. The headings used below correspond to the classification of input data used in Figure 1.

Initial Conditions

Base Year Employment by Industry Type By Town—Six two-digit Standard Industrial Codes (SIC) selected—20, Food and Kindred Products; 22, Textile Mill Products; 26, Paper and Allied Products; 28, Chemicals and Allied Products; 30, Rubber and Miscellaneous Plastics Products; 33, Primary Metal Industries. Data on the average employment level by town for each of the six industry groups are compiled by the state employment office [11, annual figures].

Base Year Publicly Supplied Water Use By Town—Data from surveys of water suppliers collected annually by the state water supply agency [12, annual surveys].

Base Year Population By Town—Municipal-level population data produced by the state planning office [13, 14].

Initial Coefficients

Base Year Industrial Water Use Coefficients Per Employee By Industry Type By Town—Data from the Census of Manufactures Water Use in Manufacturing Reports for each of the six industry groups.

Base Year Publicly Supplied Proportion of Industrial Water Use By Town—Data from the Census of Manufactures for each of the six industry groups.

Base Year Proportion of Population Publicly Served By Town—Data from regional planning agencies [10, 16, 17]. (These studies were used here and where cited below as the basis for estimates for municipalities not covered in the studies.)

Base Year Per Capita Water Use Coefficient for Self-Supplied Population—Data from regional planning agencies [10, 16, 17].

Projected Coefficients

Coefficient To Apply To Base Year Per Capita Water Use To Forecast Water Use for Municipal Consumption—Increase at an assumed constant rate of 1 per cent (compounded) per year. (Alternative possibilities should be examined, including correlation with per capita income.)

Coefficient To Apply To Base Year Per Capita Water Use To Forecast Water Use for Self-Supplied Population—Same coefficient as above.

Proportion of Population Publicly Served By Town For Target Years—Data from regional planning agencies [10, 16, 17].

Publicly Supplied Proportion of Industrial Water Use By Industry Type By Town For Target Years—Data from the Census of Manufactures.

Industrial Water Use Coefficients Per Employee By Industry Type By Town For Target Years—Assume constant at current values. (Alternative possibilities should be examined, including those associated with increased water conservation.)

Future Conditions

Population By Town For Target Years—Municipal-level population forecasts produced by the state planning office [13, 14].

Employment By Industry Type By Town For Target Years—Municipal-level employment forecasts by SIC codes produced by the state planning office [18].

USE OF THE MODEL IN THE CONTEXT OF STATE PLANNING

The flexibility of the approach and the model described lend themselves to many future adaptations. Some of these advantages can be summarized here. As mentioned earlier, the ability of the model to aggregate planning areas in a variety of ways makes it useful not only to state agencies, but also to other users such as regional planning agencies and counties. In addition, water resource planners might want to examine alternative water use areas corresponding to supply alternatives, including interstate alternatives.

As indicated previously, if efforts are made to collect better data on commercial and institutional use of water across the state, the same methodology used for industrial demand projections can be used to forecast water use of these sectors. Similarly, if more recent or improved population, industrial activity or water use data sources were to become available, these could be substituted for existing inputs to the model to improve or update the resulting forecasts. The model might be advantageously adapted to provide forecasts useful for wastewater planning. This could be accomplished by substituting coefficients to estimate pollution loadings for the water use coefficients. Also, a system combining a supply optimization model (for example, de Lucia and Rogers) with this model could be used to examine the interactions of various water supply alternatives or water resources management policies with demand forecasts, including an examination of the reasonableness of future demand forecasts with respect to future supply prices [6]. The model described in this paper would thus become the first phase of the development of a continuing water resources planning capability for a state.

SUMMARY AND CONCLUSION

The selection criteria, design, and data set proposed for use in a water resources forecasting model for a state (Massachusetts) in which modeling

techniques have not been used for water resource planning on a large scale have been described. The model is a requirements forecasting system based on information that is available or is likely to become available at the state level. A distinguishing feature of the model is that the base year municipal water use by town, which is not directly available from the data, is estimated by subtracting base year publicly supplied industrial water use for major water using industries from total base year municipal use. Total water use, in the simplest version of the model, is then forecast as the sum of two components: industrial use based on employment, and municipal use based on population growth.

The model recommended for use was selected to meet the criteria of: compatibility between data availability and the requirements of the model; ease of understanding and use; compatibility with existing planning systems; usefulness at various levels of planning; and flexibility for further development and integration with other models. By these criteria, the model appears to be appropriate for use at the state level. The model can be viewed as the first step toward the development of an integrated long-term water resources planning system for a state.

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REFERENCES

1. D. C. Major and R. L. Lenton, *Applied Water Resource Systems Planning*, Prentice-Hall, Englewood Cliffs, New Jersey, 1979.
2. P. Rogers, On the Choice of the 'Appropriate Model' for Water Resources Planning and Management, *Water Resources Research*, 14:6, pp.1003-1010, 1978.
3. U.S. North Atlantic Regional Water Resources Study Coordinating Committee, *North Atlantic Regional Water Resources Study*, New York, June, 1972.
4. D. C. Major, Impact of Systems Techniques on the Planning Process, *Water Resources Research*, 8:3, pp. 766-768, 1972.
5. J. J. Wineman, D. C. Major and T. Kuusinen, *A Framework for Forecasting Water Requirements for the Commonwealth of Massachusetts*, staff report, Commonwealth of Massachusetts, Department of Environmental Management, September 1977.
6. R. J. de Lucia and P. Rogers, North Atlantic Regional Water Supply Model, *Water Resources Research*, 8:3, pp. 760-765, 1972.

7. J. C. Schaake, Jr. and D. C. Major, Model for Estimating Regional Water Needs, *Water Resources Research*, 8:3, pp. 755-759, 1972.
8. U.S. Water Resources Council, *The Nation's Water Resources: The Second National Water Assessment*, 1978.
9. U.S. Army Corps of Engineers, North Atlantic Division, *Northeastern United States Water Supply Study*, November, 1976.
10. Commonwealth of Massachusetts, Metropolitan District Commission, *Wastewater Engineering and Management Plan for Boston Harbor-Eastern Massachusetts Metropolitan Area EMMA Study*, March, 1976.
11. Commonwealth of Massachusetts, Division of Employment Security, unpublished list of current employment data by town and SIC code, prepared annually.
12. Commonwealth of Massachusetts, Department of Environmental Quality Engineering, Division of Water Supply, unpublished water supply statistics questionnaires prepared by Water Districts throughout the state, annually.
13. Commonwealth of Massachusetts, Executive Office for Administration and Finance, Office of Planning and Program Coordination, unpublished population projections, October 1972.
14. Commonwealth of Massachusetts, Office of State Planning, unpublished population projections, rev. August 1976.
15. Commonwealth of Massachusetts, Metropolitan District Commission, *Report on Metropolitan Water Transmission and Distribution System*, December, 1975.
16. Lower Pioneer Valley Regional Planning Commission, *Water Supply Facilities Inventory and Identification of Needs and Problems*, December 1968.
17. Metropolitan Area Planning Council and Commonwealth of Massachusetts, Department of Commerce and Development, *Inventory of Water and Sewer Facilities*, May, 1967.
18. Commonwealth of Massachusetts, Office of State Planning, unpublished employment projections, October 1976.

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