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REFINEMENT OF TECHNIQUES FOR WATER DEMAND FORECASTING: A REVIEW OF SOME CANADIAN CONTRIBUTIONS

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The development of accurate forecasts of future demands is one of the most important tasks in water planning, but until recently it has been one of the most neglected. In part, this has been the result of the traditional supply-orientation of the water industry, particularly in countries where supplies are plentiful and there is no shortage of capital for development. In contrast with the situation in many other resource industries, such as petroleum, natural gas, or agriculture, relatively little effort has been devoted towards the development and application of sophisticated techniques for forecasting water demands.

A number of recent discoveries, however, have underlined the need to remedy this deficiency. Amongst these are the anticipated major water scarcities in several regions of the United States (U.S. National Water Commission, 1973), the United Kingdom (Water Resources Board, 1974), and elsewhere (White, 1976) by the end of the century. Another is the recognition that capital requirements for water development projects are likely to skyrocket in the next few decades (Sewell, 1976). Both discoveries emphasize the need for a

shift from the traditional "extensive" approach in water management to a more "intensive" one in which demand is the primary focus in planning.

The need for improved techniques for water demand forecasting has been recognized by scholars, administrators and policy-makers in several countries. Major efforts have been made to identify and measure the factors underlying demands for particular water uses, and to develop aggregate models covering water use as a whole. While most of the research has been done in the United States, there have been some important contributions in several other countries, including the United Kingdom, Hungary, and Canada. The United Nations Secretariat has also undertaken some valuable work in this regard (United Nations, 1976).

This paper presents a review of attempts to refine water demand forecasting techniques, particularly in connection with residential, industrial, agricultural and recreational water use. The review begins with a description of major trends in the field, based particularly on work undertaken in the United States. It then turns to a discussion of contributions of Canadian researchers, particularly since the publication of the volume on *Forecasting the Demands for Water* in 1968 (Sewell & Bower, 1968). The present paper is intended as a complement to a much more detailed discussion by Tate (1977).

Major Trends in the Field

The search for improved techniques for water demand forecasting in the past decade has shown some important shifts in approach, an increasing sophistication in research methodology, and some major progress with respect to forecasting of demands in certain sectors.

Changing Approaches

The traditional approach to water demand forecasting has been to prepare a simple linear projection of past experience of per capita consumption or consumption per unit of product. More refined versions take into account such factors as per capita income, the level of saturation of water-using devices, or costs of supplying given volumes of water.

The requirements approach is widely used throughout the water industry and by water resource planners. It is used in the preparation of specific proposals for the expansion of water supply systems, electric power schemes, waste disposal facilities or irrigation schemes. It is the main method employed in developing forecasts of aggregate water uses at the national level. Illustrations include the forecasts prepared by Wollman for the United States (Wollman & Bonem, 1971) and the Water Resources Board for the United Kingdom (Water Resources Board, 1974).

Several researchers in recent years have criticized the requirements approach to forecasting on the grounds that it fails to recognize the influence of price on demand (Milliman, 1963). They charge that this failure may have led to the over-expansion of water systems and serious social costs resulting from foregone opportunities for the resources devoted to their development (Hanke & Davis, 1974). Several attempts have been made to overcome these deficiencies, such as those by Boland and Mallory (1973) who apply a computerized model to estimate the components of municipal water demand. It estimates demand on the basis of forecasted values of a number of water use parameters. These are derived from projections based on historical data, correlations, and independent forecasts. Price is included as a variable in the forecasts of residential water use only. Other studies taking price into account include Darr, Feldman and Kamen (1976), Berry and Bonem (1974), and Katzman (1977).

Thus far the major emphasis in demand forecasting has been on individual sectors, such as residential, industrial, or irrigation demand. Work by Grima (1972) on residential demand, Mercer and Morgan (1972) and Rees (1969) on commercial and industrial water use, and Ruttan (1965) on agricultural water uses is illustrative. Recently, however, there has been a trend towards the development of multi-sectoral analyses. Some of these studies have used highly sophisticated techniques of linear programming and input-output

analysts. An interesting example is the study by Haines and Nainis (1974).

Another trend is the shift in sophistication of analysis in regional and national forecasts. Most of the initial work was devoted to the improvement of models for forecasting of demands at the local level. The research of Headley (1963), Gottlieb (1963), and Wong (1972) is typical. Researchers commonly attempted to extrapolate co-efficients derived at the local level to the regional and national levels. Such a practice, of course, is highly suspect and may lead to erroneous conclusions and predictions. Conditions (climatic, social and economic) vary considerably from one area to another. Conflicts in water use also vary, thus giving rise to differences in shadow prices. Attempts to overcome the lack of sophistication in regional and national forecasts include the work of Heady (1974) who utilized a programming model to estimate the extent to which land could be substituted for water and vice versa, in developing estimates of water required for irrigation in the nation as a whole. Other attempts at developing more sophisticated regional and national forecasting methods include Haines and Nainis (1974) and Gray and McKean (1976).

Refining Techniques

There has also been progress in the refinement of techniques of analysis. The most popular technique is that of

multiple regression. Linaweaver and his colleagues at Johns Hopkins University appear to have been one of the earliest users of the technique in the water demand forecasting field. Their study of residential water demands in Baltimore, Maryland remains a classic (Linaweaver, 1967). The approach has been widely adopted in studies elsewhere, particularly with respect to the forecasting of residential water demands. Illustrations include the work of Grima (1972), Katzman (1977), and Wong (1972).

There have been attempts to refine the technique, particularly through the use of factor analysis, the latter making it possible to take account of a much larger number of variables. Particular use of the combined techniques has occurred in forecasting the demands for water-based recreation. The research of Gum and Martin (1977) and Sewell and Rostron (1970) is exemplary. Despite its apparent usefulness, the multiple regression factor analysis approach appears to have had limited application to other water demand sectors.

The most significant developments in technique refinement appear to have taken place in connection with linear programming. The specification of an objective function, subject to various constraints (such as price, technology, costs, etc.) seems especially appropriate in forecasting demands in connection with the industrial and agricultural sectors. Thompson and Young (1973) have described some of

the developments in the use of the technique in this regard. Some researchers such as Haines and Nainis (1974) and Gray and McKean (1976) have coupled linear programming and the use of input-output models. Most importantly, a number of researchers have extended thie application of the technique by allying it with computer models. The work of Haines and Nainis (1974), again, is illustrative.

Developments in Various Sectors

Among the various sectors of water use, residential, or more commonly, municipal, applications have received by far the largest attention in the development of forecasting methodologies. Municipal studies are typified by those undertaken by Berry and Bonem (1974) while residential investigations are illustrated by those of Howe and Linaweaver (1967) and Grima (1972). The basic thrust of these studies has been to identify the various factors which influence municipal water demands. Per capita income, price, and climatological variables have been given particular attention.

While most of the initial work in this field was undertaken in North America, there has been growing interest in it elsewhere, notably in Europe and in a number of Third World countries. The work of Herrington (1973) in the U.K. and case studies cited in the U.N. report (United Nations, 1976) offer examples of the research being done in Europe. Darr, Feldman and Kamen (1976) have done innovative work in

this regard in Israel. Studies by Katzman (1977) in Malaysia, and Reid and Muiga (1976) of water demands in a number of developing countries indicate the mounting interest in water demand forecasting elsewhere.

There has also been important work in industrial water demand forecasting. Studies by Thompson and Young (1973), using linear programming models to derive estimates of demands for water for electrical generation, and by de Rooy (1974), employing multiple regression techniques to derive functions for various water uses (notably, cooling, electrical generation and processing). The energy crisis, and the revived interest in coal production and hydro-electric power development have sparked further interest in the development of techniques for industrial water demand forecasting (e.g., Englebert, 1973).

In most regions commercial water use is of relatively minor importance, and this probably accounts for the fact that it has engendered little interest among researchers. There have been only a few studies in North America since the pioneering work at Johns Hopkins University. The research of Mercer and Morgan (1974) which tried to take specific account of commercial water use in developing estimates for local areas, and of McCuen, Sutherland and Kim (1975) who used multiple regression techniques to develop predictive equations from a study of four shopping centres offers an interesting exception to this generalization.

There has been a good deal of useful work in the development of techniques to estimate water demands in agriculture. While much of the early research was based on physical requirements for given levels of production, more recent studies have taken specific account of price, irrigation efficiency, and shifts in technology. Heavy reliance has been placed on linear programming models. Examples include Young (1970) and Craddock (1974).

The past decade has witnessed a growing interest in water-based recreation, a use where estimates of future demands are difficult to make because there is no simple way to determine the values derived. This is because, in contrast with most other water uses, typically a price is not charged for the service. Progress has been made, however, in developing surrogate measures of values. Much of this work has been based on the methods developed by Clawson (1963) and Knetsch (1966), using expenditures on travel as a measure of values derived. This has been supplemented by research which has tried to identify motivations for participation (Sewell & Rostron, 1970) or the role of such variables as social status (West, 1977).

Canadian Contributions

In sponsoring the seminar on Methodologies for Forecasting Water Demands in 1967, the Department of Energy, Mines and Resources hoped not only to provide a state of the art

review of available methodologies, and the types of techniques then in use by government agencies in Canada, but also to stimulate an interest in the development and use of more sophisticated approaches. It was clear that there was a major gap between theory and practice, and that most methods then in use were relatively crude. For the most part, forecasting was little more than straight line extrapolation of past experience. Improvement of the situation hinged upon an expansion of the research effort to provide more sophisticated methods, a major expansion in the collection of data on water demand, and a shift in the attitude of water planners to give greater attention to this dimension of the planning task. The ensuring ten years have witnessed some important progress in each of these connections.

On the research side, the federal government offered much larger funds than had previously been available for economic and social studies in water research (Sewell, Judy & Ouellet, 1969) and this encouraged the development of expertise in water forecasting methodologies at several universities across the country. At the same time, the federal government, particularly through the Socio-Economic Studies Section of the Inland Waters Directorate, began to devote more attention to this field. Several important developments followed, notably reports describing improved methodologies (Lee, 1972; Tate & Robichaud, 1973; Kitchen, 1975); attempts to expand the data base relating to water

use, and the specific inclusion of water demand forecasts in the major river basin planning efforts co-sponsored by the federal government and the various provincial governments. The studies undertaken in connection with the Okanagan Basin (Canada-B.C. Okanagan River Basin Consultative Board, 1974) provide a useful illustration.

Approaches

In common with the progress in the United States, there has been a growing tendency to move beyond the strict "requirements" approach to forecasts based on considerations of price, technology, and economic structure. As in the United States, most of this effort has been devoted to the local level, rather than the regional, state (provincial), or national levels.

Techniques

There has been a modest but useful effort towards the development and refinement of techniques of water demand forecasting in Canada in the past decade. Perhaps the most significant contribution is that of Tate and Robichaud (1973) who devised a water demand simulation model focussing upon the industrial sector, but which could be readily adapted for forecasting of other sectors as well. This model includes several critical variables such as economic activity, technology and extent of recirculation, and takes account of negative water demands and positive water demands. While

imaginative in concept, it suffered in application from limitations of data availability.

Developments in Sectoral Estimating

There have also been some useful Canadian contributions to the development of techniques for estimating demands in the various sectors. This has been especially so in the residential and municipal sector. The work of Grima (1972) is notable in this regard. He has undertaken studies in southern Ontario, focussed on the identification of residential water use and the level of the related investment in water supply. Using a multiple regression technique, he found that the price elasticity for winter use was -0.75, while that for the summer was -1.07. The results of the study also suggested that metering *per se* has little impact on the level of residential water use. To be effective, it must be accompanied by significantly large increases in price.

There have also been a number of micro studies, aimed at establishing income and price elasticities. An investigation by Sewell and Roueche (1974) analyzed water demand (annual, peak, off-peak and mid-peak) in terms of independent variables (price, income, average summer temperature and average summer precipitation). The results indicated an annual demand function price elasticity of -0.395, and an off-peak price elasticity of -0.579, an elasticity higher

than that for the peak (-0.116). The latter result was especially interesting as it is opposite to what other studies have suggested. The relative insensitivity of summer water consumption to price changes in Victoria may be the consequence of a "green lawn syndrome" which characterizes that city. The residents of the area place a very high value on having green lawns and beautiful flowers, and are prepared to pay high prices to overcome the aridity which often characterizes the summer months.

A more recent study by Mitchell and Leighton (1977) used a multivariate approach to forecast water demands in Barrie, Ontario. They checked the results with data derived from records of water consumption in two metered sub-divisions in the area. They also prepared a trend forecast and then compared the findings of the two techniques. They led to broadly similar results but the multivariate technique proved to be somewhat more precise.

There have also been some useful developments in connection with the estimation of water-based recreation demands. Much of this work has been focussed upon the improvement of surrogate measures of values derived by recreationists from various activities. This research has been reviewed in some detail elsewhere (Pearse, 1968a; Pearse & Bowden, 1969). There have been a number of attempts to estimate values from the expenditures by recreationists in getting to a recreation site, and in pursuing various activities while they are there.

The work of Pearse (1968b), Cheung (1972), Knetsch and Cheung (1976), and Laub (1974) provides some interesting illustrations.

While travel-costs or other expenditures do furnish a useful measure of recreational values in some forms of recreation, this may not be so for all types. From the results of an investigation of salt water sports fishermen in British Columbia, at least, it seems that there is reason to doubt such a direct connection. Using multiple regression and factor analysis techniques, Sewell and Rostron (1970) showed that numerous factors condition the decision whether to go fishing, and that cost is not always one of the most important. The study also indicated that the connection between the motivation to go fishing and the values derived is a tenuous one. The prospect of catching a fish may be required to encourage the fisherman to go fishing but once at the fishing site, other factors appear to take on equal or even greater importance.

While only a few of these studies of outdoor recreation have focussed on water-based pursuits, and although they are not concerned with forecasting of demands *per se*, their findings are of considerable value in the development of methods for the latter.

Even though irrigation is an important component of Canadian agriculture, there has been surprisingly little effort devoted towards the development of sophisticated

techniques for estimating demands in that sector. A useful assessment of the state of the art a decade ago was prepared by Capel (1968). Since then, there have been one or two attempts to refine methodologies. Amongst the more notable are the studies of Craddock and his colleagues at the University of Manitoba (Craddock, 1974) in developing and refining linear programming techniques. According to Tate (1977), however, it seems that lack of appropriate data severely limits the broad application of such methods on the Canadian scene.

As is the case with agriculture, there has been only modest progress in improving methods for forecasting industrial water demands in Canada. Only a few studies have been undertaken, most notably those of Tate and Robichaud carried out under the auspices of the Inland Waters Directorate of Environment Canada. In one study, noted earlier in this paper, they developed a simulation model, using general co-efficients, and taking into account shifts in economic activity levels, technology, water re-circulation, and the application of effluent discharge standards. The model was simple but flexible, allowing for modifications as the data base in Canada is improved.

Priorities for Future Action

It is evident that there has been some important progress in refining water demand forecasting methodologies in several

parts of the past decade. It is also clear that there remain some important gaps in understanding and in the facility for operationalizing some of the techniques that have been developed so far.

There are a number of initiatives now underway in Canada for overcoming these deficiencies. Attempts are being made to refine methods for forecasting demands in certain sectors of particular importance to the Canadian economy, notably industry, agriculture, effluent discharge, and outdoor recreation. The research effort, however, is small in comparison to the need. Lack of appropriate data has hampered the application of several techniques, notably in the fields of industrial and agricultural water demands. The federal government, particularly through Statistics Canada, and Environment Canada, is making efforts to expand the data base (Tate, 1977). Finally, there is a growing interest in the development of regional models for forecasting. Studies undertaken in connection with federal-provincial river basin planning agreements offer illustrations of the kinds of investigation being carried out.

In short, there has been significant progress in developing water demand forecasting techniques in Canada in the past decade. But there is still a long way to go before accurate estimates can be expected in many of the sectors or for most of Canada's regions.

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