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Industrial Water Demand Forecasting

D. M. Tate and R. Robichaud

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INLAND WATERS DIRECTORATE,
WATER PLANNING AND MANAGEMENT BRANCH,
OTTAWA, CANADA, 1973

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Abstract

This study is intended as a contribution to water demand forecasting methodology. The model developed will be useful to river-basin planners interested in formulating alternative development for their areas of study and in determining the effects of these alternatives. Although this model was developed and is framed in terms of a study of industrial water demand, the approach is generally applicable.

Introduction

Through its proclamation of the Canada Water Act in 1970, the Government of Canada expressed an active interest in comprehensive water management. Specifically, the Act denotes that planning and research in the water resource field are desirable for the conservation, development, and use of Canada's water. The preamble of the Act indicates concern due to increasing demands on the water resources of the country, and suggests that more knowledge of the nature, extent and distribution of those demands, both present and future is needed. Thus, the Canada Water Act makes clear the need for active involvement of the federal government in examining future water demands.

This paper is intended as a contribution to water demand forecasting methodology. The model developed will be useful to river-basin planners interested in formulating alternative development for their areas of study and in determining the effects of these alternatives. The model as presented here was developed from a study of industrial water demand and is framed in terms of this subject. However, it is felt that the approach is more generally applicable, and suitable linkages with the municipal sector are suggested in the concluding section of the paper.

Before proceeding with an examination of the methodology and results of this research, it may be profitable to examine in detail the objectives of this type of study. If these types of undertakings are deemed necessary or desirable, some commitment must be made to them in terms of labour input and financial allocation. If they are not required, this fact should be made clear.

One objective of demand forecasting is the avoidance of severe water shortages. There are areas in Canada, especially in the prairie region, where such shortages occur frequently. While evidence is lacking that these situations curtail economic growth, they certainly are not beneficial in attracting industry, and should be avoided if possible. Even in the more humid areas of the country, water shortages can occur during the summer months. A detailed knowledge of expected demands is necessary in anticipating water shortage in any area of Canada and in effective planning to meet such situations.

With increasing population and living standards, conflicts in the use of water are occurring with increasing frequency, particularly in the large urban areas of the country. One such conflict is the reduced availability of water-based recreation in industrialized areas. Another objective of water demand forecasting is the anticipation of such conflicts. In this way, planning may proceed to avoid them.

A third factor in the need for water demand forecasting is the increasing scope of water resource planning in Canada. The need for comprehensive river basin planning has been put forward in Part I of the Canada Water Act. Among other considerations, comprehensive planning implies that development schemes must focus upon water use in entire river basins. This task entails the examination of many, often competing, water uses; the determination of future water demands by these users; and the formulation of alterative development plans to meet these demands. To execute these tasks effectively calls for the satisfactory examination of future water demands. Further, this increase in scope of water resource planning has been accompanied by a general escalation in the capital costs of projects. In view of this trend, the water manager must quantify future water demands and their expected values. In this way project proposals can be evaluated to ensure that they will meet anticipated demands, and to determine whether in fact such projects are warranted.

Water demand forecasting is also useful in the evaluation of government policy in the water management field. For instance, effluent standards are being imposed at present on certain heavy water using industries in Canada. Over the long run, these standards are intended to diminish the amount of polluting material entering the receiving streams around the country. One of the payoffs of water demand forecasting is an indication of the expected amount of effluent which will be deposited in the various watercourses over the forecast horizon. In this way, the effectiveness of the effluent standards policy may be examined, given the projected growth, technology, and water use patterns of industry in the future.

A major task in the water demand forecasting is the imputation of economic values to water use. The estimation of future water use quantities is not sufficient in developing water demand forecasts. The use of water, say by industry, is a "burden" on the water resource, in the sense that such water is temporarily eliminated from use in other activities. Likewise, water can be considered as a "value" to industry, in that, without water, industry would have difficulty operating. The lack of a method of assessing the economic value of water in industrial and other uses has resulted in inefficient water usage. The fact that water has been viewed traditionally as a "free" good is partly responsible for its abuse, one example of which is the deterioration of water quality in many areas of the country. Thus, there is a need to assess the economic value of water required for those uses in the future. A program of forecasting water demands is the best means by which to examine these issues.

This outline of the objectives of water demand forecasting identifies the role of such a program in water management and more specifically within the Department of the Environment. Forecasting of this type has been done in the past, as will be shown in Chapter 2. However, the traditional practice of predicting the future on the basis of past trends, a questionable practice to start with, is no longer adequate in our society, with its expanding population, rapid technological advances, and growth in per capita wealth. For example, in much of Canada's urban water environment, recreational areas are constricted, or even unacceptable from a health point of view in terms of swimming, fishing, and sailing, because of the discharge of municipal and industrial wastes. Evidence for this conclusion is found in closed beaches in the neighbourhoods of major urban centres. What emerges is that past experiences, which have resulted in present water management problems, are inadequate as the sole basis for predicting future water allocations. In other words, forecasts based upon past trends alone will not provide an adequate framework for planning of water resource allocation in the future.

From the above material, it seems clear that a *national* program to examine future water use among several, often competing, sectors of the economy is required in fulfilling the water management mandate of the Department. This requirement fits in with some of the already established programs of the Department, such as the examination of pollution damage functions, the collection of water quality information, the calculation of the costs of waste treatment. Moreover, the task of forecasting water demands is not a "one shot" undertaking. It is not, in other words, completely amenable to contractual work. To do an adequate job, it becomes necessary to establish methods, carry out the forecasts, and evaluate the results. The initial forecasts must be evaluated in regard to their implication for future water use. This step will enable the manager to modify some of the assumptions of the initial forecasts (if such modifications are required) and then to re-do the forecasts on the basis of new assumptions.

Thus water demand forecasting is seen as an integrative type of undertaking by which the planner and the manager can examine the trends in water use in a given area over a selected time horizon. The exercise will give insights into probable water allocation problems over the period of forecast. The manager has important input into this process for it is he who must decide upon the probable shape of the area's social and economic future. The planner has an important function in specifying the precise future alternatives for examination. Both must evaluate the results of the forecast and modify the basic assumptions where necessary. The function of the generalist in this process is to develop the methodologies of forecasting necessary for the planning and management operations.

It is in this last area that the present paper lies. Most water resource planners acknowledge that water demand forecasts are essential in the future allocation of available water supplies. The difficulty is that to date, most forecasting techniques have been either too simple (e.g. straight line extrapolations of past trends) to be meaningful, or too complex for ready implementation in a relatively short term study. This paper was initiated as an attempt to steer a middle course through these to alternatives, taking account of the complexities of forecasting water demands, while retaining enough simplicity to be useable in the short term. The result is a very flexible and readily usable technique.

OUTLINE OF THE PAPER

The second chapter will review the most recent contributions to the literature of water demand forecasting and will introduce the major variables used in this type of work.[1] In Chapter 3, a model of industrial water demand will be developed. The model is of the simulation type, and will allow for a wide range of the component variables. It is constructed such that sensitivity analysis may be performed to isolate the crucial variables of the model. Chapter 4 will give an example of a future water demand simulation derived using the model. This example is based upon hypothetical figures to allow the broadest opportunities for exploring the capabilities of the model. Later papers on specific industries will afford the chance to apply the model to actual cases. This last chapter will also explore briefly some extensions of the model. Inter-industry linkages will be suggested using input-output coefficients. Also, the interplay between the industrial and municipal sectors are explored in this chapter.

1. In order to examine the main ideas in this paper, the reader may skip Chapter 2 on first reading.

An Examination of Relevant Variables

WATER-USE COEFFICIENTS – THE ROLE OF ECONOMIC ACTIVITY

Forecasts of water demands in the past in Canada have been based upon application of coefficients of water use to measurements of economic activity. Most commonly a relationship between water use and an economic parameter such as output, input, or employment has been observed. This relationship or coefficient has been assumed constant and applied to projections of the related parameter to derive future water requirements.

In Canada, a large number of studies of varying complexity have been based upon this 'coefficients approach'. The most simplistic of these merely forecasts the related economic activity and applies the fixed water use coefficient to derive the water demand "forecast".[1] Some Canadian studies have been more comprehensive in their approach, and have manipulated water use and related economic data in the generation of water demand forecasts.[2] However sophisticated these studies may be, the use of coefficients to derive water requirements is the underlying method to derive their future demands.

Numerous studies in the U.S. have used a similar approach. An example is the Wollman-Bonem (W-B) study entitled *The Outlook for Water*[3]. The aim of the W-B study is to develop a model of future water-demand, water-supply relationships, both for the U.S. as a whole and for its component water resource regions. Water demand is defined strictly in terms of physical quantities. Unit water requirements are developed for various uses and assumed constant throughout the forecast horizon. Projection of economic activity is based on the assumption the regional economies will grow or decline relative to the national economy at rates consistent with recent trends. In projecting growth, three sets of assumptions were made, giving rise to high, medium and low levels of economic activity. Applying the set of water-use coefficients to these projects generates high, medium and low forecasts of future water requirements. The W-B study does not consider the price of water to be an important variable. It also omits specific reference to foreseable technological change. Any future technological change affecting water demand, the authors maintain, will be taken up by the high, medium and low estimates generated using their methodology.

The coefficients approach is based upon observable relationships between water use and certain parameters of economic activity. For example, the U.S. Census Bureau publishes data on water use in the U.S. manufacturing sector, accompanied by data on employment and value added in the industries surveyed. Analysis of 16 major groups selected from the Bureau's publication shows that in 75% of these industries, the correlation between total water intake and value added is greater than .75, indicating a strong positive relationship between the two variables. This relationship demonstrates that economic activity levels are important in the determination of water demands. Any forecast of water demand will be linked closely to forecasts of these levels. This conclusion, however, is not adequate rationale for the coefficients approach as the sole method for forecasting water demands.

The water-use coefficients are a function of a number of important determinants of industrial water use. A few of these are the state of recirculation technology in the industry, the age of the plant, the process-product mix, the cost of water, and requirements due to the imposition of effluent standards. All these factors are potential sources of variation in quantitative water use. Thus, the use of the coefficients approach obscures a number of important variables. The use of average coefficients of water use is probably more accurate for industries considered in the national context. As soon as coefficients are applied to regional areas or to river basins, error may become very large. In addition, this methodology precludes any future change unless the coefficient data base is variable. Even with updating of water-use coefficients, the approach still obscures most of the major determinants of industrial water use. In general then, the coefficients methodology is unsatisfactory for forecasting water demands. Even with the limited data base available in Canada, it is thought that

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1. See for example: Ontario Water Resources Commission, *Water Resources Survey of the County of Welland,* 1964, mimeographed, p. 86.

2. Examples are: Warnock, J.G., "Our Water Needs – What Will They Be? ", Conference on Water Resources Management, The Conservation Council of Ontario, Toronto, 1966; Cass-Beggs, D., "Water as a Basic Resource" in Resources for Tomorrow, *Conference Background Papers, Volume 1,* Ottawa, Queen's Printer, 1961, pp. 173-189; and Canada, Department of Fisheries and Forestry, "Water Requirements of the Iron and Steel Industry in the Canadian Great Lakes Basin" by D.M. Tate, Policy, Research and Co-ordination Branch, *Discussion Paper 71-2,* 1971.

3. Wollman, N., and G.W. Bonem. *The Outlook for Water-Quality, Quantity and National Growth.* Resources for the Future, Washington, D.C. 1971.

better methodologies can be formulated. The following sections examine the relationships which should be incorporated into a water demand forecasting model.

WATER PRICING AND COST – SOME ECONOMIC ASPECTS OF WATER USE

The field of water resources has been traditionally the preserve of the engineer, and industrial water use was considered only so far as it affected plant operations. With the rise of importance of resource economics and the concern of social scientists with resource utilization, water use in industry has come under closer scrutiny. What is of concern is that economists began to treat water as a factor of production, comparable to labour, machinery, etc. In other words, the demand for water was given a price connotation, and economists called for the analysis of water use from a cost viewpoint[4]. At the same time, it was recognized that water utilization costs (composed generally of cost of intake water, cost of intake water treatment, and cost of effluent treatment) were relatively small in relation to total production costs. For example, Gurnham[5] showed that, over several years, annual water pollution control expenditures ranged between 0.6% and 1.4% of net plant and equipment evaluation. According to Bower[6], these costs range between 3 and 6 times the cost of water intake. Thus, Bower states that water utilization costs lie between 0.1% and 3% of total production costs.

The majority of industries which use large amounts of water have their own sources of supply, and acquire only a small amount of their total intake from community water supply systems. The only "price" which is paid for self-supplied water is the cost of acquisition, such as pumping, piping, etc. In other words, large water users do not have an exogenously determined water price. This point raises some interesting methodological issues which cast a good deal of light on industrial water use. It will be fruitful to examine it in detail.

The most extensive approach to using water price in the determination of industrial water demand was done by De Rooy[7]. Water is considered as a factor of production and an integral part of the production function of the industry under study – the chemical products industry. Using the theory of derived demand, De Rooy synthesized a water demand function for the industry. Recognizing that there is no exogenous price for self-supplied water, the cost of water to the industry was adopted as a proxy for price. This approach to pricing is rationalized by the following:

> "This 'price' (i.e. the proxy), if it reflects true 'economic costs' of production, can be directly compared to market price since the market good is a substitute whose cost should appear in the demand function."[8]

In the final model the average cost of water per thousand gallons was used as the proxy for water price. After a discussion of the implications of this assumption, De Rooy summarizes his argument as follows:

> "Due to the ways in which (water) is obtained by industrial users, 'price' presents a problem of definition. Little of industry's supply is purchased on the market, and since public utilities generally sell water of high quality (for human consumption) it would often be uneconomical to do so, particularly for large plants. To generate its own supply the firm must purchase facilities such as pumps and treatment equipment, as well as dig wells or lay pipelines. In addition, it must assume the current costs of operation for labour, chemicals, and maintenance. So, as stated earlier, under such circumstance the average (unit) cost of water should be used in place of market price."[9]

Total (annual) costs of water utilization were calculated from an extensive questionnaire administered to the chemical industry. These costs combined the cost of intake facilities (including operation and maintenance), the costs of intake treatment (facilities + O & M) and the costs of effluent treatment (facilities + O & M). The costs of facilities were amortized over pre-determined time horizons and averaged to give cost per thousand gallons of capacity. The sum of the average costs of each type of expense gave a total average cost of water in each plant under study. This cost figure was used as a proxy for water price.

The data on water 'price' were then used in a regression model to explain the determinant effect of price on water demand. The outline of the analysis used is very long and detailed, hardly amenable to summary in this paper. In a very brief fashion, relationships such as the following were hypothesized.

$$GC = f\,(X, WATC, W/X)$$

where: GC is the gross water used for cooling
WATC is the weighted average total (water) cost
W/X is the wage bill divided by value added

The results of this particular analysis, after the application

4. For a full discussion of this viewpoint, see: Bower, B.T., "The Economics of Industrial Water Utilization", in Kneese, A.V. and S. Smith (eds.) *Water Research,* Johns Hopkins Press, Baltimore, 1966, pp. 143 – 173.

5. Gurnham, F.C. "Control of Water Pollution", Chemical Engineering, vol. 70, # 12, 1963.

6. Bower, op. cit., p. 150.

7. De Rooy, J. The *Industrial Demand for Water Resources, and Econometric Analysis,* PhD. dissertation, Rutgers University, 1970.

8. Ibid. p. 51

9. Ibid. p. 80

of several functional forms, is stated as follows:

> "The portion of GC attributable to WATC (an index of water price) is nearly as great as that for X, the output of the firm. . . There can be little doubt, with this evidence, that factor cost, or market price deserves major consideration in estimating or predicting most industrial water demand."[10]

The calculation of water cost, as outlined by De Rooy, is directly dependent upon the amount of water taken into and used in the plant. For example the costs of pumping water from the self-supplied source to the plant is dependent upon pump capacities, which are a direct function of the amount of water required. De Rooy's methodology then takes this cost, averages it out over the amount of water pumped, and uses the result as a proxy for price. This 'price' is then used as an independent variable in the determination of the water demand at the plant. Thus, the object of the analysis (i.e. water demand) is assumed in the calculation of an independent variable. Hence the finding of a strong relationship between water price and quantities used is not surprising. It is felt that this relationship is *not* due to the responsiveness of quantity used to price, but rather is the result of high correlation between average water cost and quantity used.

Thus, using the De Rooy approach in forecasting water demand leads to a form of circular argument where the quantity of water required must be known in order to approximate price, a determinant of water required. A variation of De Rooy's methodology was tried in an attempt to find a workable forecasting model using the production function approach. The variation is based upon the Cobb-Douglas production function.[11]

Suppose that there are three factors of production for a firm — capital (K) labour (L) and water (W). Taking Q as the output of the firm,

$$Q = A\,K^a L^b W^c$$

where A, a, b, and c are constants, and $a+b+c = 1$

The marginal physical products of the three productive inputs are:

$$MPP_k = a\frac{Q}{K}$$

$$MPP_l = b\frac{Q}{L}$$

$$MPP_w = c\frac{Q}{W}$$

where K is the amount of capital used in production.
L is the amount of labour used in production.
W is the amount of water used in production.

The total cost (TC) of production is

$$TC_x = F + P_k K + P_l L + P_w W$$

where F is the fixed cost of production.

$P_{k,l,w}$ are the prices per unit of capital, labour and water respectively.

In an optimal situation (which is assumed here) the marginal costs of production will be equal to the ratio of the price of each input to its marginal physical product.

$$\frac{\partial TC_x}{\partial Q} = \frac{P_k}{MPP_K} = \frac{P_l}{MPP_L} = \frac{P_w}{MPP_W}$$

$$\frac{\partial TC_x}{\partial Q} = \frac{P_k}{aQ/K} = \frac{P_l}{bQ/L} = \frac{P_w}{cQ/W}$$

The Lagrangian multiplier, LM is equivalent to the marginal cost of production. Setting the output at a constant level we can introduce LM into the analysis.

$$\bar{Q} = AK^a L^b W^c$$

$$LM\,(AK^a L^b W^c - \bar{Q}) = 0$$

or $$\frac{P_w}{cQ/W}\,(AK^a L^b W^c - \bar{Q}) = 0$$

Now if this equation is introduced into the total cost equation, cost is obtained in terms of price and the production function.

$$TC_{\bar{x}} = F + P_k K + P_l L + P_w W + LM\,(AK^a L^b W^c - \bar{Q})$$

To minimize production cost, set the partial derivatives equal to 0.

$$\frac{\partial TC\bar{X}}{\partial} = P_w - LM\,(\frac{\partial Q}{\partial W}) = 0$$

$$P_w - \frac{P_w}{cQ/W} \cdot \frac{cQ}{W} = 0$$

From these manipulations, the following demand equation for water emerges.

$$W = \frac{c \cdot Q \cdot P_x}{P_w}$$

where Q is output
P_x is the price of the final good
P_w is the price of water, which is the value of the marginal product of water ($MPP_w \cdot P_x$)

Thus, to use the Cobb-Douglas production function in forecasting water demand in an industry, there is a need for a forecast of production (in terms of value), a forecast of the proportionality coefficient (which may be assumed constant) and an estimate of the future price of water. In forecasting price, a problem similar to that identified in the De Rooy model is met. To determine the equilibrium price of water a measure of its marginal physical product (in value terms) is required. To obtain the latter, an estimate of water used is required, which is exactly the object of the exercise. Again, a circular argument!

A possible solution to this circularity is to assume that this price is determined exogenously, and to test the effect of various price levels on the demand for water. Now other problems become apparent. The analysis, with price given *ex ante*, will give a curve of quantity against price, but a

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10. Ibid. pp. 160–162.

11. See Chiang, A.C., *Fundamental Methods of Mathematical Economics*, McGraw-Hill Inc., 1967.

final water demand figure will continue to be elusive. If assurance could be given that the demand curve would intersect the curve of available water supplies, an equilibrium quantity and price could be determined. However, most often in Canada the water supply curve is located to the right of the demand curve in the manner displayed in Figure 1. This situation will arise because it is clear that this situation will occur even when the cost of pollution control is included in the price function for water. Put another way, water demand in the majority of areas in Canada creates its own supply. A large industrial plant in the Great Lakes area will not curtail its production because of the *price* of water. Thus there is no way of determining the equilibrium of the water demand system based on the Cobb-Douglas formulation.

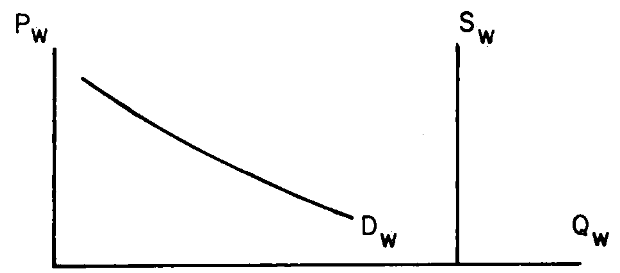

Figure 1. Hypothetical water market situation.

It appears to us that conventional neo-classical economics do not offer a suitable methodology for forecasting water demand. The approach using cost as a proxy for price seems to lead into a type of circular reasoning. The adoption of an exogenously determined price will yield a demand curve for water, but will not define an equilibrium water demand. This conclusion does not imply that economic information, such as water cost, does not have an important part to play in forecasting. Data pertaining to cost are essential if the exercise is to proceed in an adequate manner. However, some underlying relationships in industrial water utilization must be emphasized in order to gain perspective of the problem. The following paragraphs and the next section are the basis of the model proposed in Chapter 3.

The relationship between water cost and the quantity used is not a direct relationship. Water use should be considered not from the price point-of-view, but rather as a manufacturing cost.[12]

The recirculation of water in an industrial operation depends in part upon the cost of water. Gilkey and Beckman[13] found that the amount of fresh intake water used in copper refining in Arizona is responsive to the cost of intake water. When that cost increased, the proportion of gross water use met by fresh water intake declined. This conclusion is slightly suspect due to physical supply limitations and the variable technology in use at the plants studied. However, the data suggest that recirculated water costs only about 10% of the cost of new water intake.[14]

With the increased pollution of water courses, industrial plants with high-intake water quality requirements are forced to spend more money for their water supplies. This increased cost is the result of purification requirements before treatment, or the need to seek alternate supplies. A common response to increased cost is greater recirculation, and resultant lower intake. Clarke has written "... industrial waters (i.e. intake) generally cost from 2 to 25 cents per 1,000 gallons compared with 1 to 5 cents for recycling cooling water and 2 to 13 cents per 1,000 gallons for treated sewage effluent[15]." This points out that in some cases, where intake quality is low, recirculation of water will be economical.

Let us formalize the relationship between increased cost and reduced water demand. A decline in intake water quality, or perhaps the application of an effluent standard by a water management agency will cause an increase in the cost of industrial water use.

Increased cost = f (decreased intake quality, effluent standards, etc.)

This increased cost will give rise to increased recirculation.

Recirculation = g (increased cost)

Since recirculation is related directly to water intake,

Water intake = h (recirculation)

an increase in the recirculation rate will decrease the amount of water intake. In this manner, it becomes clear that a jump directly from increased cost to a change in water intake will obscure at least two important considerations, the cause of the increased cost and the nature of the connection between cost and recirculation. In the model presented in this paper, the economic aspects of the problem will be considered implicitly to allow us to focus upon more important determinants of water demand.

TECHNOLOGICAL CHANGE – IMPLICATIONS FOR WATER DEMAND FORECASTING

Industrial water use is not a static parameter, but shifts with technological change and innovation. This factor is responsible in part for the ineffectiveness of the coefficients methodology outlined at the beginning of this chapter. Technological change may result from a variety of causes, among them new productive processes, new product re-

12. This type of approach was taken by Bramer and Motz in: Bramer, H.C. and D.J. Motz, *The Economic Value of Water in Industrial Uses*, U.S. Dept. of the Interior, Office of Water Resource Research, Contract 14-01-0001-1990, 1969.

13. Gilkey, L.M. & R.T. Beckman, as cited in Bower, B.T., op. cit. p. 167.

14. Ibid.

15. Clarke, F.E., "Industrial Re-use of Water", *Industrial and Engineering Chemistry*, vol. 54, #2, 1962, p. 25.

quirements, and the desire for increased efficiency in production. The effects of technological change on water use are extremely variable and require careful study on an industry by industry basis. A couple of examples will illustrate this.

Nelson has shown that, over a period of time, petroleum refinery complexity has increased and is projected to increase at a greater rate in the future.[16] This increased complexity is due to the growth in demand for petroleum products and increasing product deversification. After an analysis of factors controlling water use in a refinery, Nelson concludes that water requirements will move from an average of 80 gallons per barrel of crude processed oil in 1970 to around 140 gallons per barrel in 1990.[17] The latter may be somewhat higher depending upon refiner complexity.

The second example is drawn from the iron and steel industry. In recent years, a major advance in converting pig iron to raw steel has been made through the use of the basic oxygen furnace in place of the older open hearth method. This advance has made possible a tighter control of the injection of alloys as well as a decrease in the time needed for conversion. This process change has a decrease in gross water requirements per ton of steel from 4,150 gallons to 2,400 gallons.[18] Future expansions in steel-making are likely to use the basic oxygen method. Thus, technological advance in this case will decrease water requirements. At the same time, the trend to larger production units, such as larger blast furnaces, rolling mills, etc., is tending to increase gross water requirements. In analysing future water demands in this industry, both types of technological change should be taken into account.

Government policy can result in technological change. One example in Canada might be the adoption of effluent standards, a policy which would probably induce increased recirculation and a resultant decrease in water demand. The imposition of effluent standards may also lead to the adoption of new production methods which would change existing water demands per unit of product. This type of change has occurred recently in Canada. Partly as a result of the introduction of effluent standards for pulp and paper mills, the industry has begun to phase out the older sulphite mills in favour of the Kraft process. This is not to say that the effluent standards policy is solely responsible for this change, since it would have occurred over a period of time because of other factors. However, the policy has hastened the change. This major change in the pulping process will decrease water demand in the industry because of the lower gross water requirements of the Kraft process.

The projection of technological change in industry is difficult because of the secrecy with which these changes occur. However, from technical literature, it is usually possible to discern significant trends. It is essential that these trends and their impact on future water demand be incorporated into a predictive model.

APPROACH TO THE PROBLEM

In light of the material presented, it is possible to determine an approach to the problem. This approach must be designed in view of the limited amount of water-related data available in Canada.[19] A primary requirement of this approach will be flexibility, both in terms of the number of factors included in the model, and in terms of the precision of the relationships. As more data become available, the important variables in the forecasting problem will emerge, and possibly some variables excluded from the initial formulation will be included. This type of situation arises in considering cost. The role of water cost in reducing the demand at the present time is not known, although it is possible to suggest a functional form for this relationship. At present, water cost can be defined as a dependent function of water intake. As the project continues it may become possible to convert water cost into a determinant of water demand. With regard to other relationships in the model, estimates may be made for secondary sources which will enable some water demand forecasts. However, as better data become available, the model must be amendable to up-dating, parametric change, etc. This is particularly true in the portions of the model concerned with technological change.

The simulation model which is suggested in the following section has been designed to achieve the flexibility necessary given the state of Canadian water demand information. Each of the important determinants of water demand will be dealt with in its own module. These modules will be amenable to updating of the information base. For the first attempt we have been forced to use general coefficients of water use. As the data from the joint Statistics Canada – Environment Canada survey of industrial water use[20] become available, these coefficients will be discarded in favour of concrete data.

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16. Nelson, W.L. "Future Water Requirements of Refineries", *Oil and Gas Journal*, vol. 61, #37, 1963, p. 118.

17. Nelson, W.L. as cited in Bower, B.T. op. cit. p. 156.

18. These figures refer only to gross water requirements in refining pig iron to raw steel ingots. They are drawn from: Tate, D.M., op. cit. p. 38.

19. A summary of the state of Canadian data on industrial water use may be found in: Tate, D.M. *Water Use in the Canadian Primary Manufacturing Industry*, unpublished manuscript, 1972, pp. 4-6.

20. Arrangements for this survey are now essentially complete. The questionnaires will be distributed to major water using manufacturing industries (i.e. those using over 10 million gallons per day). Workable results may be expected in the autumn of 1973.

An Industrial Water Demand Simulation Model

The previous section has identified several important determinants of industrial water demand. These must be linked together to form a useful forecasting model. The approach used here is based upon simulation modelling. At first, it will not be possible to define relationships in a sufficiently mathematical manner to take full advantage of the simulation technique. However, this precision will be attained in the future; in the interim, the simulation approach will organize the concepts in a useful manner.

This approach was selected to allow a breakdown of the water demand forecasting problem into its individual variants. Since each major variable has its own module (see Figure 2), the flexibility required in the problem will be built into the model. This flexibility is necessary, given the nature of Canadian water use data. Flexibility is also desirable because of the tentative nature of some relationships. For example, we cannot make water cost a determinant of demand since no Canadian information is available on the nature of this relationship. The best that is possible is an estimation of water cost to the industry based upon the amount used. As more data become available it may be possible to define the role of cost as a determinant of water demand.

In summary, the model put forth here is a hypothesis intended solely as a means of including the relevant variants of the problem, with relationships defined as well as possible. As work progresses, the data base and the relationships of the model will be altered to conform with available information. This type of model is consistent with the philosophy that a forecasting model must be amenable to parametric change and re-evaluation. In other words, a forecasting model must be under constant scrutiny and evaluation in light of actual experience in order to attain maximum utility.

THE PRIMARY BREAKDOWN – POSITIVE AND NEGATIVE WATER DEMANDS

In all literature on industrial water utilization, gross water use is defined as the total amount of water used in

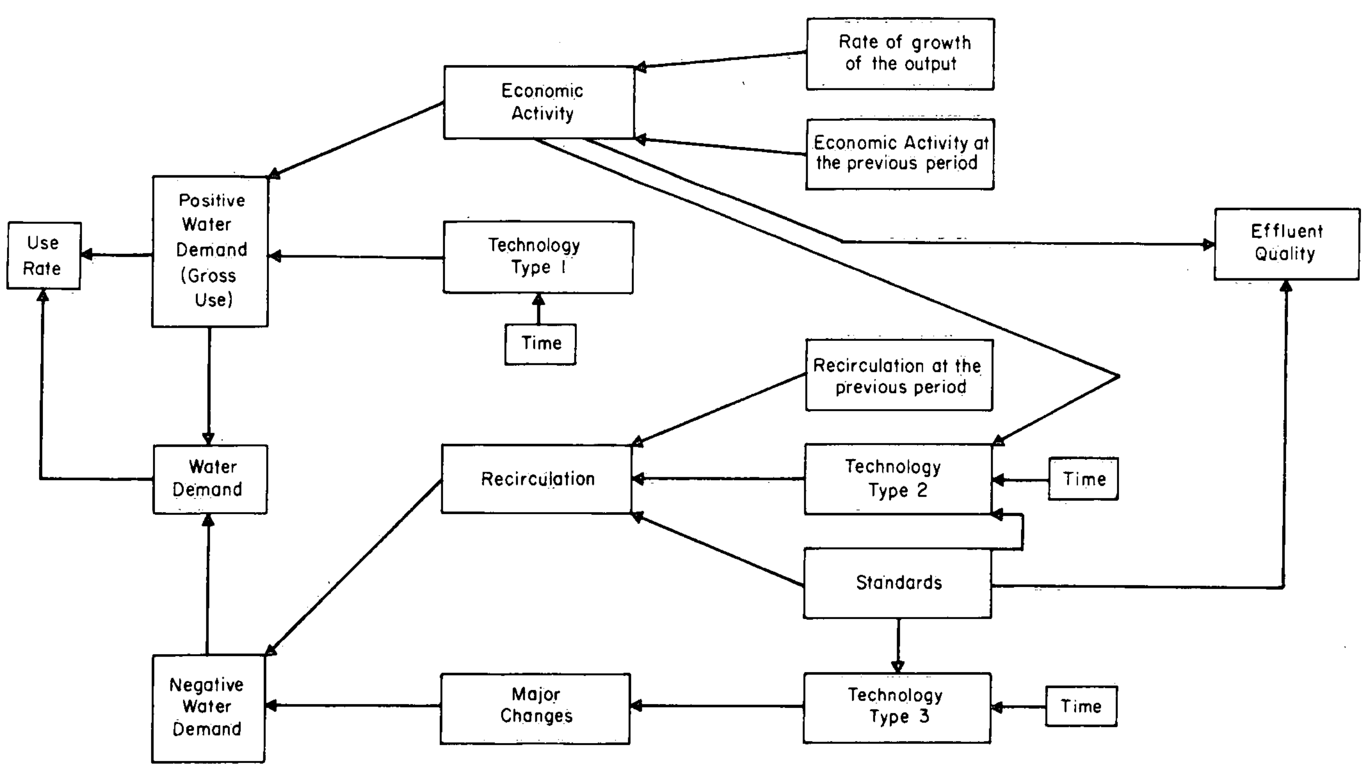

Figure 2. Flowsheet of industrial water demand model.

product manufacture. This quantity is composed of new water intake and recirculated water. In this paper, *water demand,* the subject of investigation, is taken to be the amount of new water intake. The new water intake at a plant can serve several functions in plant operations, among them cooling, processing, and make-up water in the steam production equipment. Water consumed during production averages between 3% and 15% of total new water intake. Water effluent from the plant is equal to total water intake less water consumption. Forecasting water demands as total water intake is valuable in two ways. First, it permits conclusions as to minimum flows required in specific areas. Secondly, and more important, such a method permits prediction of rates of effluent-discharge at any point in the river basin. The ability to predict the latter will give insights into future industrial waste loadings by industry.

Water demand has a positive component, gross water use, and a negative component, recirculation. In other words, forces tending to increase water demand act upon gross water use, while those tending to decrease water demand act mainly upon recirculation. This relationship can be stated mathematically:

$$WD_t = PWD_t - NWD_t \qquad (1)$$

where: WD_t is the water demand in period t; in million gallons per day (Mgd)

PWD_t is the positive water demand in period t, in Mgd

NWD_t is the negative water demand in period t, in Mgd

FACTORS AFFECTING POSITIVE WATER DEMAND: AN EXAMINATION OF GROSS WATER USE

Gross water use is a function of two major variables, the level of economic activity, and technological trends[1]. In concise terms, and using gross use to represent positive water demands:

$$PWD_t = GU_t$$

$$GU_t = f\,(EA_t\,,\,T_t') \qquad (2)$$

where: EA_t is the economic activity levels in time t, in appropriate units depending upon the industry

T_t' is the technological change affecting water requirements per unit of output in time t.

Measurements of economic activity levels can be in a variety of forms, the most common being output, value added, or input. Usually the best place to measure these levels are at a spot in the production process where raw materials or outputs blend into a common product. In the petroleum-refining industry, where there are a large number of outputs, the best place to measure activity levels is at the initial point of manufacture – input into the crude distillation unit. On the other hand, in the iron and steel industry with a number of inputs and a large number of outputs, an intermediate point in production – the output of crude-steel ingots – is possibly the best place to gauge activity levels. Final demand levels, the term for growth rates can usually be converted into units corresponding to the point where economic activity is measured.

Economic activity levels, as discussed in the previous chapter, are related directly to water utilization. In general, the more of a good produced, the more water used. A coefficient of gross water use may be used to link activity levels to water utilization. The effect of technology on gross use may be positive (increasing gross use) or negative (decreasing gross use). To derive a relationship, let it be assumed that gross use is inversely proportional to the technical change. Now, it is possible to define the relationship set forth in (2) as being:

$$GU_t = \frac{a_1 EA_t}{T_t'} \qquad (3)$$

where: a_1 is the coefficient of gross water use per unit of activity.

The variables in (3) can be defined more precisely. Economic activity levels in any period are related to levels in the preceding period, and sometimes to levels two periods past. In this model, a one year time lag is incorporated, and the present levels are related to the preceding period by the observed product growth rate in the following manner:

$$EA_t = (1+k_1)\,EA_{t-1} \qquad (4)$$

where: EA_{t-1} is the economic activity level in the preceding period

k_1 is the observed growth rate per period (usually annual), measured in terms of percentage change in output.

A constant rate of growth (perhaps the average over 10 years) has been assumed in this formulation. If, for example k_1 equals 4%, $(1 + k_1)$ equals 1.04, and that constant times the activity level in the previous period will give the forecast activity in the specified period.

The relationship given in (3) for technological effects on water use was somewhat arbitrary in assuming an inverse relationship between gross use and technical change. A direct relationship is also possible here. However, as long as the model is consistent, the nature of the relationship will be correct. Technological improvements are generally a function of time. This type of change is exogenously determined, and may increase or decrease over time. It can be assumed for simplicity that the change is constant over time, smoothing out the probably more realistic step-wise function. The initial value for T'_1 should be 1, and will increase at a constant rate for the following periods. (This, in effect, amortizes the effect of technological change on gross use, over time). The amount of the weight given to the change will be determined by a coefficient relating the change to the percentage change in gross use. This relationship should take the following form:

$$T_t' = 1 + \frac{k_2 t}{100} \qquad (5)$$

1. This is the first of three technology variables.

For example, if $k_2 = 1$, the value of T'_t after the first period will be 1.01, after the second period it will be 1.02, etc. As formulated, this relationship means that the given technical change will have a constantly increasing effect on T', and by equation 3, a constantly decreasing effect on gross use. If the technical change is such as to have an increasing effect on gross use, k_2 will be negative. Another situation occurs in which the change will affect gross use upon its incorporation into the process, but will not be of a constantly increasing or constantly decreasing nature. In other words, there will be a step-like change in gross use. In this case, after the period in which the change takes place, T'_t can be held constant. This flexibility is built into the model to take account of the many possible ways in which technological change will affect gross use.

FACTORS AFFECTING NEGATIVE WATER DEMAND: AN EXAMINATION OF WATER RECIRCULATION

Negative water demands are determined by the amount of water recirculated in an industry and by technological change which affects recirculation technology, or completely alters the pattern of water use at a plant, such as a switch to air cooling. The latter change is built into the model specifically because, while it is only a sporadic one it may have a large impact on the water demand of a plant. The hypothesized relation is:

$$NWD_t = R_t + a_2 MC_t \qquad (6)$$

where: R_t is the water recirculated in period t.
a_2 is a coefficient specifying the amount of water presently in use which will not be required after a major change in water using technology, in Mgd
MC_t is the major changes in water using technology.

This relationship implies that all recirculated water is part of negative water demand, and from the commonly held definition of recirculation[2] this implications seems logical. The major change component a_2 indicates the amount of water which is saved through diminished requirements after the major technological change. For example, if a plant switches to an air cooling system in period 5, and thereby saves 100,000 gallons of water, $MC_5 = 1$ and $a_2 = 0.1$ million gallons per day.

The examination of the factors affecting recirculation is central to the problem of forecasting water demands. The next equation deals with these factors and postulates some general relationships which will be useful in analyzing this parameter of water use. The variables included are the imposition of effluent standards, technological change as it affects recirculation, the amount of water recirculated in the previous period, and the added recirculation due to additions in gross use. The relationship will be of the following form:

$$R_t = R_{t-1} + a_3 T_t'' + a_4 (S_{t-1} - S_t) + \left(\frac{R_{t-1}}{PWD_{t-1}} PWD_t \right) - R_{t-1} \qquad (7)$$

where: R_{t-1} is the recirculation in period t-1, in Mgd
a_3 is the amount of water affected by T_t''
T_t'' is the technological change affecting water recirculation
S_t is the value of the imposed effluent standards in pounds per unit of production in period t
S_{t-1} is the value of effluent standards existing in period t-1 in pounds per unit of production
a_4 is the amount of the change (usually in recirculation) which will be induced by the imposition of effluent discharge fees in period t.

T_t'' is assumed to be a 0 — 1 type of variable, whereby the technological change vis-a-vis recirculation either occurs or does not occur. A coefficient a_3 relates the occurrence of a change in T" to the new amount of recirculation, and is measured in millions of gallons per day. The imposition of effluent standards, as outlined in Chapter 2, will probably have the effect of inducing increased recirculation. The relationship suggested is quite hypothetical as there is no precise way to determine the effects of standards on recirculation. Equation 7 suggests that increasingly stringent standards $(S_{t-1} - S_t)$ can be related to the increase in recirculation through a coefficient a_4 measured in million gallons per pound of imposed or increased effluent standard. The terms are ordered in the designated way to obtain the necessary positive relationship. It is assumed that standards imposed in period t will be more stringent than those existing in the previous period. Thus the value of S_t will be *lower* than the value of S_{t-1}. It is clear that if there are no technological changes affecting recirculation, or no changes in effluent standards in time t, the amount of water recirculated will be equal to the amount recirculated in the previous period plus the increase due to added production, which is defined by:

$$\left(\frac{R_{t-1}}{PWD_{t-1}} PWD_t \right) - R_{t-1} \qquad (8)$$

The relationship set up in equation 7 thus takes into account many of the determinants of recirculation. These have been included so as to increase the ultimate flexibility of the model. If information pertaining to one of the included variables is unavailable, the variable can be omitted without destroying the usefulness of the model. The more relevant the variables that are omitted, the less reliable the model will be.

The amount of S_t will actually be a constant k_3 measured in terms of pounds per unit of economic activity. It is clear that in the simulation, k_3 can be modified, enabling the analysis of the effects of modified (or newly imposed) standards.

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2. See for example Bower, op. cit., p. 147.

Technological advances affecting water recirculation may be difficult to identify, and still more difficult to quantify. In the past, the information available on this subject, has been sparse, since industrialists have not been concerned with water conservation. In making forecasts of real life situations, it is probable that this area would become the subject of detailed questionnaires. An alternative is to assume that such technological changes do occur, and to set up some arbitrary rules for their entry into the model. These rules would of course be based upon all the fragments of information available. Likewise, the coefficient a_3 could be arbitrarily selected to be quite small in relation to total recirculation. Such a set of rules could be formulated as follows.

T''_2 will assume the value of one when two of the following three conditions are met:

1. when the output has grown by more than 50%, or

$$\frac{EA_t - EA_0}{EA_0} \times 100 > 50$$

2. when the value of effluent standards decreases (i.e. increased stringency) by more than 10 pounds of waste material per unit of activity, or
3. when a specified number of years have elapsed; assume five years.

It is obvious that this is a very arbitrary set of rules, and that such a procedure involves more "educated guesses" or "out-of-the-window estimates" than scientific investigation. Nevertheless, this capacity is believed to be a necessary part of the model to provide required flexibility. The relationship, after all, needn't be used if it is deemed too uncertain. However, it is methods like these, based upon some foundation in fact, which will enable the use of the model in testing alternative assumptions. After careful study, it was found that this is the best method of speculating about future trends in recirculation technology.

The factors governing major changes in technology affecting water use are again time dependent.

$$MC_t = T_t'''$$

where: T_t''' is a 1 – 0 type of relationship whereby the major change occurs or it does not.

First of all, T_t''' is suggested to be a function of the imposition of effluent standards, and time. The technical literature indicates that a possible way to abate water pollution is to employ air cooling, thus using less water. In this way, effluent standards can be met. On the other hand, the evolution of industrial methods alone can modify the water-using characteristics of an industry. It is suggested that, as a preliminary procedure, the model use a conditional type or relationship to determine whether T''' becomes operative. According to our discussion, to deal with these variables, a set of rules governing when T''' assumes a value of 1 may be hypothesized in a manner similar to that outlined previously.

$$T_t''' = f(S_t, t)$$

DISCUSSION OF THE MODEL

Chapter 4 of this report will deal with some examples of operations possible, using the model. Before preceeding with these applications, some of the more general aspects of the model will be discussed.

Verification In order to test the effectiveness of the model in simulating accurate observations, an approach using a random number generator was used. Data representative of 1960 conditions in the iron and steel industry were estimated, along with the relevant parameters required by the model. A range of variation for these parameters was selected, and it was assumed that deviations from mean conditions would have a normal distribution. Using a table of random normal deviates, observations were generated for the period between 1960 and 1970. On the basis of these normalized data, forecasts of water demand in the industry were made for 1970, a year for which real data are available. Twenty such simulated forecasts were made. In 11 cases, the resulting forecasted water demand was within 10% of the observed value. (i.e. within a band the limits of which were 5% on either side of the observed value.) A wider band covering 15% on either side of the observed value encompassed 17 of the 20 simulated runs. The conclusion to be drawn is that the model will generate accurate forecasts of water demand, given accurate data and assumptions about future industrial morphology.

Versatility The design of the model is based upon the need for versatility in water demand forecasting. The model is applicable to many different situations and problems, which may be classified into two main types, the complexity of the forecasting method and the kind of forecast required.

The complexity of the forecasting method refers to the number and types of variables used in the forecast. By omitting the modules referring to technology change and effluent standards, the model reverts to the simple coefficients approach, where generalized coefficients are applied to forecasts of future economic activity to obtain the water demand forecasts. The incorporation of more variables, such as technological change, and the imposition of effluent standards, brings the model more in line with reality. Further alteration will add more variables, such as water cost, to improve the investigative power of the model. In addition, each of the existing modules could be broken down into finer detail to become sub-routines. This step would also add to the number of situations which could be investigated. However, the model as it has been presented seems powerful enough for our purposes without too much alteration.

The kind of forecast required refers to the *areal scope* of the study in which the model is used, or to the *activity* (e.g. water use in a specific industry) under investigation. Most important at present for the Environmental Management Service is the need for forecasts of water demand for specific *river basins*. Clearly, the parametric content of the model can vary for different river basins; many of these parameters can be determined by preliminary research. Once these have been obtained, they can be incorporated in the model to obtain unique river basin forecasts. The last part of this chapter will cover the linkages between the industrial model and municipal models. With these two types of models available, the application to river basin problems is even more apparent. These same points pertain to forecasting *regional* water demands. The model is also useful for estimating *national* patterns of future water demands. Such forecasts provide a framework for constructing regional or river basin forecasts. Thus, the proposed simulation model is adaptable to any areal base uses in water management studies in Canada. The forecasting problem may also be approached from an industry-by-industry, or a municipality-by-municipality point of view. For example, if the pulp and paper industry is the main subject of study, the model can be constructed using parameters drawn from that industry.

The Effects of Policy In the forecasting of water demands the effects of government policy must be taken into account. The role which the imposition of effluent standards may play in water demand by industry has already been outlined. The effects of this policy alternative are explicitly built into the model. This feature allows the policy maker to examine the effects of varying proposed standards.

This model will be useful to the river basin planner examining the effects of various development alternatives for the river basin under study. The forecasting model developed for this particular basin will determine the effects of different alternative futures upon water use and waste loadings.

Expandability The structure of the simulation model has been constructed in blocks or modules. This type of structure enables incorporation of more variables as these are found important in the forecasting problem. On the other hand, components which are already in the model can be discarded if future study should prove them unnecessary. Some of the subjects for future incorporation are water costs, raw materials used in production, and linkages between industrial sectors or other water uses.

The case of water costs is used as an example. Chapter 2 suggested that the costs of water use are important in determining the water demand of an industry. At this time, no Canadian data exist on the costs of water use in industry and thus relationships between water cost and use are impossible to define. These inter-relationships are in fact implicit in the model as it now stands. The effects of technical changes on water recirculation are presently given by a coefficient, whereby a given technical change results in a change in water recirculation of X gallons per unit of activity. Information on the structure of water cost will enable the construction of a sub-model where water recirculation will be a function of water cost. The given technical change will cause a variation in water cost which will in turn affect recirculation. In this way, it will be possible to discard the use of coefficients in favour of a precise relationship.

Information Requirements The model as presented above requires prior estimation of three constants and four parameters. This estimation will be a major task in the development of specific models, and will require a good deal of background research. The following section will outline some of the general information requirements for the model, and the degree of accuracy possible in estimating the constants and parameters.

The constants in the model, k_1, k_2, and k_3 refer, respectively, to the growth in economic activity per period, the effect of technology on gross use, and the value of any imposed effluent standards. The growth in economic activity may be generated from available statistics for the recent past. Projection of future production may be done by linear extrapolation of the growth trend, or by a more complex model. Frequently, such projections are available from agencies dealing with the specific activity under study. The second constant is very difficult to measure, as it implies detailed knowledge of the way in which past technological changes have affected gross use. This information is seldom available in any form, and especially not in Canada. In technical journals, and other literature, scattered information on this subject can be found but such sources are usually incomplete. Given this situation, k_2 will be an assumed value, based upon whatever data are available. The third constant refers to imposed effluent standards in pounds per unit of economic activity. If no standards exist, this constant is the amount of waste material presently in the effluent from the industry or plant under study.

Parameter a_1 is the gross water use per unit of economic activity. Estimates of this parameter are readily available. The second parameter refers to the effect on negative water demand of major changes in the water using system of the industry. Like k_2 this value is very difficult to determine, and will probably be an "educated guess" based upon available information. The latter statement is also true in regard to parameter a_3, which gives the amount of added recirculation induced by changes in technology. The effect of effluent standards on recirculation is not yet available, and in the earlier stages of use of the model will probably be handled like k_3. With the imposition of effluent standards in Canadian industry, this information may become available in the future.

Major Limitations of the Model This model is dependent upon the estimation of several values, data for which are not readily available. The foregoing paragraphs outlined the nature of these values. Information conditions are such that some of these parameters require estimation, sometimes based upon very sparse data. These parameters cannot be dropped from the model without resulting loss of flexibility. Sensitivity analysis on the parameters and constants provides one way of coping with the approximations required. By varying each parameter in turn with the model otherwise static, the effect of the parametric value upon the forecast can be traced. Such an analysis was carried out on the model. The results are outlined in Chapter 4.

A second limitation on this type of model is the availability of manpower and financial resources for its development. To obtain a high degree of precision in the model, parameters will require large financial expenditures and manpower commitments. However, for Water Management Service (WMS), purposes, it is felt that the model can be used right away, and it is intended that this be demonstrated in the near future. Hence, the high degree of sophistication possible with the model is not required immediately. Manpower and financial resources do not pose immediate limitations, although they will affect the speed of work output.

The third limitation is the unavailability of information on water cost as it affects water demand. Most of the cost relationships are implicit in the present model. To better define these relationships, and also to define more precisely those independent variables helping to determine water demand, are the principal future development directions which the model will take.

Simulated Water Demand Forecast and Sensitivity Analysis

This chapter is based upon a hypothetical industry in one of the river basins in Canada. It is intended to demonstrate the usefulness of the model, rather than to produce results pertaining to real situations. This procedure may be unwise in view of the need to produce real results and forecasts. However, it is by far the simplest and quickest means of showing the operations of which the model is capable. Work is underway to model the future water demand in an actual situation, but this is not yet ready for release. It is desirable to report the initial results here. The real-life example will be reported upon as work progresses.

THE HYPOTHETICAL MODEL

The industry selected for modelling has an initial economic activity level of 100 units in year 0. Each unit refers to a specific package of inputs or outputs depending upon the type of industry. For example in the petroleum refining industry, one unit of economic activity may refer to 1,000 barrels of crude oil processed per day. The forecasting horizon is 20 years. The annual growth rate, based upon the recent past and projected demands, is forecast to be 4% for the first eight years, at which time increased product demand will raise the growth rate to 6%. At year 15, the growth rate declines again to 4%. The progressive effects of time on gross use is taken as a constant and given the value 1 per annum. There are initially no effluent standards, and waste discharge measured in terms of Biochemical Oxygen Demand (BOD), is 146 pounds per day per unit of activity. Forecasts of regulations in this field indicate that standards will be imposed in year 10, and will fall to 100 pounds per unit and then to 75 pounds per unit at years 10 and 17 respectively. These specifications indicate the values for some areas of the model:

$EA_0 = 100$

$k_1 = .04$, changing to .06 in year 8, and back to .04 in year 15

$k_2 = 1$

$k_3 = 146$, changing to 100 in year 10, and 75 in year 17

Average water use data indicate that gross water use is 12,000 gallons per unit of activity, and that, of this amount, 2,000 gallons is recirculated water. After 11 years gross use will decrease to 10,000 gallons per unit, with the same recirculation. A technological forecast has indicated that a switch to air cooling in one of the productive processes will probably occur in year 6, resulting in a 100,000 gallon per day increase in negative water demand. The impact of the imposition of effluent discharge fees upon water use cannot be predicted accurately, but is postulated to be quite small. It has arbitrarily been set at .002 million gallons per pound for present purposes. Another effect on recirculation will occur when T'' becomes 1, such that when T'' = 1, then .05 million gallons are added to recirculation.

Summarizing this information:

$a_1 = .012$, decreasing to .010 in year 11

$a_2 = .1$

$a_3 = .05$

$a_4 = .002$

T'' will become 1 when either $t > 5$, or $S_t - S_{t-0} > 10$, or $\frac{EA_{tn} - EA_0}{EA_0} \geq .5$

This completes the specification of the model. Table 1 gives the detailed calculations for each annual iteration of the model. Figure 3 charts these figures, and gives a graphical representation of the results. The assumptions set forth in year 0 for the model result in a 150% increase in production of this industry over 20 years. The positive water demand increases by 93% from 1.2 million gallons per day to 2.32 million gallons per day. Accompanying this increase is an increase of 300% in negative water demand, from .2 MGD to .8 MGD. The net effect of these changes is a 52% increase in the water demand of the industry. The use rate for the plant is an index of recirculation in the industry, such that an increase in the rates indicates an increase in recirculation of water. This rate is formed by the ratio of gross use to water intake. The model shows that the use rate increases from 120 at year 0 to 154 at year 20, indicating the strong effect of negative water demand of net water demand. The amount of BOD generated at year 0 is 7.3 tons per day. The model indicates that despite the imposition of effluent standards the gross amount of waste rises by 28% at year 20. This indicates that the effluent standards as set at year 0 are not stringent enough to roll back water pollution from this industry.

SENSITIVITY ANALYSIS OF THE PARAMETERS AND CONSTANTS

In order to assess the stability of the model under uncertain conditions, sensitivity analysis was performed on

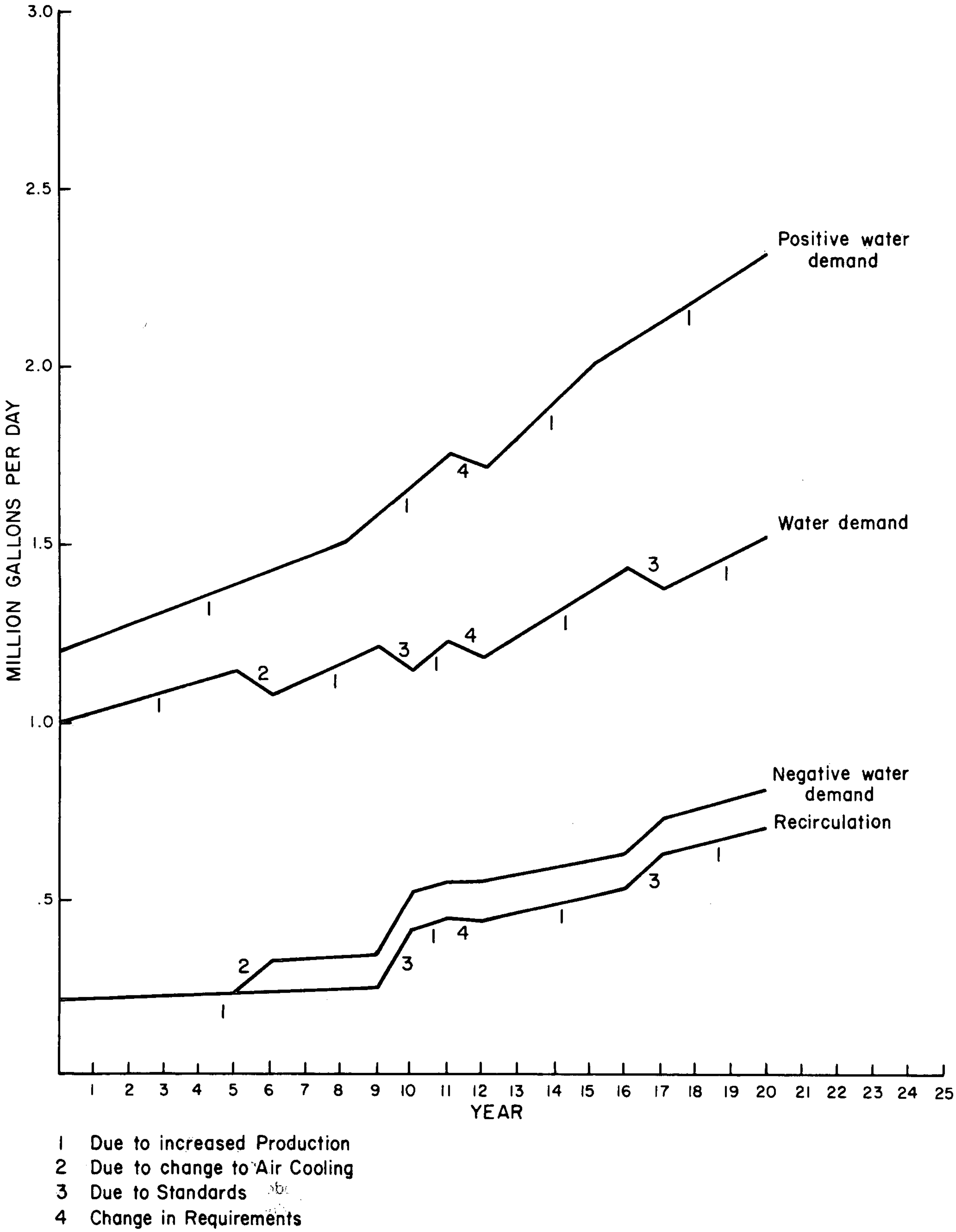

Figure 3. Positive, negative, and net water demands over 20 years.

Table 1. Sample Simulation of Industrial Water Demand

(water figures in Mgd)

YEAR	EA	T'	a_1	PWD	S	T''	R	T'''	MC	NWD	WD	EQ	UR
0	100	1	.012	1.20	146	0	.200	0	0	.2	1	14600	120
1	104	1.01	.012	1.24	146	0	.207	0	0	.207	1.03	15184	120
2	108.2	1.02	.012	1.27	146	0	.212	0	0	.212	1.06	15797	120
3	112.5	1.03	.012	1.31	146	0	.218	0	0	.218	1.09	16425	120
4	117.0	1.04	.012	1.35	146	0	.225	0	0	.225	1.12	17082	120
5	121.7	1.05	.012	1.39	146	0	.232	0	0	.232	1.16	17778	120
6	126.5	1.06	.012	1.43	146	0	.238	1	1	.338	1.09	18469	130
7	131.6	1.07	.012	1.48	146	0	.247	1	1	.347	1.13	19213	130
8	136.9	1.08	.012	1.52	146	0	.253	1	1	.353	1.17	19987	130
9	145.1	1.09	.012	1.60	146	0	.266	1	1	.366	1.23	21184	130
10	153.8	1.10	.012	1.68	100	1	.421	1	1	.521	1.16	15380	145
11	163.0	1.11	.012	1.76	100	0	.441	1	1	.541	1.22	16300	145
12	172.8	1	.01	1.73	100	0	.441	1	1	.541	1.19	17280	145
13	183.1	1.01	.01	1.81	100	0	.461	1	1	.561	1.25	18310	145
14	194.1	1.02	.01	1.90	100	0	.484	1	1	.584	1.32	19410	145
15	205.8	1.03	.01	2.00	100	0	.510	1	1	.610	1.39	20580	145
16	214.0	1.04	.01	2.06	100	0	.525	1	1	.625	1.43	21400	145
17	222.6	1.05	.01	2.12	75	1	.640	1	1	.740	1.38	16605	154
18	231.5	1.06	.01	2.18	75	0	.658	1	1	.758	1.42	17362	154
19	240.7	1.07	.01	2.24	75	0	.676	1	1	.776	1.46	18052	154
20	250.4	1.08	.01	2.32	75	0	.700	1	1	.800	1.52	18780	154

Overall Effect

EA = + 150%
PWD = + 93%
R = + 250%
NWD = + 300%
WD = + 52%
EQ = + 28%

Identification

EA = Economic Activity
T', T'', T''' = Technological Change
a_1 = Water requirements
PWD = Positive Water demand
S = Standards

R = Recirculation
MC = Major Change
NWD = Negative water demand
WD = Water demand
EQ = Effluent Quality
UR = Use Rate

each of the constants (k) and parameters (a). The results reported below deal mainly with the behavior of the model varying one item at a time. An analysis was also made of joint variations in k_1 and k_2. It is apparent that there is an infinite number of combinations.

Figure 4 shows the results of the sensitivity analysis of k_1 and k_2. The forecast horizon used was 10 years. Each point on the graph gives the results of the predicted water demand over the 10-year period. To examine the overall effect on water demand due to a modification of k_1 and/or k_2, a comparison is made of the original assumptions and the new assumptions on economic growth and technological change. The actual quantities of water demanded are given on the vertical axis of the graph. For example, consider point P_0 of Figure 4, the result of a 10 year forecast with the economic activity growth rate at 4% per annum (given on the horizontal axis) and the effect of technology on gross water use assumed to be 1 per annum. The forecasted water demand is 1.34 million gallons per day. Now, independently of k_1, if k_2 is assumed to be 2, the water demand forecast falls by 8.3% to 1.23 Mgd. (P_2). If, on the other hand, independently of k_2, k_1 is assumed to be 5% per annum, forecasted water demand rises 10% to 1.48 Mg. (P_3). Similarly the effect of joint variations in k_1 and k_2 may be examined. For example, if k_1 is assumed to be 6% instead of the original 4%, and k_2 originally assumed to be 2 is increased to 3, the forecasted water demand increases from 1.23 (P_2) to 1.38 (P_3), an increase of 11.7%.

Further, the information displayed in Figure 4 will give ranges of predicted water demand under uncertain assumptions regarding the constants of the model. For example, Range A shows the forecasted water demand given that the analyst believes that (i) the growth rate will lie between 4% and 5% annually, and that k_2 is between 2 and 3. The maximum possible overestimation is 19.5% over 10 years. The predicted water demand will lie between 1.14 Mgd. and 1.36 Mgd.

Variations in k_3, relating waste loading to the level of output, are passed directly on to final waste discharge. In other words, a fall in the assumed waste loading per ton will result in a 10% decrease in total waste discharge. The parameter a_1, the gross water use per ton of output, behaves in a similar manner. A 25% decrease in this factor results in a 25% decrease in final predicted water demand other things being equal. The other parameters are direct in their effect on the model output. For example, an increase in the parameter relating major change to negative water demand of 100,000 gallons per day (i.e. a_2 = .61) will mean a corresponding decrease in forecasted water demand.

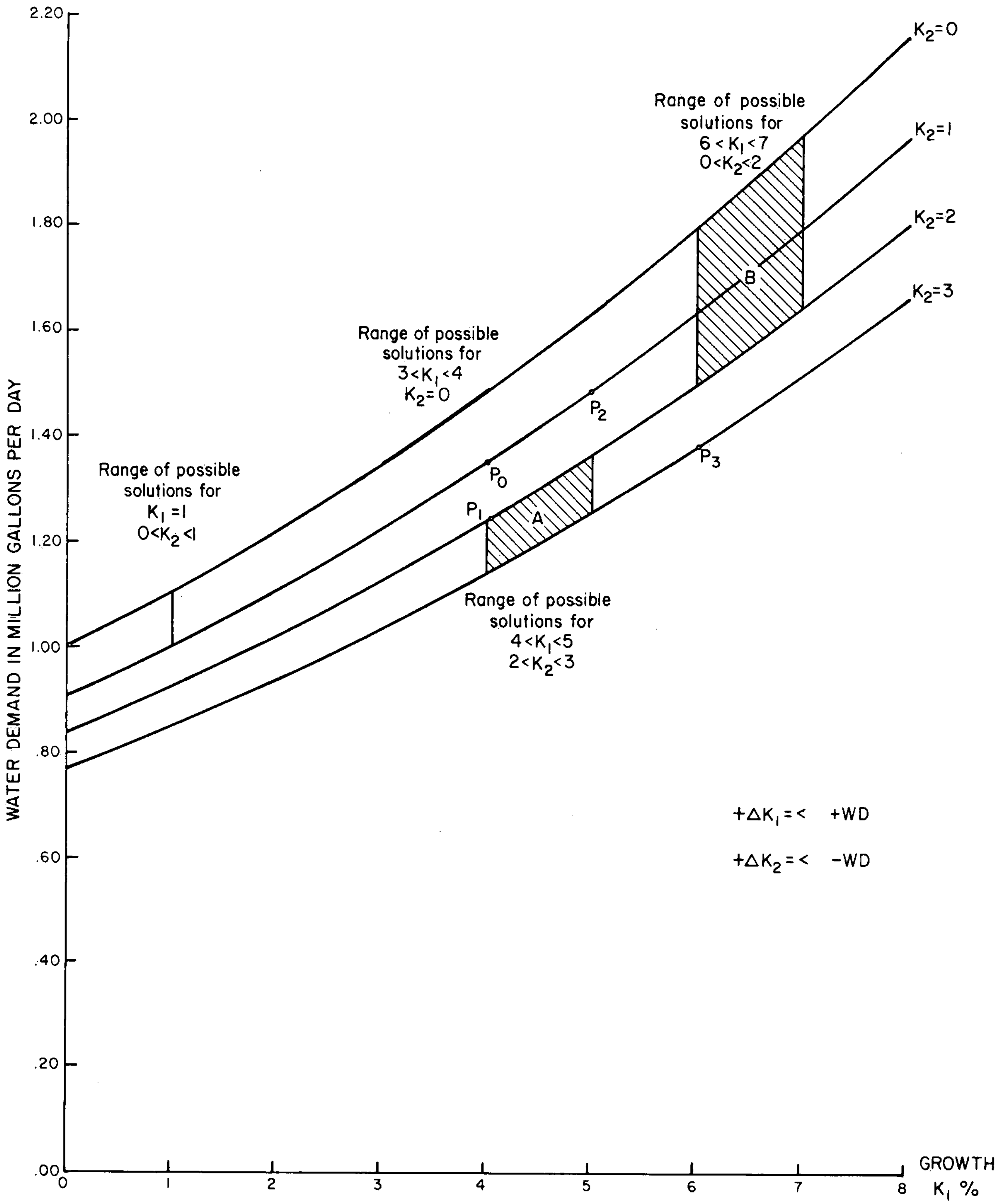

Figure 4. Sensitivity analysis of growth (k_1) and technological change (k_2).

EXTENSIONS OF THE MODEL

It is clear that an economic sector or sub-sector cannot be viewed as separate from its surrounding environment, but has linkages to other sectors. Earlier in the paper it was mentioned that the model built up here can be extended and tied into other sectors. This section will explore briefly the nature of these linkages. The aim here is not to be exhaustive in covering this field, but simply to scan the other areas of interest to the water manager. This outline should add evidence as to the versatility of the model.

Other Industrial Sectors The components of the industrial sector are interrelated in a complex fashion. For example, the petroleum-refining industry and the iron and steel industry have obvious linkages in that expansion in the latter, caused say by an increased demand for automobiles, will tend to generate expansion in the former. These complex linkages between industries have recently been the subjects of input-output analysis, both in Canada and in other countries. For Canada, national input-output coefficients have been produced by Statistics Canada for 1961. Although we have no time series on the resulting technological coefficients, an estimate may be derived as to the quantitative relationships between industries. Using the interrelations defined by the input-output coefficients, it is possible to trace the effects of growth in one industrial sector on the growth of other industries.

By using this method, the industrial model becomes extremely complex. The aggregate model will have to be solved simultaneously for each component, possibly incorporating time lags as well. The growth rates for each industry will be composed of (i) the rate of growth of final demand, and (ii) the impact of growth in other industries. The mechanical aspects of this enlarged model remain to be worked out. Future work will include computerization of the model to allow manipulations of the complex relationships which have to be built into it.

The Municipal Sector In constructing demand forecasts for an economy, the municipal sector is an important component. Factors such as residential demand, commercial demands and demands by the public sector are major sub-components. Within these, a diversity of variables have to be considered, such as birth-death rates, immigration-emigration, peak loadings, and water price. Again, the quality of flexibility is vital in the forecasting model. There is available a preliminary model of municipal demand, which is to be linked to the industrial model developed in the paper. The major linkage between the models will be the growth rate of industry, for an expanding industry creates employment which leads to municipal growth. This linked municipal-industrial model is under development at present.