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WATER USE AND DEMAND FORECASTING IN CANADA: A REVIEW

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Preface

Interest in water resources systems has been a critical part of resources and environment related research at IIASA since its inception. As demands for water increase relative to supply, the intensity and efficiency of water resources management must be developed further. This in turn requires an increase in the degree of detail and sophistication of the analysis, including economic, social and environmental evaluation of water resources development alternatives aided by application of mathematical modelling techniques, to generate inputs for planning, design and operational decisions.

In the years of 1976 and 1977 IIASA has initiated a concentrated research effort focusing on *modelling and forecasting of water demands*. Our interest in water demands derived itself from the generally accepted realization that these fundamental aspects of water resources management have not been given due consideration in the past.

This paper, the fourth in the IIASA water demand series, reports on water use and demand forecasting in Canada. As a result of the Workshop on Modelling of Water Demands (Laxenburg, 17-21 January 1977), it is one of several invited contributions to our Survey on Methods for Estimating Water Demands and Wastewater Discharges.

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Abstract

This paper reviews the state-of-the-art with regard to water use and demand forecasting in Canada, and presents a framework for such studies in a national, regional, and river basin context. The paper demonstrates that, in view of Canada's overall water abundance, water supply has been the primary orientation of most Canadian studies, with little attention paid in the past to the water use side of the resource. Yet, as shown in the paper there are several problems arising in Canada which require water use and demand forecasting studies; these are recurring water shortages in some parts of the country, the growing importance of energy production, the investigation and solution of conflicts between water uses, the need to consider water uses in managing water quality, and the needs frequently to take water uses into account in solving international water management problems. The paper then outlines the constituents of an adequate water demand forecasting program, including an alternative futures framework, a systems approach, water pricing, technological change and economic interrelationships. Canadian efforts in water demand forecasting are then reviewed, the finding being generally that most studies have used the simplistic coefficients approach. Exceptions have occurred in the few studies done at Canadian universities, mainly on residential water use, which use much more adequate methodologies than the coefficients approach. The paper concludes by presenting a framework being developed in Canada for water demand forecasting at both the national and local (river basin) levels.

A. INTRODUCTION

Canada is one of the world's most well-endowed countries with respect to water supply. Of the country's total area of just under 10 million sq. km, about 7.6% is covered by water, including a substantial portion of the world's largest lake system, the Great Lakes. Of course, not all of this water is available for use, as much is stored in lakes and swamps, or frozen in permanent glaciers. A better measure of water availability for use is streamflow, and here also Canada has formidable advantages. The average annual runoff in Canada as a whole is 107,000 m^3/sec., about 9% of the world's total. With less than 1% of the world's total population, this is clearly a generous natural endowment.

Aggregate data, however, can be misleading. In terms of the water resources available for man's use, the spatial and temporal characteristics of Canada's water supply must be considered. These characteristics are dealt with rigorously elsewhere (1); here, only a few of the salient points are mentioned. Canada is a very large country with widely varying climatic and geographic conditions. About one-third of the total precipitation falls as snow, to be stored until spring, when it runs off quite rapidly. Some use is made of this water, for example for winter sports or for waste assimilation during the spring freshet, but its use is minimal due to rapid runoff. About two-thirds of Canada's renewable water supply flows northward, away from the centers of population. This water is also used only minimally. Because of evaporation, only 50-60% of the maximum possible water supply (precipitation) is available as runoff. Thus, climatic and geographic influences on evaporation are very important in determining actual available runoff. The concept of reliable flow describes a runoff level which is available during a given proportion of the time (2). Reliable annual flow has been defined as the annual runoff available 90% of the time, or 9 years out of 10. Similarly, reliable minimum monthly flow is the runoff available in all but the lowest month in 10 years. Both of these flow levels are considerably lower than the mean annual flow, as shown in Table 1.

In spite of spatial and temporal considerations, most areas of Canada have water supplies significantly in excess of current uses. In 1972, an internal federal government study compared

Table 1 COMPARISON OF FLOW LEVELS BY REGION FOR CANADA

(% of mean annual flow)

Region	Reliable Annual Flow	Reliable Minimum Monthly Flow
Atlantic	70	26
Quebec	75	32
Ontario	70	34
Prairie	30-40	5
Pacific	80	24

daily water withdrawals by various categories of water use with reliable annual and reliable minimum monthly flow for 26 river basin regions (3). This comparison was based upon 1970 water use data, the latest available at the time (4). It showed six river basins in which total daily water use exceeds 50% of reliable minimum monthly flow, and thus where water withdrawals might be considered to be approaching available supplies (Table 2). Some care must be taken in interpreting these data, because neither the time pattern of water use throughout the day and year nor the storage of water by natural or artificial means have been taken into account. Also, water withdrawal data are used in the comparison, thereby failing to reflect water actually consumed (5). The important point emerging from the analysis, however, is that in some regions, water use may be approaching available supplies, and that Canada's traditional image as a "water-rich" country may no longer be accurate.

Two consequences, which in turn have an implication for Canadian water demand forecasting have resulted from the perceived abundance of Canadian water supplies. Firstly, water has been used extensively rather than intensively. For example, recirculation rates for manufacturing and power generation are low in comparison with similar rates in the U.S. (6), and many plants have once-through cooling systems. The absence of the need to price water in an economically efficient manner is a principal factor causing the extensive nature of water use in Canada. This absence is attributable in large part to water abundance, and the consequent perception that water is a "free" good. Secondly, Canadian water management has concentrated on measuring and analyzing water supplies to the virtual exclusion, until recently, of cataloguing and collecting data on major water uses. There are very few other resource management fields where the implications of demand and use for management have been ignored in such a manner.

The implication of these factors for water demand forecasting has been the relatively small amount of effort devoted to this activity. Methods of forecasting used in Canada have been elementary for the most part, with no national models and few unique methodologies for water use and water demand forecasting being developed (7). While some attempts have been made to develop a more comprehensive approach (8), the seeming-abundance of water in Canada has assured a low priority for demand forecasting in the context of the whole water management field.

In spite of the small amount of effort devoted to water use and demand forecasting, the needs for this activity in Canada are clear. The next section of the paper discusses these in detail. Section C then proceeds to discuss some of the general considerations in forecasting water demands, providing a framework against which to measure past Canadian studies in this field, which are discussed in Section D. Section E examines current Canadian work in water use and demand forecasting and presents a framework suitable for carrying out such studies. Section F summarizes the paper and draws conclusions as to the usefulness of demand forecasting for Canadian water management.

TABLE 2

CANADIAN WATER SUPPLIES AND WITHDRAWALS, 1970
in millions of litres per day

	Drainage Region	Supplies[a]		Withdrawals						
		Reliable annual runoff	Reliable min.monthly runoff	Total excluding hydro	Municipal-rural res.[b]	Manu-fac.	Mining	Agri-culture	Electrical Thermal	Electrical Hydro
1	Fraser	258,213	61,153	1,523	582	218	45	609	68	2,287
2	Okanagan	4,637	1,100	696	50	14	41	559	32	-
3	Columbia	50,147	1,309	1,309	68	1,059	45	77	55	165,279
4	Yukon	168,202	40,455	41	9	-	27	-	-	46,951
5	Pac. Coastal	841,010	100,293	6,437	200	3,241	55	41	2,900	39,155
6	Mackenzie	468,238	56,261	50	9	-	45	-	-	586
7	Peace-Athabasca	222,299	57,975	896	45	409	364	36	41	80,687
8	Arctic Coastal	171,839	61,889	-	-	-	-	-	-	-
9	Milk	382	-	214	-	-	50	164	-	-
10	Churchill	88,192	73,632	318	9	241	41	14	14	44,192
11	Nelson	39,414	18,834	1,459	41	1,191	109	59	59	255,640
12	North Sask.	15,093	1,809	4,746	241	386	91	145	3.882	255,662
13	South Sask.	12,502	2,982	7,124	336	241	255	4,210	2,078	15,075
14	Red-Assin.	2,864	341	3,273	327	455	332	195	1,964	-
15	Winnipeg	41,732	34,981	446	27	327	55	5	36	201,161
16	Northern Ont.	387,319	92,957	536	36	373	36	5	91	172,466
17	Northern Que.	927,384	222,604	123	19	5	68	-	-	45,760
18	Keewatin	245,029	58,707	-	-	-	-	-	-	-
19	Lower St.Lawr.	135,925	65,067	8,465	2,046	6,164	14	23	9	1,099,146
20	Upper Gr.Lakes	145,472	104,453	5,623	273	3,823	209	127	1,191	168,566
21	Southern Ont.	32,095	11,497	31,154	2,632	5,187	14	355	22,971	791,677
22	Ottawa	134,562	80,478	2,323	373	1,459	177	68	250	498,137
23	Quebec Coastal	609,164	220,158	1,682	182	1,246	95	27	136	581,783
24	Nfld.-Lab.	595,526	212,821	1,227	168	550	382	5	127	54,966
25	Maritime Coastal	156,382	56,020	4,523	377	1,373	77	45	2,655	20,171
26	Saint John	49,551	22,748	1,759	136	609	-	9	1,005	96,703
	Totals			85,947	8,187	28,572	2,628	6,987	39,564	4,636,050

a Excluding inflow contributions from the United States and/or from upper basin region(s)

b Excluding manufacturers served by municipal systems. These have been transferred to the manufacturing column.

The term "water demand" is used in this paper in its strict economic sense, to denote a relationship between quantities purchased at various price levels. Forecasts of water demand are therefore based upon the prevailing price of water, with water quantities demanded minimized so as to minimize withdrawal costs to the user (9). As used in this sense, the number of water demand forecasting studies in Canada is virtually nil; although, of course, there have been many examinations of future water use or water requirements in conjunction with various water management studies. Thus, the term "water use" is used more frequently than "water demand" throughout this paper, denoting quantitative assessments and forecasts of withdrawal, flow, or on-site uses of water conducted without necessarily taking into account pricing relationships. The term "water use and demand" is also used in addressing theoretical issues or future studies in which economic considerations of water use may or may not be important.

B. THE NEED TO FORECAST WATER DEMANDS IN CANADA

The need for water use and demand forecasting studies in Canada appears to be growing as new water management issues arise. Although interest in the subject is still only minimal, there are a few plans for future studies by government agencies, which will be aimed at projecting water demands. One such example is the proposed Prairie Provinces Water Demand Study (10). This section of the paper outlines the factors behind the growing need to forecast water demands. It contributes to the overall theme of the paper by examining some of the institutional and policy issues which generate a requirement for water demand forecasting.

1. Water Shortages

The autumn and winter period 1976-77 in Canada was the driest on record in Northern Ontario, the southern Prairies and southern British Columbia (11). By the spring of 1977, drought conditions threatened all major water uses in this area, particularly municipal, industrial, agricultural and power generation. Some of the early signs of the onset of drought conditions were soil drifting, dust storms, low flows on interprovincial and international streams (12), low lake and reservoir levels, water shortages for irrigation, and many others (13, 14).

In much of the drought-threatened area, late spring rains alleviated many of the potential water shortages, although some areas are still seriously deficient with respect to water. Despite the abatement of the drought conditions, two observations resulted from the drought situation which threatened and which may yet occur; both of these have significance for water demand forecasting. Firstly, droughts in the future will be felt less in the agricultural sector than in other sectors, in contrast to the droughts of the 1930's which devastated much of Canada's agriculture. Government actions to improve agricultural water supplies have afforded increased drought protection to this sector. In contrast, hydro-electric power generation, upon which the Canadian economy is very dependent, relies strongly on adequate water supplies, and flows in some areas still remain low for power production (15). Thus, future water shortages may have very serious effects on all parts of the economy through their impacts on power generation. Other important water-related effects of drought are degraded water quality, threats to domestic and industrial water supplies and interprovincial and international water apportionment. Secondly, in Canada's most drought-prone region, the southern Prairies, there have been preliminary investigations of methods for increasing water supplies via diversions from the water-abundant northern Prairie region (16). These diversion possibilities, together with the storage required, will be very expensive, giving rise to the need for examining future water demands to determine whether they warrant such large public capital expenditures.

2. Water and Energy

The importance of water in energy production is a second factor in the growing need for water demand forecasting. Energy-related issues have dominated resource management throughout the 1970's, and will likely continue to do so into the future. As previously mentioned, the link between water supplies and hydro power generation is direct and obvious. Water intake for cooling and steam generation in thermal power plants is Canada's largest withdrawal use of water, accounting for almost 40% of documented water intakes (17). Water is used extensively for injection into oil and gas wells to maintain pumping pressures (18). In transporting crude oil via pipeline, water is mixed with crude oil to permit flow. Other areas where water is important for energy production is in the recovery of crude oil from tar sands, coal gasification, petroleum refining, proposed slurry transporation of coal and mine site reclamation.

With relatively abundant water resources, Canada has many excellent hydro power generation sites. In 1973, about 75% of total electrical energy generated in Canada was by hydroelectric means (19). However, most of the potentially good hydro sites available have already been developed, and most of the projected growth in capacity will be taken up by conventional and nuclear steam generating plants (20). By 2000, it has been estimated that some 65% of electrical energy generated in Canada will be by thermal methods, both conventional and nuclear (21). The implications of this trend, assuming current patterns of water use, are large increases in water withdrawals to meet the cooling and steam generating requirements of thermal power plants, corresponding increases in water consumption, aggravated water quality problems because of heat discharges and increased pressures on available water supplies, especially in urban areas and the Prairie region. In view of the importance of water in energy production, and the potential conflict of this activity with the water uses, the need to carry out water demand forecasts for this use in relation to others must be carried out. These forecasts should examine where water demands will arise for energy production, what types of technology (e.g. recirculation) are practicable for minimizing the quantity and impact of these demands, and what will be their effects on competing water uses.

3. Water Use Conflicts

A third factor creating the need for water demand studies relates to the growing number and complexity of conflicts between water uses. In the past, in Canada, there was ample water for all users, and the goal of water management was to minimize conflicts by assuring adequate supplies for all users. Because of the small size of the Canadian population and economy, relative to the size of the water resource, this management strategy was largely successful. With trends such as population and economic growth, increases in individual income and well-being, and more leisure time (22), all water uses have increased in magnitude to the point that competition between water uses is growing. Examples of such conflicts are the use of the same water body for both municipal water supplies and waste disposal, and industrial pollution of waters used for recreation.

In Canada, comprehensive river basin planning, done either jointly by the federal and provincial governments under the Canada Water Act or by provinces alone, has been adopted as a primary method of handling water use conflicts. Through the use of river basin planning, future development options in a basin are examined in the context of their impacts on water use, with the aim of selecting the most desirable uses for development and minimizing water use conflicts (23). Water demand forecasting plays a major role in river basin planning, as it is the key to translating economic and social projections into impacts on the water resource. River basin planning done to date in Canada has used only the simplest water demand forecasting approaches, except possibly in the case of the Okanagan study (24). Water demand studies undertaken in the context of basin planning in the future should become better as more experience is gained with the various methodologies now being formulated.

4. Water Use and Water Quality Management

The role of water demand forecasting in water quality management is a fourth factor in the growing need for water use and demand analyses. Regulation of pollutants is the major water quality management tool in Canada today (25). However the ultimate form of water quality protection and enhancement should be based upon use-related water quality objectives. In establishing these objectives, both current and future water uses are of considerable importance for they will determine the level at which the objectives must be set.

5. International Water Management

A fifth factor in generating a need for water demand forecasting is found in some of the international problems which arise along the border between Canada and the U.S. Actions taken on one side of the border to develop the water resources frequently affect users of the other side, and since the Boundary Waters Treaty of 1909, disputes have been dealt with by the International Joint Commission (26). The continuing pace of developments, particularly in the U.S., is placing heavier and heavier demands on the water resources on both sides of the border, with Canada, as the later-developing and less-developed nation, frequently being placed in the position of reacting to U.S. initiatives (27). Such emerging issues as the ever increasing consumptive use in the Great Lakes basin; increasing water demands for energy production (28); increasing water demands for irrigation, and impending water shortages in the Prairie region will all clearly require substantial efforts to forecast Canadian water demands to ensure adequate protection of Canadian interests.

The preceding conditions all point to the necessity for preparing water demand forecasts. These conditions, combined with the fact that basic water use data are more readily available than heretofore, have made demand forecasting more feasible than it once was. Beginning in 1972, a survey of water use in industry was initiated by the federal government (29). The sectors of industry covered were manufacturing, mining, oil and gas extraction, and power generation, both hydro and thermal. The survey is being repeated for 1976 in the manufacturing, mining and thermal power generation sectors. These surveys do not attempt to obtain information on water costs to industry, although this may be attempted once the surveys become well established. Water use information has been collected beginning in 1975 for municipalities (30) and this survey will continue in future years, thus establishing a time trend on this type of water use. Future data collection efforts will include an attempt to survey agricultural water use. Thus, water use data for Canada is slowly becoming more available, putting water demand forecasting on a firmer foundation.

C. SOME GENERAL CONSIDERATIONS IN FORECASTING WATER USE AND DEMAND

Before discussing Canadian experiences with water demand forecasting, it will be useful to consider some general points concerning procedures and methods. These points include the alternative futures framework for demand forecasting, the spatial framework for this task, the usefulness of a systems approach, the issue of practicality, the role of price in water demand, the need to consider economic interrelationships, and the role of technological change. This discussion will form the background against which to assess past Canadian studies of water use and demand, and will provide an outline of the concepts which should be built into future work.

1. The Use of an Alternative Futures Framework

The problem of forecasting water demands is a problem of inductive inference and is subject to the same set of principles which apply when attempting to infer one set of conditions from another. A forecast is a statement of a set of outcomes which (in this case the amounts of water used) which will develop from a set of events. To make this process valid, tested theories, as denoted by "lawlike" generalizations, are required. Such "lawlike" generalizations have not been developed in water use and demand forecasting, as they have for example in the physical sciences placing some doubt upon the validity of the forecasting process (31).

Thus, much of the general theory of water demand forecasting remains to be developed. It is a moot point whether the required "lawlike" generalizations will ever be developed to the same degree that they exist in the more traditional sciences, such as physics and chemistry (32). For this reason, water demand forecasters must develop methodologies which, although based upon proven theoretical principles to the greatest extent possible, taken into account the uncertainties involved in prediction over a 10- to 50-year time horizon.

In the absence of accurate theories and laws, it is still necessary to carry out water use and demand forecasting studies. While as high a degree of accuracy as possible is to be strived for, absolute accuracy is not a prerequisite for such studies to be useful. It is suggested here that the real benefits of forecasting water demand lie in determining how water demand will vary under a variety of future possible socio-economic developments, as opposed to predicting the purely quantitative withdrawal or consumptive use at some point in the future with 100% accuracy.

If the basic principle is sound, then water demand forecasting should be a tool for translating future trends (e.g. population or industrial growth) into impacts on water. It is basically a policy instrument used by the water manager to examine the implications of alternative possible developments. The U.S. National Water Commission (33) based its work on the "alternative futures" approach to examining future water management options, and because this concept is considered fundamental to water demand forecasting, it is dealt with in more detail below.

The "alternative futures" approach to forecasting is built upon the hypothesis that the future is a complex function of socio-economic conditions, technological developments, life styles and public policy. Assumptions about these factors underlie any forecast of future water demands, and should be made explicit both in the forecasting model and in the final output of the exercise. Because each set of factors can take various development paths, none of which can be foreseen with complete accuracy, forecasting should examine alternative combinations of the underlying factors. These combinations are termed "alternative futures", and the task of water demand forecasting is to translate these into impacts on water use (34). In terms of water demand forecasting, alternative futures might consider the following:

1. a number of assumptions about future population levels

2. a number of economic growth assumptions in various industries

3. a number of assumptions on technological developments as related to water use

4. the effects of alternative macro-economic policy alternatives, such as promoting regional as opposed to national economic growth

5. the effects of various types of pricing policy for water and other elements of overall water management strategy

6. the effects of a policy to promote environmental quality

and so on (35).

Water demand forecasting methodology development in Canada recognizes the alternative futures approach. For example, the comprehensive study of water resources in the Okanagan River Basin of British Columbia examined three alternative paths for future development in the basin: a maximum economic growth future, an environmental quality future, and a status quo future (36). In this particular case, it was demonstrated that, although the basin was located in a semi-arid area, there was ample water for all foreseeable needs, eliminating the need for a costly water transfer scheme which had been previously proposed. This is one example which shows that Canadian forecasting efforts in the water management field will aim towards developing models in which at least underlying variables and relationships between variables are correct. Over time, the demand estimating models will be improved by making these relationships more precise. The following material expands upon some of the more important dimensions to be considered within the alternative futures framework.

2. Spatial Framework for Demand Forecasting

In Canada, water demand forecasts are prepared using the river basin as the principal spatial unit. River basins are considered most useful because all of the data on water supplies, against which demands must be measured, are compiled on this basis. The hydrologic unity of a river basin provides a useful framework for management of water resources and is the type of region used in planning under the Canada Water Act. A listing of the principal Canadian river basins appears in Table 2 of the introduction to this paper.

The use of river basins as principal spatial units for forecasting poses some real difficulties for data collection, because the socio-economic data, upon which the forecasts are based, are collected and compiled by political and census-collection region, not by river basin. In addition while all required data are available in useable form at the national level, as areal units become smaller, data availability becomes progressively more limited due to confidentiality restrictions. The outline for the Prairie Provinces Water Demand Study (37) describes these problems in detail, concluding that they can be resolved by using computerized data storage and retrieval systems.

Water demand forecasting in Canada, is seen as being useful mainly at the local and regional level. At this level, emerging shortages, for example, can be quantified for specific locations and remedial measures planned and undertaken. The national picture, therefore, consists of a series of regional water demand profiles. However, reliable water demand forecasts cannot be carried out at the strictly local level because of several problems which could bias the results (38). These problems include local optimism in regard to new developments, a tendency to assume that new supply systems will be "required" before they actually are, a tendency to build in excess capacity in order to attract new industry, and methodological inconsistencies from one locale to another. Therefore, any water demand forecasting exercise must be approached from the "top down", or from the macro to the micro level. In other words, aggregate data used in the regional water demand forecasts be co-ordinated with available national predictions. To ensure this co-ordination, required data which are compiled on a national basis (e.g. population and basic population projections) should be disaggregated into the required regional or river basin system at the outset of the demand forecasting exercise. The actual prediction of water demands is then carried out at the regional and local level, and the results may then be aggregated to give the national picture.

3. The Usefulness of a Systems Approach

An approach to water demand forecasting using alternative futures, and the primary use of river basin regions, give rise to the need to collect, collate and manipulate a large amount of data. As shown in the preceding sub-section, some of the required data for forecasting exist principally at the national, or macro-economic level, while the detailed analysis of future demands must be carried out at the river basin and local level to permit integration with analyses of water supply. At both the macro and the micro level, alternative possibilities for future development should be investigated. At the macro level, for example, population projections should incorporate several sets of demographic assumptions. At the micro level, several different technological assumptions about water use in an industry may be desirable. Clearly, the number of permutations and combinations of variables will increase rapidly given a number of possible alternatives.

Systems analysis techniques have been applied to water resource studies to fulfill the need of handling large amounts of data, disaggragating to the river basin or local level, and considering alternatives (39). The capacity for using the systems approach has improved greatly over the past fifteen years. With high-speed computers and other electronic equipment, the analyst can now handle a virtually unlimited amount of data and much more sophisticated demand forecasting models than were once possible. Reasonable care must be taken to assure that technological sophistication is not interpreted for "accuracy" (40). However, assuming that results are carefully qualified, a very wide range of possible developments affecting water use in the future can be examined meaningfully.

The use of a systems approach may even help to compensate for the absence of precise laws linking the variables of water demand forecasting. For example, in regard to residential water use, several studies (41, 42, 43, 44, 45) have defined the important variables in the demand-estimating relationship. The problem is that these have not been generalized from one area to another. Thus, each time a new area is studied, data collection must be carried out to calibrate the demand estimating equation. A possible substitute for this usually-expensive effort would be to adapt models, developed on the basis of past work, to examine the effects of variables which might otherwise remain unanalyzed. To follow the example of residential water demand, a number of types of pricing relationships, defined by previous studies in other areas, could be incorporated into a computerized systems framework. The resulting sub-model would allow testing of a number of demand-estimating equations in an area under study where no past studies are available.* The ultimate goal of course must be to make demand estimating relationships as precise as possible, but in the interim while the required research is being carried out, the use of models which incorporate and attempt to quantify the correct underlying relationships between variables would be better than some of the methods which have been used in the past. An application of systems analysis to water demand studies is outlined in the section E below.

4. The Issue of Practicality

At the outset of designing a methodology for forecasting water demands, the forecaster must consider the type of user requiring the final product. Water demand forecasts are not ends in themselves, but rather are required by planners and water managers as inputs to other studies or decision-making. Thus, the methodology designed must be suitable for application in studies where budgets, time and manpower are probably restricted. Highly sophisticated models may thus be of little value if their data or validation requirements are too severe. This poses real challenges to the forecaster to construct methodologically sound models while keeping an eye to simplifying his final product as much as possible. It may be that initial methodologies should be quite simple, with increasing sophistication, aimed at greater accuracy and confidence, being incorporated as more data become available and as experience is gained.

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* An approach to residential water demand forecasting using two different sets of estimating equations is dealt with in Section E2a below (pp. 29-32)

5. The Role of Water Pricing

As noted in the introduction to this paper, the term "water demand" denotes a relationship between the price at which water is supplied and the quantity demanded or used. Above a certain minimum level of basic "need" (e.g. basic requirements for drinking or sanitation), according to theory and as observed in practice in a number of studies, water demand behaves in a manner similar to the demand for most other goods and services, exhibiting an inverse relationship between price charged and quantity used. The implication of this behaviour is that, by raising the price at which water is supplied, the "variable" portion of water use (i.e. that portion above basic need) can be decreased (46).

Many studies have investigated the relationship between water price and the amount of water demanded, and have generally found that, above minimum levels, water is indeed an economic commodity. Linaweaver et al. (47), Howe and Linaweaver (48), and Grima (49), for example, have all found that residential water uses are responsive to price, and the peaks in the daily and seasonal pattern of municipal water demands can be diminished through the use of metering and economically-derived pricing schedules. Granstrom et al. (30) found that firms in the chemical industry will lower their use of water in response to even small water price changes. Lee (51) cites a study which found that water withdrawals in an industrial plant was a function of the price at which water was supplied, for the price level influenced the degree of in-plant water treatment and thus the amount of water which could be recirculated. Lofting and Davis (52) cite other instances where price has an influence on water use.

In spite of this theoretical evidence, there are problems in establishing clearly the need for pricing considerations in applied water management. The first is conceptual in nature. Water demand falls into the category of derived demand, since for the most part, water is an input to products, which, in turn, satisfy consumer demands. Not only is water demand itself derived, but also, in many cases the price component of the supply/demand relationship must be derived. For example, consider an industry which supplies its own water from surface water sources, a situation which is very common in Canada (53). The principal component of the "price" for water faced by this plant is the cost of acquisition, such as capital and operating and maintenance costs of pumps, pipes, etc. Most provinces require industries to obtain a water withdrawal licence, but rarely is the licence fee based upon the actual quantities of water taken into the plant and the "value" of this water. In other words, users in this situation do not have an exogeneously-determined price for water. Given this situation, de Rooy (54) suggested that average cost of water per thousand gallons be used as a proxy for price, and through multiple regression analysis established that this unit cost is a major determinant in estimating water quantities used. However, the calculation of the average unit cost of water is partially dependent upon the amount of water brought into the plant, in other words the dependent variable. It is possible therefore that the concluded significant relationship between average unit cost and quantity taken into the plant does not reflect the responsiveness of quantity to price, but rather is the result of the high correlation between average water cost and quantity used. A federal-government study (55) attempted to formulate a model of industrial water demand, taking water price into account, based upon a firm's production function. However, it was found that to make water demand forecasts using this model required an estimate of water used, again precisely the same type of circularity which the de Rooy model encounters. Lofting and Davis have arrived at the same conclusion that the role of water price in industrial water demand forecasting is uncertain. They state that, "... there appears to be no clear-cut method of empirically deriving and projecting demand functions for industrial water use" (56).

In the industrial water use area, there is evidence that some types of effluent control policies, particularly effluent discharge fees, will have an impact on water demand. While effluent discharge fee systems may not produce economically efficient patterns of water demand, the evidence indicates that they will result in substantially lower water use. In theory, effluent discharge fees are aimed at assuring that the waste assimilative capacity of a water body is allocated efficiently among users, inasmuch as users who value this capacity highly obtain its use, while lower valued users adopt cheaper forms of pollution control (57). The level of the fee is established to assure that the ambient water quality does not fall below a predetermined desirable level. It is the internal adjustments to plant operations as a result of the effluent discharge fee that are of interest to the demand forecaster. For example, Russell (58) developed a model of a typical petroleum refinery which expressed water withdrawal as a function of intake price and effluent charges. He suggests on the basis of the model that cooling water withdrawal and heat discharges will decline substantially as a result of increasingly stiff environmental quality policy in the U.S. Bower (59) suggests that the imposition of effluent discharge fees or other types of effluent regulation will generally lead to a curtailment of water intake, possibly through in-plant treatment and recirculation of water. A finding by Penman (60), in connection with the effects of effluent discharge fees in the City of Winnipeg, indicates that fees of this nature not only reduce waste discharge to the sewer system, but also reduce industrial water intake demands.

The first problem, therefore, in assuring that pricing becomes a major consideration in Canadian water demand forecasting is technical in nature, related to showing why price is important and in establishing correct price levels. The solution to this problem lies in more research to establish the nature of the price: quantity relationship, what are the best methods of application and whether there are some easily derived variables which can suffice in the demand relationship.

A second problem in "selling" the pricing philosophy relates to the issue of attitudes. Section A touched briefly on this issue in outlining the common perception that Canada is a water-rich country. In many areas, such as around Great Lakes region, water supplies are virtually limitless. It would be folly for a water manager or a responsible politician at no matter what level of government to advocate higher charges for water in the name of economic efficiency and more rational water use to industry which withdraws water directly from the lakes. This is especially so at the present time when larger economic problems like unemployment, inflation and energy crises dominate national concerns. The fact is that in many areas cheap water is used to advertize locational advantages and declining block rate pricing structures dominate the water charging methods used. Thus, while it seems clear that economically rational water use can only be achieved by implementing theoretically sound pricing principles, this approach will be particularly difficult to establish generally in Canada.

6. Economic Interrelationships

In a modern economy, a large proportion of the productive effort is devoted to the manufacture of intermediate goods. Intermediate goods are products of one firm or industry (e.g. steel) which form the inputs to the manufacture of final foods (e.g. railway cars). The level of production of intermediate goods is closely related to the output of final goods. A change in the output of final goods creates corresponding change in the production of intermediate goods used in the manufacture of the final goods. These interrelationships have important implications for the analysis of water use. An increase in the final demand for a product will affect the water use not only in the industry experiencing the growth but also in all of the industries supplying the intermediate goods to that industry.

Input-output analysis was developed to analyze these interrelationships (61). This technique begins with an input-output table or matrix in which the outputs and inputs of industries form the rows and columns of the matrix. This basic table is then converted to a direct coefficient matrix, which records the same information in terms of unit inputs and outputs. For example for the iron and steel industry, the direct coefficient matrix will show, for each dollar of output how many cents worth of input is derived from the mining industry, how many cents worth of input from the quarrying industry, etc. By inverting the direct coefficient matrix, a matrix of direct plus indirect coefficients is developed, which can be used to show how a given increase in final demand for the products of any industry will affect all other industry as it filters through the economy.

This matrix of direct plus indirect coefficients is of interest in water demand forecasting. Lofting and McGauhey (62) post-multiplied the direct plus indirect coefficients matrix by a matrix of water use coefficients. In the latter, the amount of water per dollar of shipment value in each industry formed the diagonal of the water use coefficients matrix and all off-diagonal elements of the matrix were zero. This methodology permitted analysis of the effects on water use in the industrial sector of a change in any industry's final demand. For example, an increase of one million dollars worth of final demand in the chemical industry would cause an increase of 30 acre-feet in freshwater intake by the chemical industry, and very large increased water intake by all industries of 1,681 acre-feet (63). Thus, a projected increase in production in one industry may have much more of an impact on the water resources of a region than the mere at-plant prediction increase would imply. It is imperative that such "indirect" effects be taken into account when forecasting a region's water demand.

7. Technological Change

Technological change has a large potential impact on water demands, but has seldom been taken into account in Canadian forecasting. Sewell and Bower (64) deal with four types of technological change: new products, new processes, new or different raw materials and new methods for handling water. New products may replace or substitute for an established commodity. New processes may be developed which make production of a commodity cheaper or more efficient. New raw materials may be introduced to an established production process. These three changes can generate either decreased or increased water use. New methods for handling water refer to in-plant changes such as automatic controls on water utilization, the adoption of water re-cycling, etc., almost always lead to decreased water use. Technological change most often pertains to industry, although other sectors may be affected as well. An example of technological change which affects industrial water use in the current adoption of the basic oxygen furnace to replace the open hearth method of crude steel production (65). In this case, water demands will decrease, other things being equal. Recent development of the CANWEL system, (66) a complete re-cycling system for domestic water, sewage and solid waste handling will, if adopted, lead to decreases in municipal water demands. Completely new industries and technologies (e.g. coal gasification) may lead to large increases in water demand. Bower (67) pointed out that technological change with respect to water use in industry are usually generated by causes not directly related to water (e.g. changes in relative prices of raw material inputs, depletion of a raw material source, rising labour costs, etc.).

Forecasting technological change is complex and fraught with uncertainty. One reason for this is the absence of models or any other techniques to predict accurately over more than five to ten years. A second reason relates to the relative slowness of new technology adoption, even in a technologically advanced and oriented society. A third reason is that some technology changes, because they improve productivity and profitability, are developed and made in secret, making it difficult to obtain predictive information. Despite these difficulties, there is a need to incorporate the effects on water use of foreseen technological changes. The "alternative futures" framework appears to be an excellent vehicle for taking such changes into account.

D. CANADIAN EXPERIENCES WITH WATER USE AND WATER DEMAND FORECASTING STUDIES

Many Canadian water resource studies have employed water use and demand forecasting as either the focus or an integral part of investigations. Most of the examples outlined below are drawn from government-sponsored water management projects, as these have used water use studies most extensively. Some attention is also paid to the limited but important work done by Canadian academics.

Most commonly, a "water requirements" or "coefficients" approach has been taken in current and future water use studies. At its most simplistic, this involves (a) deriving a coefficient of water use (e.g. intake, consumption or gross water use) per capita or per unit of economic activity, (b) projecting population or the amount of economic activity to the target forecast year, and (c) multiplying the latter amount by the water use coefficient to derive the future level of water use. Many indicators of economic activity have been used as the basis of projection including value added (68), output (69), and employment (70). In the past, coefficients have generally been taken directly from results obtained in the U.S. (71), although now a substantial amount of Canadian data are available for the formulation of coefficients. Forecasts of population and economic activity have either been made by extrapolation of past trends or been derived from sources external to the water resource field itself (72). Frequently, two or more growth rates have been assumed (73) to give a range of projected water use.

There are many problems with the coefficients approach to estimating future water use. The problems of forecasting the levels of economic activity by extrapolating past growth trends into the future are covered well elsewhere (74, 75). Here, the problems of using coefficients to convert economic or population forecasts directly into water use estimates is described in more detail (76). Water use coefficients are complex functions of a number of important variables of any water use. For example, coefficients of industrial water use are based upon the state of recirculation technology, age of the plants forming the industry, process-product mixes, the cost of water and possibly the stringency of effluent regulations facing the industry. All of the factors are potential sources of water use variation, and should be taken explicitly into account when forecasting water use or demand (77). The use of average coefficients is probably more justifiable in making national, as opposed to regional river basin water use forecasts (78), but even here the approach will obscure important variables.

Canadian water management studies are replete with examples using this "coefficients" approach. A study of consumptive water use in the Canadian portion of the Great Lakes Basin relied exclusively upon this methodology to estimate municipal and rural water consumption (79). The purpose of this study was to estimate total consumptive use as an input to a major study of Great Lakes water levels and their regulation. A major difficulty with the results arises because the accuracy and probability of occurrence of the predicted water use estimates cannot be assessed, making them of only marginal value to the overall study. An internal federal study (80) used American-based coefficients to estimate water uses in major water-using sectors of the Canadian economy in 1970. For example, industrial water use was estimated by deriving, from published U.S. data, the amount of water used per employee by various industrial groups in the U.S., and then multiplying these coefficients by the number of employees in the corresponding Canadian industrial groups. Other examples of the use of this methodology may be found in studies done for the Qu'Appelle (81), Saint John (82) and Red Deer (83) river basins, and in a major water resources study of the four Atlantic provinces of Canada carried out by the Atlantic Development Board (84). In general, most applied studies of water use in Canada have relied upon the coefficients methodology rather heavily.

In contrast to common practice in applied water management studies, there have been some attempts to introduce a greater degree of sophistication into water use forecasting, and to impart a recognition of the economic relationships which should be incorporated into this task. A federally-sponsored seminar on water demand forecasting, held in 1968, reviewed methodologies for projecting water demands in all major water-using sectors (85). The papers presented at this seminar represented the current state of the art in water demand forecasting in Canada, and still form very useful Canadian sources on this subject. However, the findings and implicit recommendations made by the participants have not yet been put into practice.

The Okanagan River Basin Study, sponsored jointly by Canada and British Columbia, is an example of a study which applied input-output analysis to the examination of water use (86). Primary data collection permitted the construction of an input-output table for the basin, a task which proved somewhat difficult because of the scarcity of useable data. Once this task was completed, however, it allowed analysis anticipated economic growth under different sets of basin assumptions, or alternative futures. Final demands (e.g. personal or government expenditures) were forecasted to the target years of the study, 1985 and 2000. These were then used in conjunction with the input-output methodology to determine the effects of the growth in final demand on all sectors of the basin's economy. However, the study did not go the final step to analyze the direct plus indirect economic impacts upon water use. Instead, it was assumed that water use would increase in direct proportion to increases in economic activity (87), in effect resorting to the coefficients approach. Therefore, the Okanagan study was only more advanced than the traditional coefficients approach in its handling of economic interactions, not in its water use projections.

A study by members of the Inland Waters Directorate, federal Department of Fisheries and the Environment (88) developed a model for analyzing industrial water use using a simulation approach. Water demand by industry was broken down into gross water use and recirculation, and the factors affecting each of these parameters were grouped separately. Factors affecting gross water use included in the model were the level of economic activity (e.g. employment) and technological change. Recirculation was made a function of the basic type of water circulation system in the plant and technology improvements which could be anticipated, for example through the tightening of effluent quality regulations or through the adoption of effluent discharge fees. A third type of technological change built into the water use model relates to major changes in the water circulation system of the plant, such as the adoption of air cooling. The resulting model is shown in Figure 1.

Coefficients of water use are integral parts of this model. For example the level of economic activity is translated into gross water use by means of a coefficient of water use per unit of activity. When the model was formulated, the coefficients used were average ones derived from U.S. sources. With the completion of the 1972 industrial water use survey for Canada, however, actual empirical information can be used to calibrate the gross water use area of the model. As further research is carried out, regression models could be substituted for the gross use coefficient. For example Granstrom et al. (89) developed a model of water use in the chemical industry. The best regression model of cooling water gross use (GUC) took the form:

GUC = f (output, weighted average water cost, wage bill/output)

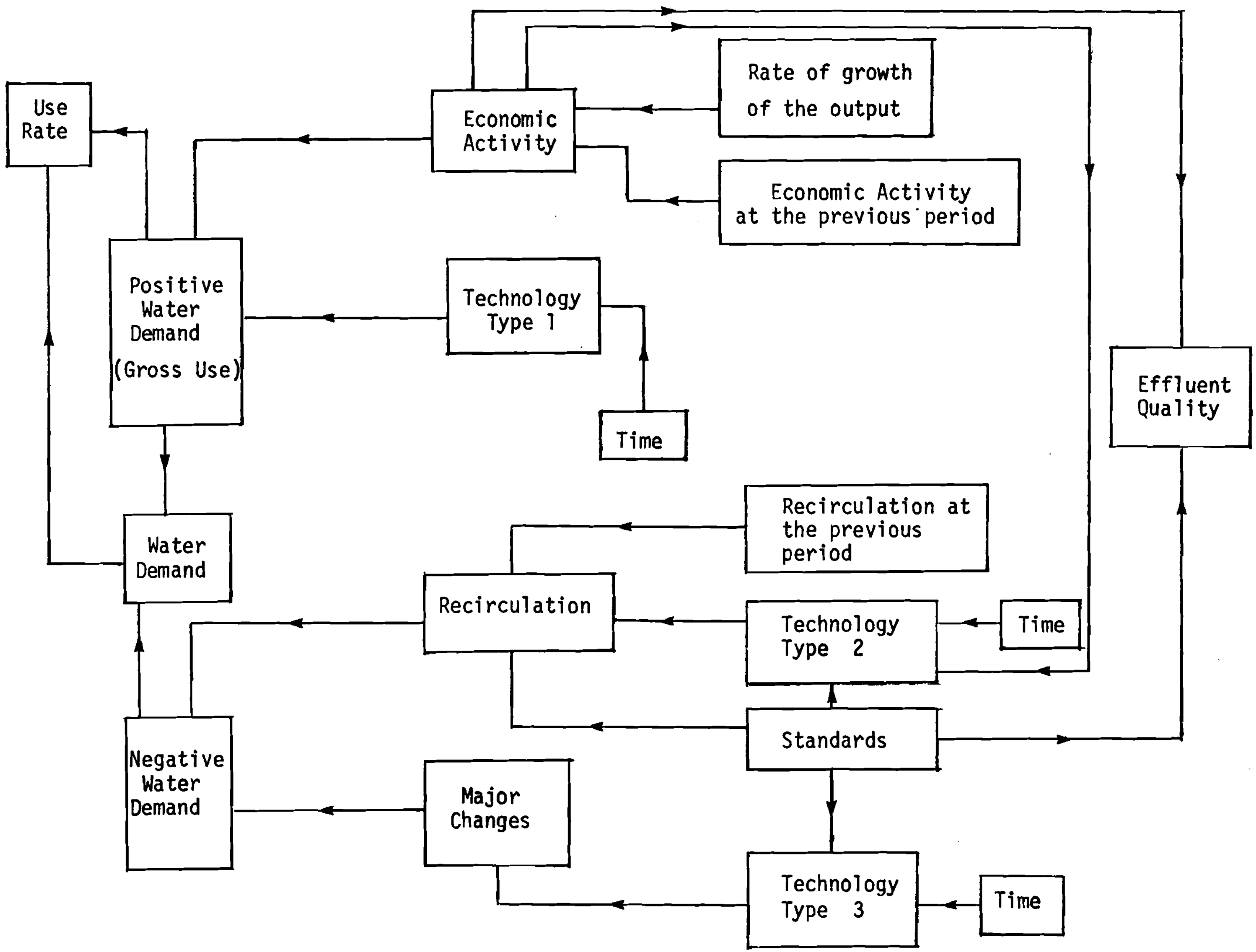
This equation proved significant at the 99% level of explanation, each of the variables were significant at least at the 95% level, and some 74% of total variance was explained (90).

Technological change is an important part of the industrial water use model, appearing in the gross water use and recirculation sectors of the model and also in the sector which takes major changes in water use into account. These technological changes would be quantified in terms of their impacts on water use. The principal difficulty with considering technological change relates to the problem of predicting it, as outlined in section 3.7, and the problem of translating it into operational terms (91). The advantage of the model is that change in technology have been broken down into its component parts and the model is able to deal with each component independently.

The industrial water use model outlined above was developed to place the important variables determining water use into a logical framework which could be used in water use forecasting studies. The model was constructed in such a way that individual components could be changed to incorporate new advances in theory or new data and also to allow the consideration of alternative assumptions about the underlying variables. Although problems still exist in this model (e.g. difficulty with quantifying technological change and inadequate consideration of water pricing), it was used to forecast industrial use in areas of southern Manitoba likely to be affected by the proposed Garrison Diversion being developed in adjacent areas of the U.S. (92), and yielded reliable results.

It is in the university research setting that a few real attempts have been made to analyze the economic nature of water demands, although this work has stopped short of forecasting water

FIGURE 1 FLOWSHEET OF INDUSTRIAL WATER DEMAND MODEL



demands. Much of this work has focussed on residential water use, related strongly in theory to the work of Linaweaver and his associates (93) on water use in Baltimore. Also most of this research has been funded by the federal Inland Waters Directorate.

Grima (94) investigated the factors affecting residential water demand. His aim was to find methods by which the large and growing capital costs of water supply infrastructure in municipalities could be reduced. In particular, the research focussed on the economic nature of residential water demands and the efficacy of using pricing practices based on economic principles to decrease these demands, thereby diminishing requirements of investment in new municipal water supply infrastructure.

Grima began his study by examining the pricing structures in current use in the study area, located in and around Metropolitan Toronto, and found that these structures fit into two types: a flat rate structure and a declining block rate structure. In the flat rate structure, charges are unrelated to the amount of water used in the residence, and most often this amount is unmetered. In the declining block rate structure, the amount of water used is metered, and unit charges (e.g. dollars per acre-foot or thousand gallons) decline as more water is used. Grima points out, as have many others, that these types of pricing structures lead to wasteful water use because there is little incentive for water conservation. The end result is an overstatement of water requirements and a subsequent overinvestment in water supply facilities.

Grima examined the structural relationships of residential water use by means of multiple regression analysis. In the analysis the independent variables were: the assessed value of the residence, lot size, area not covered by buildings, the number of persons in the residence, the variable price of water, the amount of daily water use allowed for in the minimum monthly bill and the amount of the fixed (i.e. minimum) bill for one billing period. Equations were calculated for three different dependent variables: average annual water use per day per dwelling, average summer water use per day per dwelling and average winter water use per day per dwelling. Both linear and non-linear (logarithmic) forms of the regression equation were used in the analysis and a stratified sampling procedure formed the basis of the data collection. Data were collected on both single and multiple (i.e. town house) family dwellings.

The analysis showed that the logarithmic form of the regression explained more of the total variance in annual, summer and winter water demand (49% to 56% of R^2) than did the normal form (46% to 52%), for metered single family dwellings. The value of the residence, the number of persons in the residence, the variable price for water and the amount of the fixed bill per period were all found to be significant at at least the 95% level of explanation, and the variable price in all cases (i.e. annual, summer and winter) were found significant at the 99% level. Table 3 shows Grima's equations in the logarithmic form pertaining to single family dwellings and using only the variables significant at at least the the 95% level.

For unmetered residences, the value of the residence and the number of persons living in the residence were found significant at at least the 95% level for the annual and summer models. For the winter model, only residence value was significant at this level. The equations for the unmetered dwellings explained between 23% and 27% of total variance (R^2), substantially lower than the explanation offered by the single family dwelling models. Again the logarithmic form was found preferable. The equations for town houses using only the variables significant to at least the 95% level are shown in Table 3.

Grima's results substantiate findings in other areas that pricing is significant in explaining residential water use. On this basis, he suggested that the incorporation of correct pricing practices (e.g. increasing block rates) beyond the level of basic needs would lead to decreases in residential water demand, particularly seasonal peaking which is a prime factor determining the capacity of a municipal water supply system. This would give rise to decreased requirements for expensive capital investment. The results of this work have had little impact to date at the application level (95).

Kellow (96) examined factors which influence residential water demand in Calgary, Alberta, a city which is unique in giving its water service customers a choice between flat-rate and meter-based charging. Kellow was particularly interested, as was Grima, in examining some of the economic factors determining residential water use, although his work was not a true "demand" study, in that price of water was not a variable.

In a manner similar to Grima, Kellow was interested in three types of residential water use: average annual, average summer and average winter use. Kellow computed his water use figures on an annual or seasonal total basis, as opposed to Grima's daily basis. Stepwise multiple regression techniques were used in analyzing the effects of seventeen independent variables on the dependent variables mentioned above. The number of persons, rooms and water using fixtures and appliances, the value of the dwelling unit, the family income, the lot size and the lawn area categorize the independent variables. While the study did collect primary data where required, Kellow was interested in carrying out the analysis using only secondary and easily available data. Therefore equations are presented (a) using all data, (b) using secondary and other easily available data, and (c) using secondary data alone. The result of the analysis are 32 multiple linear regression equations describing the water use under various conditions charging system (i.e. metered or flat rate), period (annual, summer and winter) and data availability class.

The study confirmed findings of many previous studies that water use is substantially higher under a flat rate system than under a metered system. While customers paid almost identical yearly charges under both charging systems, those electing the flat rate system used almost twice as much water as those electing the metered system. The study showed that users of the flat rate system had a higher number of water-using fixture and appliances, and larger families than those using the meter-based system. Summer lawn

TABLE 3. REGRESSION EQUATION FOR RESIDENTIAL WATER USE

	Equation	R^2
A	Single family dwelling	
	$\log WUa = 2.78 + 0.56 \log V^{**} + 0.59 \log N_p^{**} - 0.93 \log P^{**} - 0.31 \log F^{**}$	0.56
	$\log WUs = 3.24 + 0.51 \log V^{**} + 0.63 \log N_p^{**} - 1.07 \log P^{**} - 0.35 \log F^{**}$	0.55
	$\log WUw = 2.45 + 0.48 \log V^{**} + 0.62 \log N_p^{**} - 0.75 \log P^{**} - 0.24 \log F$	0.49
B	Multiple family (Town House) dwellings	
	$\log WUa = 0.34 + 0.71 \log V^{**} + 0.49 \log N_p^{*}$	0.27
	$\log WUs = 0.30 + 0.70 \log V^{**} + 0.62 \log N_p^{**}$	0.27
	$\log WUw = 0.12 + 0.81 \log V^{**} + 0.44 \log N_p$	0.23

* Significant at 95% level
** Significant at 99% level

WUa is water use in gallons/day/dwelling unit (annual average);
WUs " " " " " " " " (Summer period average);
WUw " " " " " " " " (Winter period average);
V is the assessed sales value of residence in hundreds of dollars;
Np is the number of persons in the dwelling units;
P is the variable price of residential water in cents/1000 gallons;
F is the fixed bill for one billing period in cents;
SOURCE (43)

sprinkling uses were reflected by the much larger monthly water use in the summer than in the winter (9,500 gallons vs. 5,500 gallons). The amount of water used was found to vary directly with income or assessed property value (97).

Higher summer water use was associated with higher incomes due to the greater use of water for lawn sprinkling by higher income families. Finally, the study showed that little or no predictive or explanatory power was lost when the analysis was confined to secondary and other easily available data. For example, house value, which is strongly income related, is actually a better estimator of residential water use than family income, data for which are more difficult to obtain. Assessed housing value, which is even easier to obtain, is as good an estimator as actual house value. Also, lot size, which is easier to obtain than lawn size, is just as good as lawn size in determining water use.

Sewell and Roueche (98) conducted a study of municipal water demands in the city of Victoria, British Columbia. As in the case of Grima's research, Sewell and Roueche focussed on the role of water price in reducing peak load demand and ultimately the amount of investment in municipal water supply systems. The research methodology was, again, multiple regression analysis, with dependent variables of annual water use, peak period water use (June through August), off-peak water use (October through April) and mid-peak water use (May and September). Independent variables were average water price in the corresponding four periods, income, peak and mid-peak average temperatures, and peak and mid-peak precipitation. Average water prices were calculated as averages per customer across the Victoria urban region. Income was measured in terms of average disposable per tax return across the urban region. All data were gathered from secondary sources, with no sampling being carried out, in contrast to the Grima and Kellow studies outlined above. Also, in measuring water use, all municipal uses, including commercial, institutional and industrial were included, and the assumption was made that because these latter three uses were small, the resulting measure of the dependent variables reflected accurately residential water use.

The results of the Sewell and Roueche study are given in Table 4 in the logarithmic (exponential) form. The four models had reasonably high degrees of explanation, with the R^2 values ranging from 63% to 80%. None of the variables was found to be consistently significant at a high (i.e. 95% or over) level. Price was found significant at the 95% level in two cases and at the 90% level in one case. Although the untransformed form of the equations was also calculated, the logarithmic form proved better in terms of the level of explanation. In contrast to Grima and Kellow, the logarithmic transformation used natural logs, not logs to base 10.

Sewell and Roueche applied their results to simulating the effects of price on urban water management, applying a technique developed by Davis and Hanke (99). Three different price levels

TABLE 4. REGRESSION EQUATIONS FOR MUNICIPAL WATER USE

Demand Function		R^2
Annual demand	$\ln Q = 1.656 - 0.395 \ln P^* + 0.191 \ln i + 0.272 \ln T - 0.066 \ln R^*$	.804
Peak demand	$\ln Q = -2.528 - 0.065 \ln P - 0.049 \ln I + 1.650 \ln T^* - 0.091 \ln R^*$	.743
Off-peak demand	$\ln Q = -0.845 = 0.579 \ln P^* + 0.504 \ln I^*$	.630
Mid-peak demand	$\ln Q - 11.96^* - 0.252 \ln P^{**} + 0.277 \ln I + 3.097 \ln T^* + 0.040 \ln R$	.674

* Significant at 95% level

** Significant at 90% level

Q = Consumption/customer

P = Average price ($1961)

I = Disposable income/Tax return ($1961)

T = Average temperature

R = Average rainfall

SOURCE (98)

were estimated: off-peak, peak and mid-peak, defined as outlined earlier. The linear regression equations were then used to simulate the effects of these price levels on water demand and revenue for the years 1967 through 1970. The results of the simulation were then compared to the actual water usage experienced during these years. On an annual basis, use of the three price levels (at the appropriate periods) results in an overall increased water use of from 6.7% to 7.6%. In the peak (June through August) period, use of the calculated peak period price results in a decreased water demand of from 5.4% to 7.6%. Similarly, in the off-peak period, use of the calculated off-peak price results in an increased water use of from 17.9% to 20.6%. Annual revenues would decline from 4% to 6.9% as a result of using selective pricing.

The authors conclude that peak load pricing will result in a decreased demand in the peak period. Since capacity of an urban water supply system is oriented to the peaks in water demand;the authors claim that this would eventually lead to a diminished requirements for (expensive) capacity expansions. Also existing capacity would be better utilized in the off-peak period.

The Canadian studies by Grima, and Sewell and Roueche generally are consistent with findings in other areas. The concept of price elasticity refers to the response of quantity demanded to price chances. It is measured as the percentage change in quantity to the percentage change in price. Elasticities are normally denoted by negative signs to indicate a demand curve sloping down to the right. Ignoring the sign elasticities greater than one are defined as elastic; less than one, inelastic; and 0, perfectly elastic.

Most water demand studies have shown the quantities of water demanded to be relatively inelastic with respect to price. Howe and Linaweaver (100) calculated demand elasticities to range between -0.231 for domestic (indoor) demand and -1.12 for lawn irrigation demand. Rees (101) showed residential demand elasticity to be a low -0.16. Wong (102) found that demand elasticities in the Chicago area to range between -0.0177 and -0.2830. Both Howe and Linaweaver (103) and Rees (104) indicate that demand elasticities are higher in the summer than in the winter.

Grima's regression models behave in the manner found in other studies, with the price elasticities ranging between -0.751 and -1.07, and being higher in the summer than the winter. Sewell and Roueche found that water demand in Victoria was inelastic, but greater in the winter (-0.579) than in the summer (-0.395). The authors attribute this finding to the peculiar water using habits of Victoria residents, which they term the "green lawn syndrome" (105) but this research result needs more investigation before it can be adequately explained.

In contrast to the studies by Grima, Kellow, and Sewell and Roueche, which focussed upon water demands and pricing in single metropolitan areas, Victor (106) studied the use of environmental resources (i.e. land, air and water) in industrial production on a national basis. The study focussed upon the flows of environmental commodities through the economy. It is really not a water demand forecasting study or water use study, but it is notable for its application of the input-output techniques and the Canadian input-output tables (107) to a materials balance view of the environment (108). Basically, the study augments the commodity-by-industry input-output table available for the Canadian economy by adding land, water and air sectors. In a manner similar to the one described in section C.6 this approach allows the analyst to trace the impacts on the environment of changes in final demand, such as an increase in personal expenditure. While Victor's work did not deal directly with water demand forecasting, the techniques developed are very relevant to such tasks, as shown earlier.

To summarize, applied water use and demand studies in Canada have been, for the most part, quite elementary in nature, and have relied almost exclusively on a coefficients approach. There have been a few excellent examples of attempts to improve the methodology and conceptual content of use and demand studies, but these have remained unadopted. The need to rationalize water use has not yet been felt in sufficient strength to generate the need for more sophisticated methods. Also, many areas throughout Canada still use water to promote other public goals, such as attracting industry. In doing so, they have established water pricing at minimal levels, thereby subsidizing some users, at the expense of encouraging efficient patterns of water use.

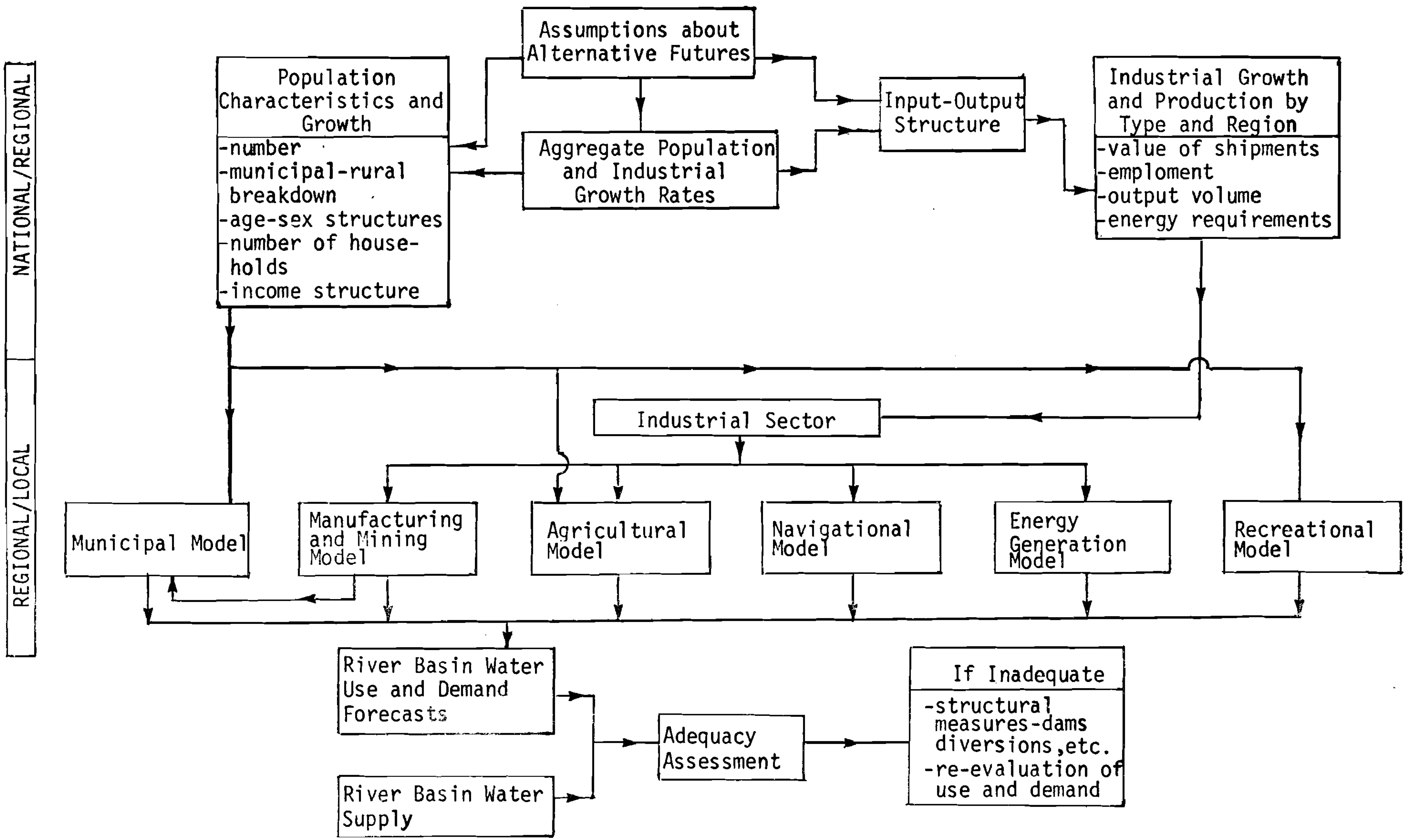
E. CURRENT DEVELOPMENTS IN WATER USE AND DEMAND FORECASTING IN CANADA

Efforts are currently being made in Canada to incorporate many of the considerations outlined in section C into practical, working methodologies for water demand forecasting, in this way fulfilling the needs for this activity identified in section B. This work is being conducted in conjunction with federal and provincial water management studies, such as the forthcoming Prairie Provinces Water Demand Study (109). This section of the paper deals with these developments, beginning with the formulation of a national forecasting framework, and proceeding to an outline of factors to be considered in each water demand sector. These sectors are municipal, industrial and recreational. The industrial sector is sub-divided into manufacturing and mining, agriculture, navigation and power generation.

1. Formulating the Basic Framework

A major point covered in section C.2 was the need for water demand forecasting to proceed from the national to the local level. In this way, basic data, vital to forecasting at the local level but available only at a more aggregated national or provincial level, form the framework for the forecasting exercise. As shown by the general framework depicted in Figure 2, there are two principal components of a national level model - population characteristics

FIGURE 2 AN AGGREGATE WATER USE AND DEMAND FORECASTING FRAMWORK



and growth and industrial growth and production. These two components are linked by assumptions concerning alternative futures and aggregate population and industrial growth rates. Thus all work in the subsectors which comprise the aggregate model is oriented to the alternative futures approach.

The population characteristics and growth component compiles nationally available data on population projections and manipulates it into appropriate river basin regions. This is carried out in the following manner:

1. Compute the numbers and characteristics of the population residing in each river basin since 1951. This is done by manipulating current and past census data into river basin regions.

2. Calculate the proportions of river basin to provincial population by 5-year intervals since 1951.

3. Using the method of 5-year rolling averages, project these proportions to the target forecast year (e.g. 2000).

4. Multiply the proportions derived in this manner to the forecasted provincial populations done by Statistics Canada, or corresponding provincial agencies.

The result of using this method will be a forecast of river basin population which is co-ordinated with official national and provincial forecasts. The same technique can be carried out to obtain forecasts of population in individual municipalities in each river basin. Since the basic population projections from Statistics Canada have been made on the basis of four different sets of assumptions, the basis for the alternative futures approach is incorporated into this method of deriving river basin population forecasts. The characteristics of the population of interest are age-sex structure, income structure and number of households (110).

The industrial component of the national-level model is concerned with deriving forecasts of industrial activity in river basins, as reflected by physical production output, employment and value of shipments. On the basis of assumptions about alternative futures and growth rates, final demand for industrial products under a range of future conditions can be estimated. These estimates of final demand can then be used in conjunction with the national input-output table (111) to forecast direct plus indirect industrial outputs in a manner outlined in section C.6. The national estimates made in this way can be disaggregated to the provincial level using Statistics Canada shares of production by each industrial group. By proceeding in this manner, the economic interrelationships amongst industries (including manufacturing, mining, agriculture and energy generation) are taken into account.

2. Carrying Out Local Water Demand Forecasts

While a national framework is important in assuring a reliable and consistent data base, most of the detailed work on analysis and projection of future water demands will be carried out at the river basin and local levels, where supplies and demands can be compared. This section, which draws heavily upon methodologies suggested by the author for the proposed Prairie Provinces Water Demand Study (112) and those outlined in Forecasting the Demands for Water (113) will describe briefly the types of variables being considered at the local level in formulating models for forecasting water demands.

(a) Municipal sector: A municipal water use and demand forecasting framework is depicted in Figure 3. The actual forecasting level is the individual municipality. In Canada it is intended that all municipalities over 1,000 persons will be analyzed separately, while those under 1,000 persons will be dealt with using coefficients of total water pumped per capita. Inputs to the individual community models will be derived from the population/agriculture component of the national/regional model and other data required only for the municipal model. The population forecasts for individual municipalities are based upon the national population projections, disaggragated in a manner similar to that outlined in section E.1 for the derivation of river basin population forecasts. All of these data are collated to form a set of community profiles as shown in Figure 2, which in turn form the basis for the water use and demand forecasts.

Municipal water demands are the sum of several different types of demands, residential, commercial, industrial and institutional - each of which should be estimated separately. For residential water use, Howe (114) outlined a series of multiple regression equations which may be used to estimate coefficients of use per dwelling unit in municipal areas. A similar set of equations by Grima (115) could also be tried to obtain a range of coefficients. The derived coefficients are then multiplied by the number of dwelling units in the municipality to obtain the residential water demand. The number of dwelling units in the future is a function of future population as given by the national framework studies. In Canada, all data required for the Howe or Grima models are available, and initial Canadian attempts to forecast residential water demands can use these models. Later efforts will refine the models by reformulating them using data collected for different areas across Canada. Although water use coefficients are still important to this methodology, the estimating data for the coefficients takes into account the economic nature of residential water demand, thereby making the methodology theoretically correct. The following table shows the equations used in the Howe models to estimate average daily in-house water demands, average daily summer sprinkling requirements and maximum daily summer sprinkling requirements. The Grima equations were given in Table 3.

Commercial and institutional water uses have been studied in much less detail than residential ones. The landmark study of these uses was done a number of years ago by Wolff, Linaweaver and

TABLE 5. REGRESSION EQUATION FOR RESIDENTIAL WATER USE

(All coefficients are in terms of gallons per day per dwelling unit)

Type of Area	Average daily in-house use	Average daily sprinkling rate	Maximum daily sprinkling rate
Metered with public sewers	$q_{a,d} = 206 + 3.47V - 1.30p_w$	$q_{s,s,} = 3657\, r_s^{0.309} p_s^{-0.930}$	$q_{max,s} = 30{,}160 r_{max}^{0.544} p_s^{-0.671}$
		$q_{s,s,} = 1130\, P_s^{-0.703}\, V^{0.429}$	$q_{max,s} = 1634 p_s^{-0.619}\, V^{0.416}$
Fault rate and apartment areas	$q_{a,d,} = 28.9 + 4.39V + 33.6d_p$	$q_{s,s,} = 94\, r_s^{1.21}\, V^{0.553}$	$q_{max,s} = 12{,}690\, r_{max}^{1.03}\, V^{0.50}$
Metered areas with septic tanks	$q_{a,d,} = 30.2 + 39.5\, d_p$	none	none

$q_{a,d}$ = average annual rate of in-house use in gallons per day per dwelling unit (g pd/du)

$q_{s,s}$ = average summer sprinkling rate (g pd/du)

$q_{max,s}$ = maximum day sprinkling rate (g pd/du)

P_w = commodity charge (variable charge) for water. Applicable at in-house rates of use, cents/thousand gallons

r_{max} = maximum day summer rate of potential evapotranspiration inches per day

p_s = commodity charge applicable at rate of combined in-house and sprinkling use during summer

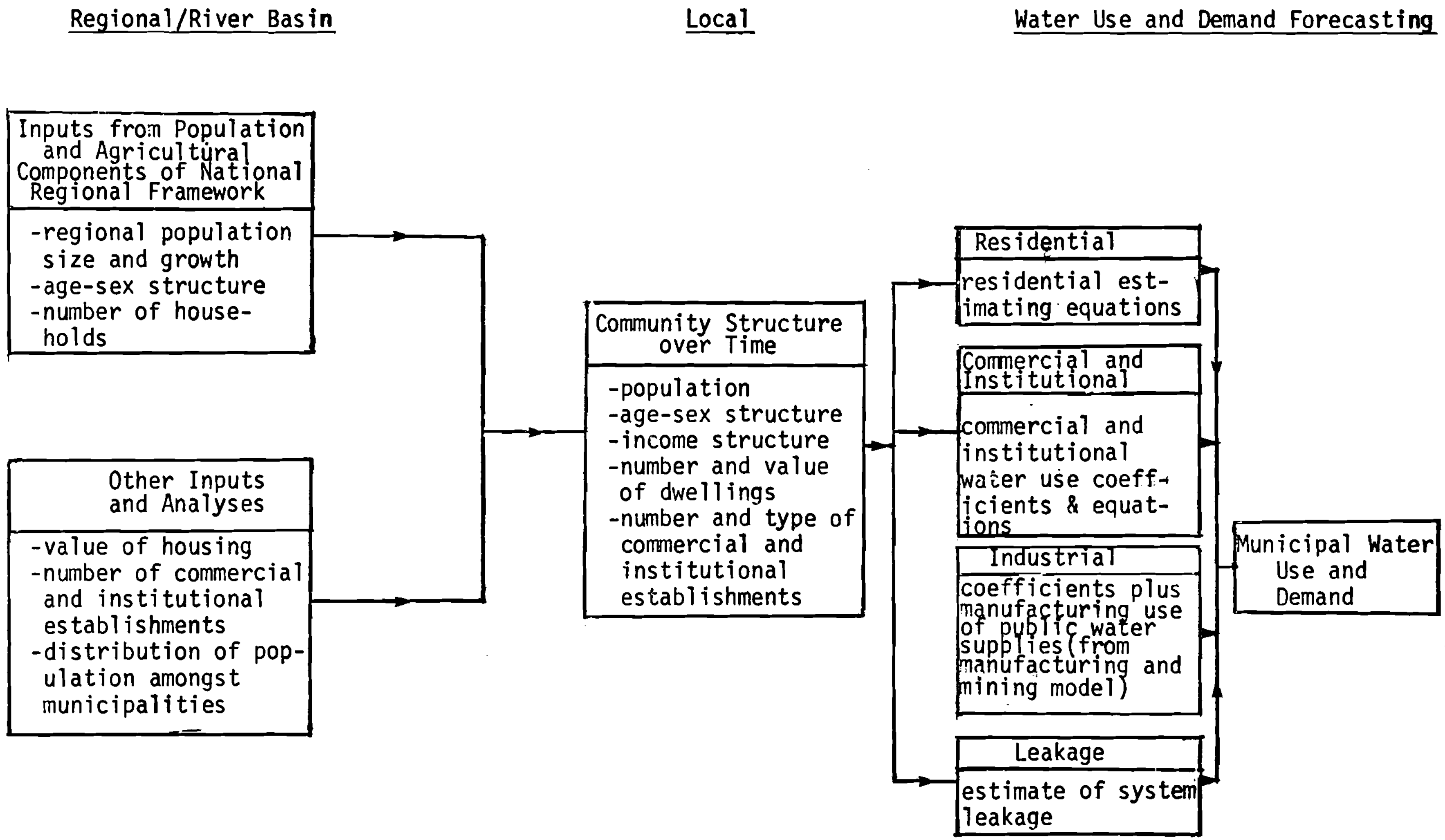
r_s = estimate of physical "requirements" of irrigated lawn area to make up for difference between average summer season potential evapotranspiration and effective precipitation, inches per season

d_p = number of persons per dwelling unit

V = value of the dwelling in thousands of dollars(1964 prices)

SOURCE (114)

FIGURE 3 MUNICIPAL WATER USE AND DEMAND FORECASTING MODEL



Geyer (116). This study broke commercial and institutional uses into their component parts, and determined for the study area, Baltimore, U.S.A., and average coefficient of daily withdrawal per unit of size. For example, for department stores, water withdrawal was given in gallons per square foot. A more recent study by McCuen et al. (117) developed a series of linear regression equations for water use in different types of commercial establishments located in four shopping centers in the U.S. Until Canadian studies of commercial and institutional water use are available, water use and demand forecasting projects will have to rely on these two sources for basic coefficients or estimating equations. Since commercial and institutional water uses account for about 17% (118) of municipal water pumpage, it is clear that more work needs to be done on formulating water demand models for these uses.

Industrial demands from municipal water supply systems may be divided into withdrawals by large primary users and withdrawals by smaller secondary and tertiary industries. The latter are small in volume, and, because no Canadian studies of them have been done, the use of water use coefficients per unit of production may be permissible. Withdrawals by large industries, on the other hand, should be analyzed as part of industrial water demands and then linked back to the municipal system.

(b) Industrial-manufacturing and mining: A model suggested for water use and demand forecasting in the manufacturing sub-sector of industry is shown in Figure 4 (119). Inputs from the industrial component of the national/regional framework are estimates of future production levels for each type of industry (e.g. iron and steel, pulp and paper, etc.) for each province. These, it will be recalled, are obtained using input-output analysis at the national level and disaggregation to the provincial level using production shares. Other inputs required are shift-share ratios (120), information on anticipated technological changes related to industry, information of effluent controls likely to be imposed in the future along with an estimate of their water use impacts, and, for mining, information and production data on new mine sites. The shift-share ratios are used to analyze past production growth by municipality and to project it to the target year. Technological and effluent control information feeds directly into the water use and demand forecasting model. The industrial production information, the shift-share data, and the data on new mining areas are combined to formulate community industrial profiles for each municipality in the study area.

The water use and demand forecasting model shown in Figure 4 has already been discussed in section D, and the reader is referred back to that discussion.

(c) Industrial-agriculture: An agricultural water use model is outlined in Figure 5. Inputs to the model derive from both the population/agriculture and the industrial components of the national/ regional framework. These inputs are supplemented by information on land under irrigation, and by economic assessments of the demand for crops produced by means of irrigation.

FIGURE 4 MANUFACTURING AND MINING WATER USE AND DEMAND FORECASTING MODEL

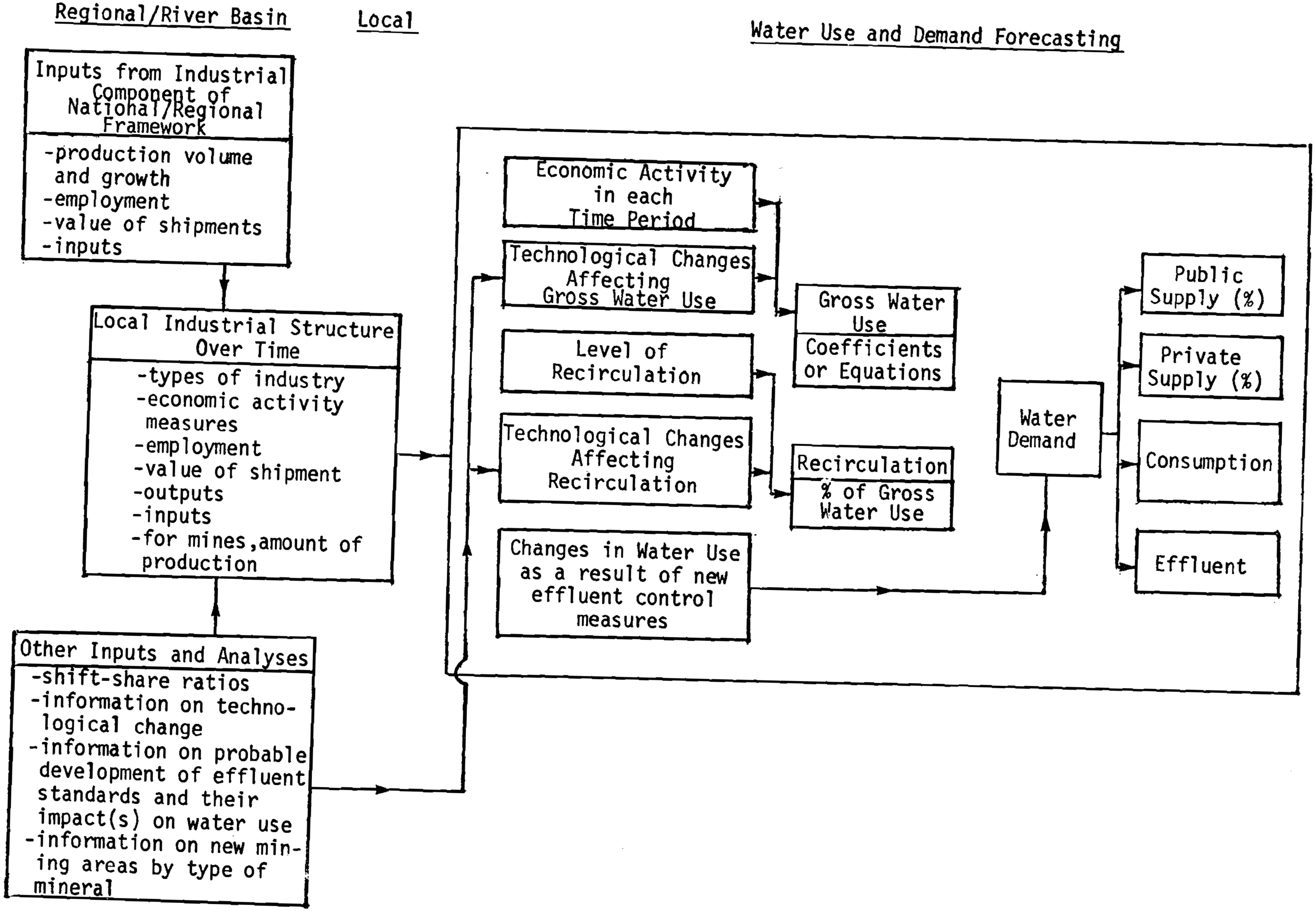
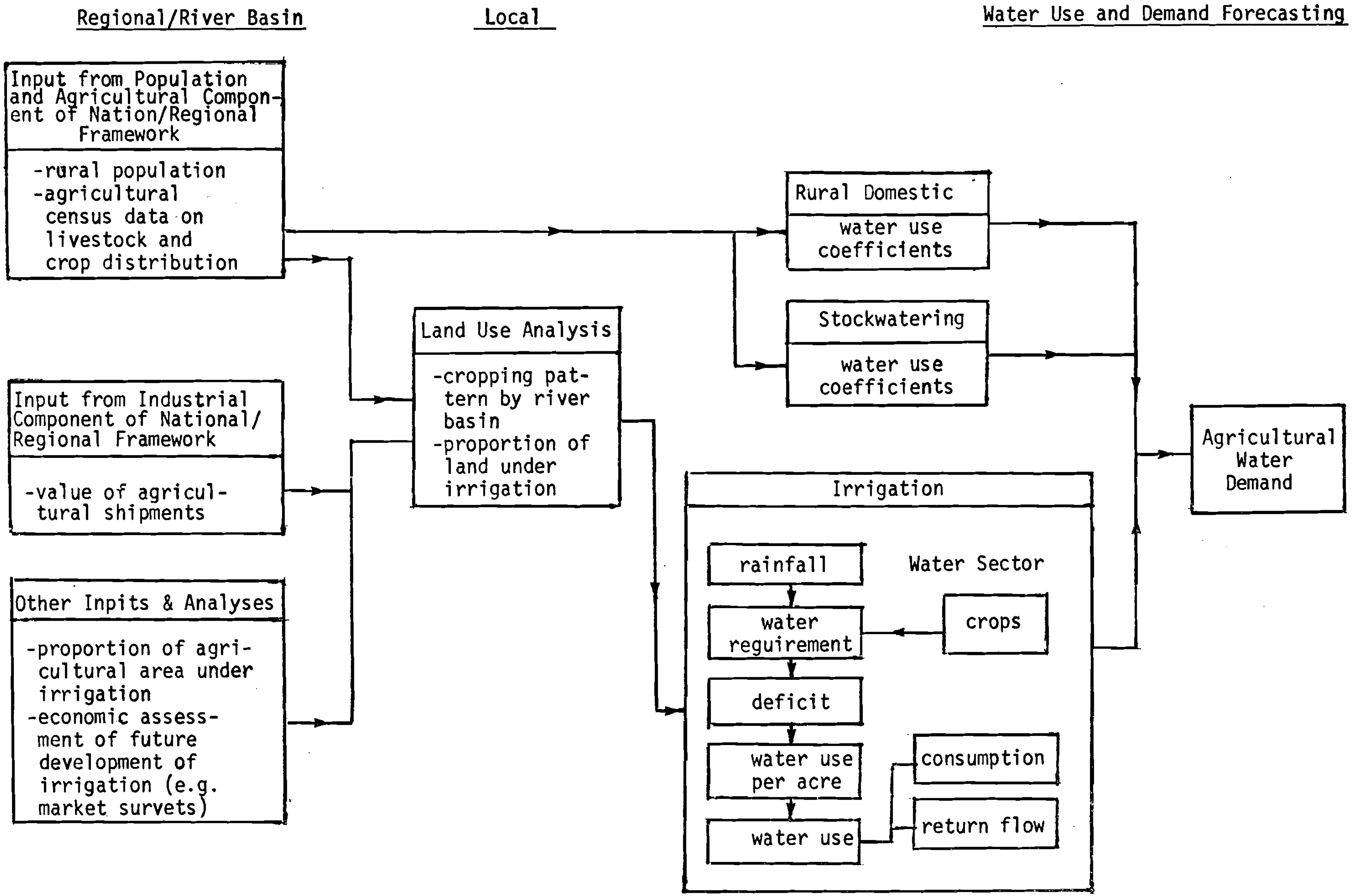


FIGURE 5 AN AGRICULTURAL WATER USE AND DEMAND FORECASTING MODEL



Agricultural water uses can be subdivided into rural domestic, stockwatering and irrigation components. For rural domestic and stockwatering uses, the amount of water used is influenced to a high degree by human and livestock populations, respectively. Since water for these uses is usually self-supplied, water pricing concepts have no application in forecasting them in Canada. Thus, reliance will likely continue to be placed upon coefficients of water intake per capita or per head of livestock for these two uses. Rural and livestock population forecasts are produced as part of the national framework studies.

Irrigation water use in Canada is substantial. The 1.1 million irrigated acres account for a water withdrawal of about 1.3 billion gallons of water per day (121), a large part of which is consumed. Forecasting irrigation water use is a very complex task, involving marketing and product demand considerations as well as physical considerations such as crop requirements and potential evapotranspiration. Water pricing has never been subject to analysis in Canada, as no irrigation area has attempted to cover more than its supply costs through water charges. Thus it is extremely difficult to speak of irrigation water "demands" in Canada.

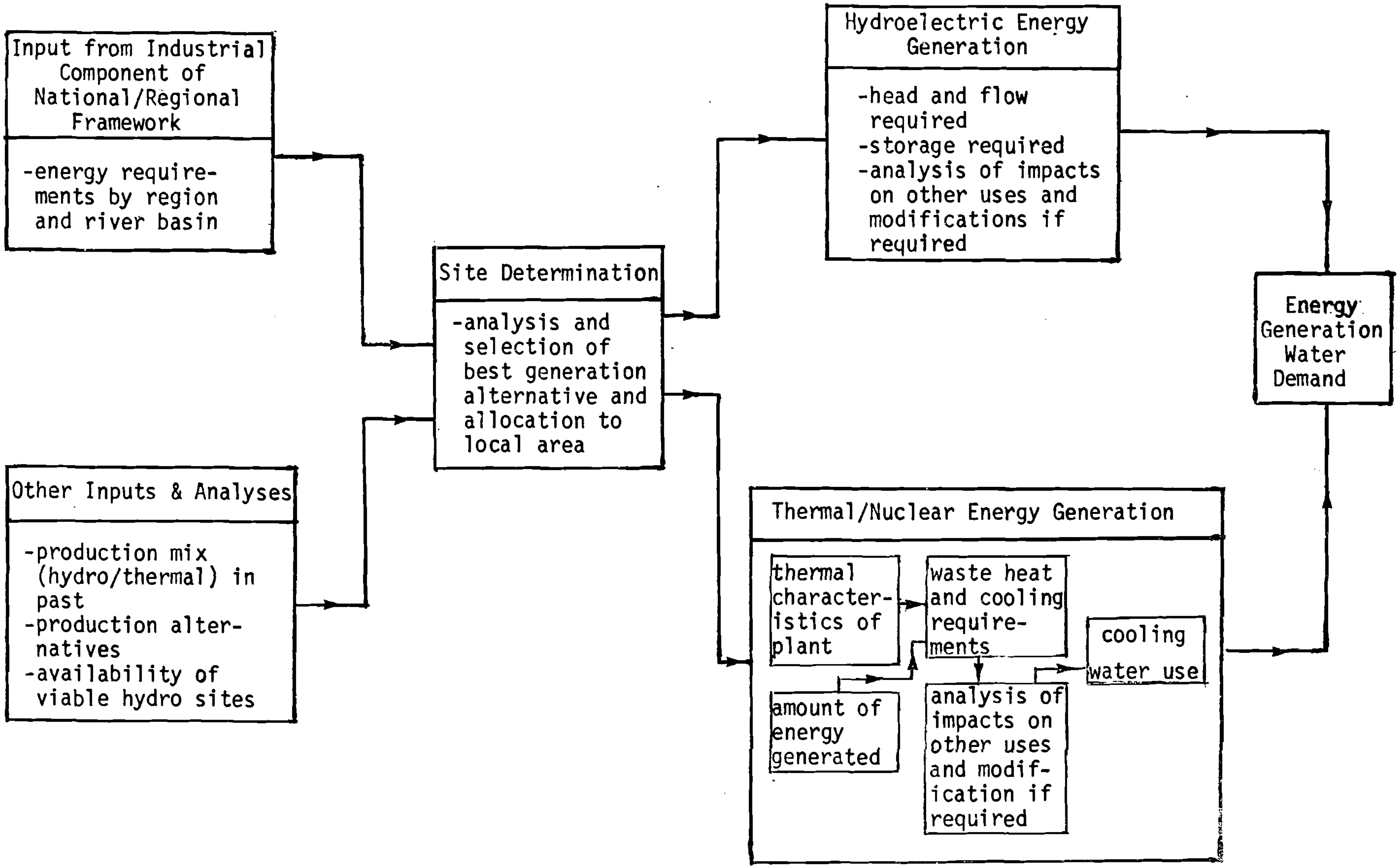
For the Prairie Provinces Water Demand Study, a framework was developed for analyzing irrigation water use, which contained three distinct units: an economic unit, a land requirements unit and a water use and demand unit. The economic unit examines the demand for agricultural products, value of production, and an economic assessment of the future area under irrigation. This unit is part of the inputs on the left side of Figure 5. Once aggregate crop demands have been determined, the demand for irrigated crops can be estimated using past proportions of total crops produced by irrigation plus information as to future policies on promoting irrigation as opposed to dryland farming. This information is then used in the land requirements unit of the model to quantify and allocate to river basins the amount of land required in the future. In turn, this information is used as input to the water use and demand unit, where it is analyzed in conjunction with data on rainfall, crop water requirements and potential evapotranspiration to give an estimate of water diversions for irrigation. This model for irrigation water demands is much more elementary than the linear programming approach (122), which seems to reflect the current state of the art in the U.S. (123). However, in Canada the data requirements of the linear programming approach are probably too great to allow the use of this approach in the near future.

(d) Industrial-energy generation (124): Figure 6 shows a model suggested for forecasting water use and demands in the energy generation sector. Inputs from the industrial component of the national/regional framework are forecasts of energy requirements by region and river basin. Other inputs include the production mix (e.g. hydro/thermal) experienced in the past, a production possibilities curve (125), and the availability of hydro sites for future developments. All of these inputs are used to determine the location and generation type of future energy generation projects.

FIGURE 6

AN ENERGY GENERATION WATER USE AND DEMAND MODEL

Regional/River Basin | Local | Water Use and Demand Forecasting



Energy generation water demands have two major components: hydroelectric power generation and thermal power generation (including nuclear). Each type has distinct water use characteristics and thus must be analyzed separately and distinctly from the other.

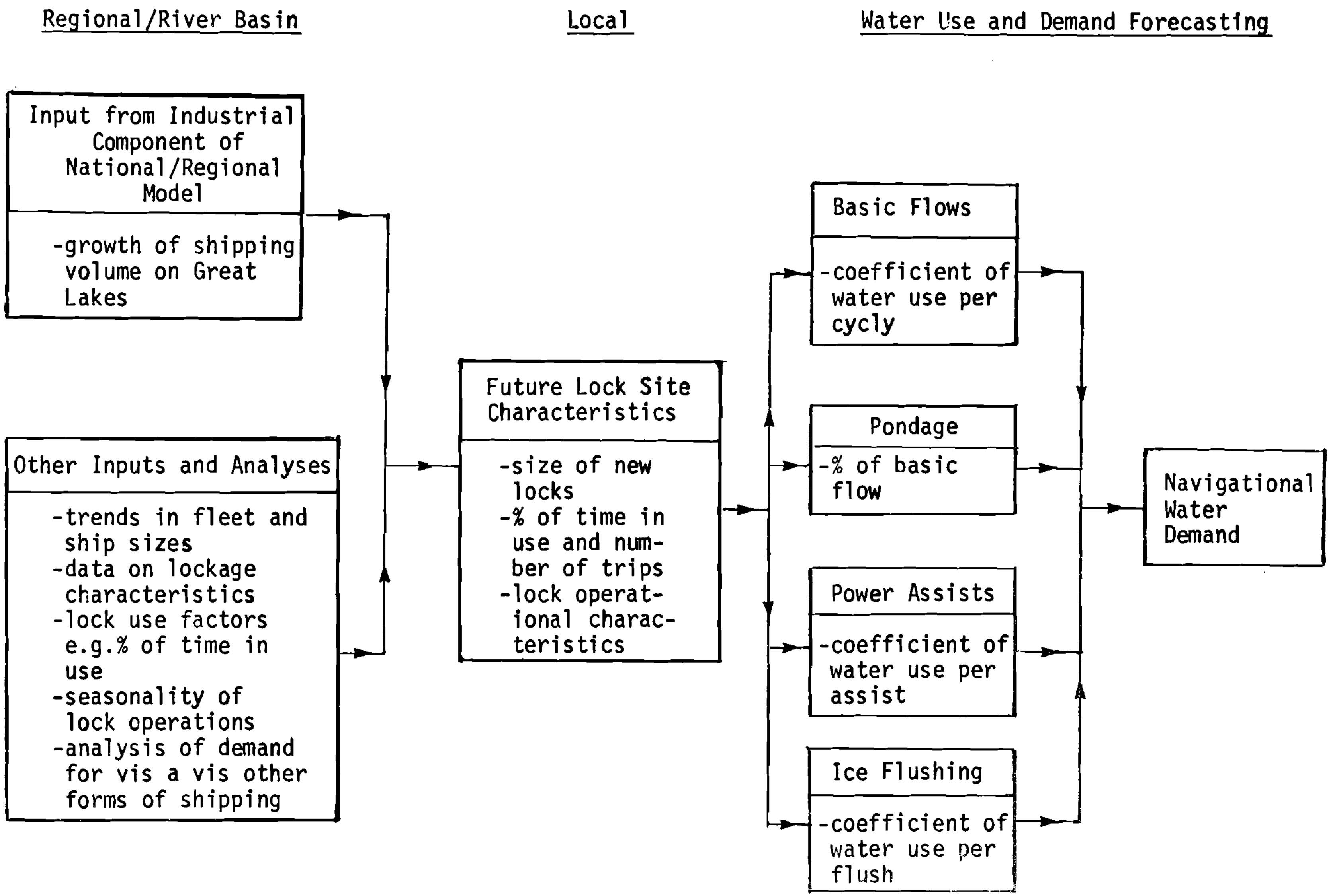
Because hydroelectric power generation may cause large changes in river flow patterns, it may affect other in-stream water uses, such as recreation, fishing and hunting, navigation or waste dilution (126). For this reason, Bower maintains that the opportunities foregone through hydroelectric development must be assessed as part of the decision to develop the site. He suggests that this is an iterative step, because for each possible set of operating rules, the effects of the competing uses will be different. For example, the trade-off between storing water for power generation as opposed to timely release for waste dilution must be evaluated for each set of power plant operating rules. After this trade-off analysis has been completed, the hydrogenerating alternative maximizing economic efficiency would be selected for development. This determined the water demand for hydroelectric power production.

For thermal power plants, following analysis of the various possible power generating alternatives, as outlined above, heat rates, plant efficiencies and unit sizes are used to determine gross cooling water requirements. Assuming a once-through cooling system, all of the waste heat borne by this water will be discharged to receiving streams. Analysis of the impacts of this discharge on other water uses may then be carried out, and, where sizeable potential damages are found, and evaluation can be made of the costs of reducing the thermal discharges, for example through the use of cooling towers. Comparing the potential damage costs to the costs of thermal discharge reduction, the analyst can select the alternative which minimizes costs. This final selection then determines the water demand at the generating site (127).

(e) Industrial-navigation: Commercial navigation on the Great Lakes is of tremendous importance to the economies of both Canada and the U.S. Water use and demand forecasting consists of estimating minimum flows necessary required to maintain the anticipated levels of shipping in the future. The input to the navigation model depicted in Figure 7 from the industrial component of Figure 2 is a set of estimates of the future weight and volume of cargo requiring transit, either by navigation or by other means. Alternative transportation methods, including perhaps several different lock and canal configurations and sizes, are then examined as methods of transporting the estimated future cargo, and the least cost alternative is selected (128). Other data required relate to future fleet characteristics such as ship size, data on lock characteristics such as the time required to complete on passage through various locks in the system, and a determination of the future navigation season.

These inputs are used to determine the future characteristics of locks and canals, together with their operational parameters. The selection of the least-cost shipment alternative will determine the future size of locks and the need for construction of new facilities.

FIGURE 7 NAVIGATION WATER USE AND DEMAND FORECASTING MODEL



Once this basic configuration has been selected, the lock operation characteristics can be determined using a methodology outlined by Bathurst (129). Basically, this methodology uses lockage transit times under various assumptions as to the number of ships in transit though the lock at one time, in conjunction with the estimated traffic volume to determine the estimated number of times each lock in the system would be used in the target year of the forecast.

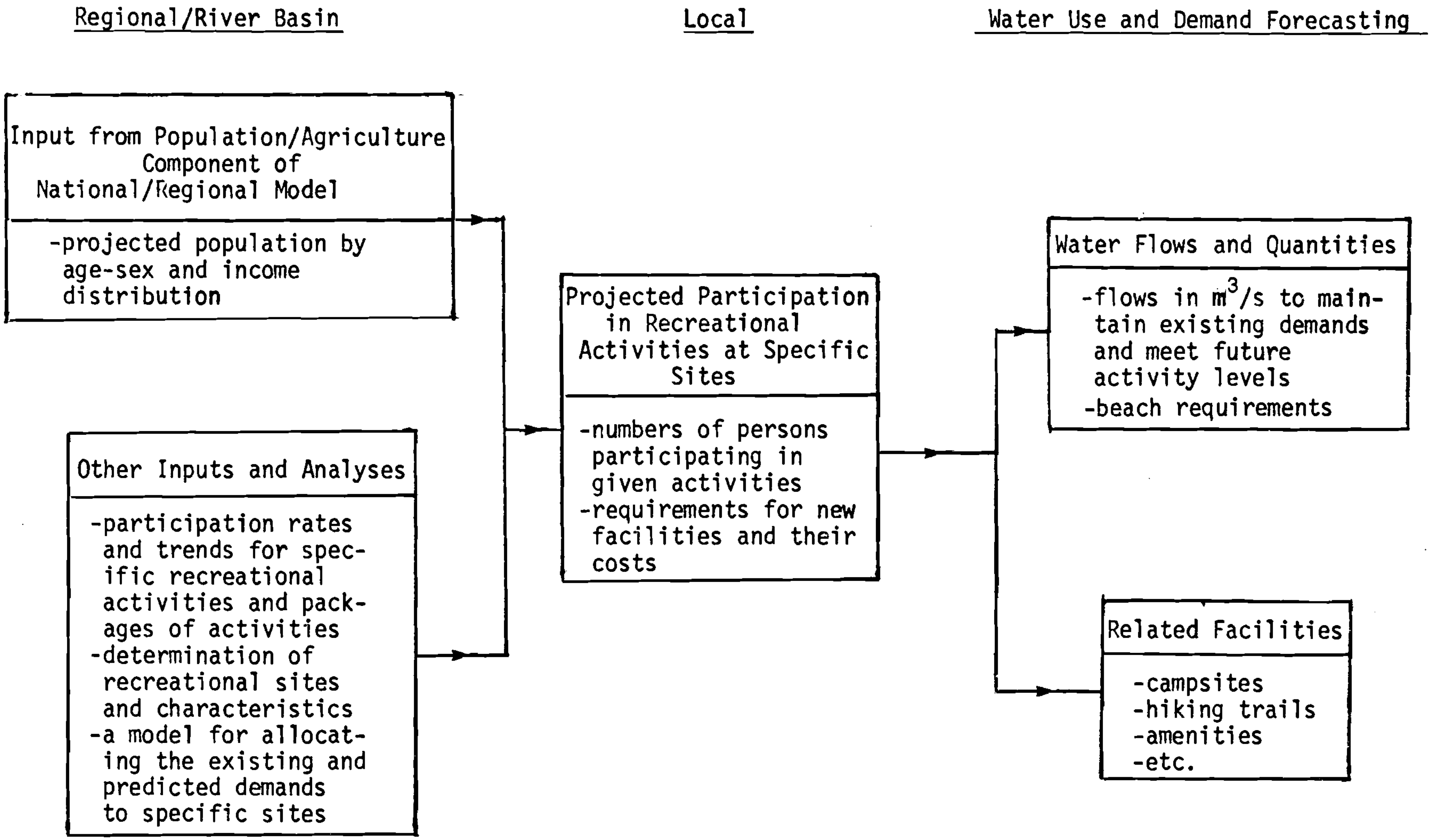
On the basis of calculations of basic lock operations in the future Bathurst (130) computes the water flow required for each of four functions: basic flow required for the passage of ships through the locks, flows required for pondage above and below the locks, flows required for power assist to large vessels clearing the locks and flows required for ice flushing in the early spring and late fall operations of the locks. Coefficients of flows required to maintain these functions are calculated on the basis of a series of equations (131) and other information from the St. Lawrence Seaway Authority.

(f) Recreation: Water forms an integral part of most recreational activities. Its role can range from the medium within which the activity takes place (e.g. swimming) to part of the total environment or experience of the activity (e.g. sight seeing). The theoretical issues in recreational water demand forecasting were outlined by Pearse (132), but to date little additional work has been done on this subject. The outline for the Prairie Provinces Water Demand Study (133) suggested a methodology for forecasting water demands for recreation, and this methodology, depicted in Figure 8, is the basis for the following material.

As Pearse states, the provision of public recreational opportunities has been virtually free in Canada, apart from nominal charges for entry to some recreational sites. It seems to be a valid assumption that this situation will continue into the future, the implication being that zero or nominal pricing must be assumed in forecasting recreational water demands. The small amount of Canadian effort devoted to this type of water demand forecasting to date has concentrated upon forecasting the amount of participation to be expected in any given waterborne recreational activity, or set of activities measuring the characteristics of supply of water-based recreational opportunities, and defining methods allocating the demand to available sites. In this manner, at least the demand for water based recreational facilities can be predicted, and planning undertaken to ensure that it can be met.

Four major questions must be faced in formulating a model for predicting recreational water demands: the supply characteristics of water-based recreational opportunities; the characteristics of demand by the study area's population; and a method of allocating the demand to available sites; and the requirements for water-based facilities as a result of predicted demands at the local level. Figure 8 suggests a model for recreational water use and demand forecasting, but this model is suggestive only because of the apparent lack of Canadian experience in this area.

FIGURE 8 A RECREATIONAL WATER USE AND DEMAND MODEL



The supply of recreational opportunities concerns the number of sites, site size (e.g. total acreage, acreage or footage of beach, etc.), site development (e.g. number of campsites, miles of walking or hunting trails, etc.) and accessibility from major population centers. Analysis of demand characteristics include the number of persons participating in individual activities, or, better still, in "packages" of related recreational activities (e.g. swimming, boating and canoeing). Participating in recreation is associated with many factors, such as income level, sex, age, educational level, etc. The Canadian Outdoor Recreational Demand Study (CORDS) (134) related participation rates to socio-economic factors, such as age, sex, and income, and forecasts of these factors provides a basis on which participation rates can be projected. The CORDS data provide an adequate basis for forecasting participation rates, but if this source is deemed out-of-date when a particular study is undertaken, a new household survey could be conducted to formulate new rates. Applying the participation rates to projected population will generate estimates of the number of persons expected to participate in each activity or package of activities.

The formulation to a model to link supply with demand is still the subject of investigation in Canada, with no one method being accepted as "correct". One promising approach is based upon the gravity model analogue, a well-established research technique in the social sciences. Basically, this model is used to explain the interaction between two "centers of attraction". In the case of recreational demand analysis, the "centers of attraction" are the source of demand for recreational opportunity (e.g. an urban area) and a particular recreation site or group of sites, and, as in the classical gravity model of physics, the attractive force between the two centers is the distance between them. Thus, theoretically, once the model has been calibrated, the demand for recreation at a particular site, in terms of numbers of persons, can be predicted using the population of centers which exert a demand on the site and the distances between those centers and the site. Ross' work on opportunity quotients (135) is one example of the application of the gravity model concept. The opportunity quotient takes into account the interaction of supply and demand factors. The result of the analysis is an index of recreation opportunity for any part of the study area; these indices can be mapped to form a "surface" of recreational opportunity, much in the same way that a topographic map depicts a physical surface. The utility of this "opportunity surface" is in its application to identifying areas deficient in recreational opportunity, and in its use in analyzing the effects of new sites in the study area.

An alternative to the approach outlined above is to use regression analysis to relate recreational site attendance to a number of independent variables such as site attractiveness, alternative sites, population of the service area, etc. Cheung (136) used this model to develop a day use park visitation model, which gave a high level of explanation (i.e. 91%) of the total variance of the dependent variable, the use of parks by day users employing, as independent variables, site attractiveness, service area population, the availability of alternative sites and the distance between the population centers and the site.

Once the future demands for recreation have been allocated to the various sites, it remains to determine the water requirements and the requirements for related facilities. One important requirement is the flow of water to meet future demands for swimming, boating, fishing, etc. This could be determined using coefficients based upon past experience (e.g. flow in cfs per 1,000 users). An additional requirement would be forrelated facilities, such as camp sites, boats, amenities, etc. Again, a coefficients approach could be taken as a first approximation.

(g) Summary

This section has outlined the current state of the art in water use and demand forecasting in Canada. The models being used take into account both the more theoretical considerations in this field and the practical limitations of data, manpower and budgetary resources. The alternative futures framework forms the basis for forecasting water uses and demands. The variables determining water use and demand have been linked together in a systems framework for each major water use sector, using the river basin and local level as the main level of analysis. Difficulty still exists in implementing pricing considerations into applied water demand forecasting projects, but this difficulty can be partially overcome by using demand equations from previous studies if time or money precludes detailed examination of price: quantity relationships. Economic interrelationships and technological advances are also incorporated into the model outlined in this section.

F. SUMMARY AND CONCLUSIONS

Water use and demand forecasting in Canada have been carried out, for the most part, using elementary methods, which have often consisted of merely multiplying a water use coefficient by a projected population or economic activity level. Even in a country like Canada which has a relative abundance of water compared to its population, economic activity, emerging water management issues may require the adoption of more sophisticated methods. These issues relate to water management in drought situations, the role of water in energy production, the growing number of conflicts between water uses, the importance of water use considerations in water quality management, and the increasing demands on water in international drainage basins.

Water demand forecasting is considered to be primarily water management instrument, the main purpose is of which to explore the water resource impacts of future developments in the national, regional and local economies. To take account of the many possibilities for future development, water use and demand forecasting should use the alternative futures approach. This approach allows investigation of a whole range of development possibilities with regard to their impacts on water use and demand. Because of uncertainty regarding the future, the alternative futures approach is considered superior to predicting water use assuming only one development path (e.g. extrapolation of past growth rates).

Water use and demand forecasting should be carried out on a river basin and local basis so that results are compatible with data and analyses of water supplies and specific emerging problems quantified as the basis for water resource planning. In Canada, the need to use river basins as primary spatial units has caused some difficulty, particularly in adjusting available socio-economic data which are normally available only on a census region basis.

The role of price in water demand has not been studied in detail in Canada. Studies which have been carried out confirm findings in other areas that the demand for water is certainly not insensitive to price, as has been assumed in most applications of water use and demand forecasting in Canada to date. Substantial difficulty exists in assuring that the economic characteristics of water demand are taken into account. This difficulty arises because Canada's general water abundance has created an attitude that water is a "free" good, which in turn has led to a failure to define and investigate the role of price in allocating water amongst users.

Economic interrelationships and technological change have been demonstrated to be important in forecasting water demands. Changes in production in any given industry will generate changes in water use not only in that industry but also in all industries which supply its inputs. In many cases the latter, indirect changes in water use can be larger than the initial change in water use in the particular industry experiencing growth. Input-output analysis is designed to take account of economic interrelationships, and the paper showed how this technique has been adapted to water demand forecasting. Technological change will affect the way in which water is used and thus the quantities of water demanded. It is essential that changes in technology be considered in water demand forecasting.

Water demand forecasting is thus a complex undertaking. In Canada, the approach being taken to it is based on systems analysis to allow consideration of the large number of variables in water use to be taken into account. The national framework of the model analyzes basic data on population and industrial production under alternative growth assumptions, and breaks these data down into river basin and local regions. These data then form the inputs to detailed sector-by-sector forecasts of water demand at the local level. The sectors of water use analyzed at the local level include municipal, industrial (including manufacturing, mining, agriculture, energy generation and navigation), and recreation. The last part of the paper outlined models being used in Canada to predict water use and demand in each major water use sector. Throughout this part of the paper, an effort has been made to outline methods which can be instituted in Canada, given the current availability of data, the types of studies in which water use and demand forecasting must be employed, and the current attitudes to this field of study on the part of Canadian water managers.

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