SCIENCE SECRETARIAT

Water Resources Research in Canada

by J. P. Bruce and D. E. L. Maasland

with a Special Report on
The Contribution of Social Science Research
to Water Resource Management in Canada

by W. R. Derrick Sewell

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IN CANADA

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水者地之血氣如
筋脈之通流者也
故曰水具材也
—管子 水地篇

"Water is the vital energy of the earth, it is like (blood) flowing through (our) veins.
Therefore I say:
Water is essential to all material wealth."

The Kuan-tzŭ, late 4th century B.C.
(Translation C. Schepel, University of Michigan)

FOREWORD

The Science Secretariat, Privy Council Office, Ottawa, is supporting a number of studies to determine the status of science in Canada. These studies inform the Science Secretariat and also serve as background information for the Science Council of Canada in its deliberations for developing broad recommendations for science in Canada.

The present report relates to one of Canada's most important natural renewable resources. There has been much public debate concerning Canada's water resources, particularly as to the sufficiency of future supplies for use in Canada. There has been widespread concern about the pollution of Canada's water resources, especially in certain sectors of the country, but authorities have differed as to the extent and urgency of the pollution and the remedies that should be applied. Answers to such questions depend on research that is appropriate both in quality and amount. It was to determine the status of research on water in Canada that the present study was initiated. Mr. J. P. Bruce of the Inland Waters Branch, Department of Energy, Mines and Resources, and Dr. D. E. L. Maasland, Faculty of Applied Science, University of Windsor, were commissioned to carry out the study. The report of their findings follows.

J. R. Weir
Director, Science Secretariat

PREFACE

Research is an activity which society supports and which must be largely directed towards achieving the goals which that society has set for itself. Unfortunately, in Canada, the goals of our society have often been not too well perceived and certainly not well articulated. However, there are two major goals which have been stated many times, in varying ways, by governmental, industrial and academic leaders. One is to manage wisely the natural environment of our country, especially its renewable resources. The second is to ensure the continuing growth of productivity and wealth of the country. A third goal that has been advocated by many Canadians is to ensure that the potential agricultural productivity of the country is developed for the benefit of the starving peoples of less fortunate lands. In striving towards all three goals, a key factor is Canada's water resource.

Canada must use its waters wisely, if recreational and aesthetic values are to be preserved both for present and future generations. Development of industry, and thus productivity and wealth, depends greatly on availability of an abundant supply of inexpensive good quality water. Further development of agricultural lands will require extensive supplies of water for irrigation. However, the optimum use of the water resources to meet these needs must rest on knowledge of these resources and the techniques for managing them. This knowledge is gained through research. Water resources research is thus a field in which a concentration of scientific effort will contribute to three major goals of Canadian society.

J. P. Bruce
D. E. L. Maasland

Ottawa, Canada
May 1968

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The authors wish to thank all contributors to this report. To list all of the scientists, engineers and administrators who provided valuable data, ideas and discussions would be impossible. However, the authors extend their thanks especially to those who took time to complete questionnaires, to the members of the Science Secretariat Advisory Committee (Appendix I), the consultants who prepared special reports, and the staff members of the Science Secretariat who contributed many helpful suggestions and comments. In a real sense, this report is a product of the whole water research community in Canada. While full agreement of all members of the water community on the many details of this report can not be expected, the authors hope that the general findings and recommendations can be supported by most of those who gave assistance and advice.

A special acknowledgment is due to Miss Faye Sheppard who typed the manuscript in its several drafts.

J.P.B. and D.E.L.M.

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SUMMARY OF MAJOR RECOMMENDATIONS

1. *Recognition should be given to the important role of water resources in the Canadian economy and to the necessity for wise and efficient water management, as a major contribution to achievement of goals of Canadian society.*

2. *In order to provide the foundations for water management, water resources research should be clearly identified as a field for major expansion of research effort in Canada.*

3. *The target for increased project expenditures* in water resources research should be 20 per cent per year to achieve a level of about $25 million per year by 1972-73 and approximately $75 million by 1978-79.*

4. *Research efforts should be increased at substantially more rapid rates than 20 per cent per annum in the fields of precipitation, streamflow, environmental aspects of water pollution, groundwater management, economic and social sciences aspects and on network design and instrumentation. Growth of research expenditures at somewhat less than the average rate are recommended in the fields of general water cycle research, snow and ice, groundwater, saline water conversion, waste treatment processes, and on processing and publication of data. The reasons for these recommendations are given in Chapter V. The recommendations are summarized in detail in Table 13.*

5. *The present distribution of research effort by sectors of the economy were considered to be reasonably appropriate for water resources research. However, slight upward adjustments are recommended in the percentage done by universities (from 19.4 per cent to 22-25 per cent), and by the private sector, to be undertaken mainly by consultants. Provincial government effort should remain about the same proportion of the total. This would mean that federal intramural research should grow at a slightly lower rate than the average of 20 per cent per annum.*

6. *To undertake the increased research effort it is essential that policies be carried out which will result in a greater percentage of university graduates being directed into the water resources field. In addition, the need for a continually improving quality of research requires that many of the new research workers in this field have their graduate training in inter-disciplinary water research centres. Simultaneous expansion of governmental and industrial programs is necessary to enable Canada to make maximum use of its professional manpower.*

**Project expenditures are the direct costs of research, excluding major capital expenditures for buildings, research platforms, etc.*

96701—2½

7. *Funding of water research at universities should be of three types: (i) NRC-type sponsored research directed primarily in support of highly qualified individual scientists without too much emphasis on the nature of their research projects; (ii) sponsored research through the new National Advisory Committee on Water Resources Research, which should emphasize development grants to major water research centres in selected universities and research on projects closely related to the "missions" of the federal agencies; (iii) purchased research on contract by federal and provincial agencies and by industry.*

8. *The private sector should also be eligible for research support of the latter two types outlined in Recommendation 7. It is especially important to encourage, through sponsorship and contracts, additional research in firms of private consultants to improve efficiency in transfer of research results to practice.*

9. *A review should be undertaken in 1972 of the recommendations concerning the distribution of water research by sub-categories, and the proposed distribution by sector of performance, in the light of economic, industrial and social development of the country and economic projections for the '70s that will be available at that time. In addition, studies should be undertaken on the achievements of the various major water research centres that have been established as government institutes, government-university centres or as university centres, to provide guidance on future organizational development.*

10. *To ensure prompt publication and distribution of research results in this field, a Canadian journal of water research should be established. The National Advisory Committee on Water Resources Research should investigate the most effective way of undertaking such a publication program.*

11. *A Canadian office should be established to provide an information service on research underway and on results published, to both water scientists and users of research results. This service should have close relations with services in this field in other countries such as the Water Research Scientific Information Centre in the U.S. Department of the Interior, and the Science Information Exchange of the Smithsonian Institution, Washington, to help insure that optimum use is made of foreign research results.*

Chapter I

PURPOSE OF REPORT

I.1 Introduction

Water is the most basic of man's resources. Without water no living thing, plant or animal, can survive. Without an adequate and usable supply no society can sustain itself. Water is used for domestic and industrial purposes, for transportation and recreation, for power generation and waste disposal, for irrigation and fisheries. Indeed, one can scarcely think of any activity in society that does not involve the use of water at some stage or another.

Wolman[1] has estimated that of the total amount of water on the earth (10^{15} acre-ft.), less than one per cent occurs as usable fresh water, in the form of groundwater, as soil moisture, in lakes, and in rivers. Man's welfare is dependent on the proper management and control of this limited resource. A level of research commensurate with the value of the resource is a necessity in each country.

The qualitative aspects of the hydrologic cycle are relatively well understood. From the land surface, from rivers, lakes and the oceans, evaporation draws water into the atmosphere. The atmosphere returns this water as precipitation to the earth's surface and to our lakes and streams. If left uncontrolled, dependent on the vagaries of nature, this free gift is, at best, a mixed blessing. Periods of drought intermingle in an unpredictable manner with times of disastrous floods.

Thus control of water on and under the land surface is the function of water resources development. Control, however, implies not only that water must be available in times of drought. It means not only the prevention of floods. Control is much broader in its connotation, and implies optimum management of water resources for man's physical, social, and economic well-being. It requires the skill of the engineer, the knowledge of the scientist, the judgement of the economist, the concern of the industrialist, the guidance of the naturalist and, above all, the awareness of the public.

Optimum development of water resources is to a considerable degree dependent on new methods of predicting and controlling floods and droughts, new ways of controlling or preventing pollution, new techniques and materials for engineering works, a better understanding of the water cycle, better ways of conserving our water supply and a greater knowledge of the social, economic, and institutional aspects of possible alternative water management

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[1] Abel Wolman, *Water Resources, a report to the Committee on Natural Resources of the National Academy of Sciences*—National Research Council (Pub. 1000-B), Washington, D.C. 1962.

programs. Research has enabled us to acquire the knowledge which permits our present level of water management.

As Canada's population grows and its productivity increases, the pressures on our water resources will become very great. In some areas we are already faced with serious local water deficiencies and with extensive pollution of available supplies. To fully solve our present water problems and to meet those that are clearly visible on the horizon, a well-conceived and balanced program of water resources research is essential.

This report reviews present activities in water resources research in Canada. It makes recommendations as to the desirable future level of total expenditures on water resources research, and distribution of expenditures in different fields. It also comments on the institutional arrangements and distribution of effort in water resources research to ensure efficient use of funds and manpower, the availability of professional manpower in the field, and the ready diffusion of new findings to authorities responsible for water management and for design of water structures. It is the authors' hope that this report will serve to stimulate active discussion among water scientists and managers on the magnitude and nature of water resources research in Canada.

I.2 Water Resources of Canada

An inventory of Canadian water indicates a number of striking features, some of which are related to the size of the country, others to hydrological and climatological conditions. Broadly speaking, the East and the far West have a surplus, whereas the Prairies have relatively low average yield of water. Cass-Beggs[2] has estimated the annual run-off for settled areas of Canada as shown in Table 1. The Prairie Provinces comprising 30 per cent

Table 1.—Estimate of Annual Run-Off for Settled Areas of Canada by Principal Regions
(Long Term Average)

Region	Precipitation	Run-off			
	Millions of Acre-Feet	Millions of Acre-Feet	Percentage of Precipitation	Depth in Inches	Ratio to Canada Average
Maritimes	234	145	62.0	25.6	1.95
Quebec	433	167	38.6	14.5	1.10
Ontario	240	89	37.1	11.2	.85
Prairie Provinces	295	51	17.3	2.8	.21
British Columbia	402	314	78.1	24.4	1.85
Total Settled Area	1,604	766	47.7	13.2	1.00

[2] D. Cass-Beggs, "Water as a Basic Resource," *Resources for Tomorrow Conference Background Papers,* Vol. 1, Ottawa: Queen's Printer, 1961.

of the settled area of the country have a run-off volume of only 6.7 per cent of the total. On the other hand, run-off depth in British Columbia and the Maritimes exceeds even the average precipitation depth in the Prairies. The table clearly shows the diversity of conditions in Canada that significantly influence the types of management problems encountered in each region.

Hydro-electric development has been very intense in the past several decades. In excess of 70 per cent of the installed generating capacity in Canada is hydro-electric capacity. Canada is the third largest producer of hydro-electric power in the world, very close behind U.S.S.R. and the second largest producer of hydro-power per capita (behind Norway). Thermal and nuclear sources will become of relatively greater importance in future years. However, hydro-electric capacity will continue to increase, especially to supply power for peak loads. The estimated undeveloped maximum water power, based on the flow available for at least 50 per cent of the time is still nearly three times that of the installed generating capacity. The importance of low-cost power to the Canadian economy is obvious.

Industry uses more water than any other substance. It requires 65,000 gallons of water to produce a ton of steel, 10 gallons of water to refine every gallon of gasoline, 250 tons of water to produce a ton of newsprint and 300 gallons of water to make a barrel of beer. Increasing levels of industrial development and the location of this development will depend in a large measure on ready availability of large supplies of fresh water.

Canadian waters are of great importance to the transportation of goods. Ships on the Great Lakes-St. Lawrence Seaway alone transport 50 million tons of goods per year. In addition to commercial navigation our waterways and lakes carry thousands of pleasure craft. Indeed, water is the basis of an estimated 80 per cent of recreational activities in Canada. Besides boating, such activities as fishing and swimming are important to many Canadians.

In I.1 Introduction, a figure was given for the total amount of water in the world. Various estimates, ranging from 20 to as high as 50 per cent, have been made of the "Canadian share" of the world's fresh water supply. In reality, knowledge of the extent of our water resources is quite limited, except in our highly developed regions.

A unique feature of Canadian water resources is the abundance of fresh surface water in lakes; lakes surfaces comprise about 8 per cent of the total area of the country—an area greater than the total area of the province of Alberta. The Canadian portion of the Great Lakes alone, with a surface area of 36,000 square miles, contains roughly 9 per cent of the world's total volume of fresh water in lakes. Another eleven lakes have surface areas in excess of 1,000 square miles each. When one considers Canada's river water, an estimated 2.5 million cubic feet per second of average discharge is about 6 per cent of the estimated total average discharge of the world's rivers (40 million cfs). Some of the mighty rivers of the world, such as the St. Lawrence, the Nelson and Saskatchewan, the Columbia, the Yukon, the Mackenzie and the Peace, are flowing in whole or in part through Canada.

The picture for groundwater is bleaker though. Although Canada comprises 8 per cent of the world's land surface, its share of the world's groundwater is probably considerably less than that. This is due to the existence of extensive areas of permafrost, very limited soil and sub-soil cover in the glaciated regions of the Canadian Shield, the common occurrence of precambrian crystalline rocks, which are unsuitable for aquifers, the presence of large volumes of saline groundwater in the prairie regions, etc. Keeping in mind that the bulk of the world's available fresh water occurs as groundwater, it is then quite likely that Canada's fresh water resources account for less than 10 per cent of the world's total. When judged on a per capita basis, however, Canada's *average supply* may be deemed quite adequate and hence the kinds of problems differ from those experienced by most other countries.

I.3 Canadian Water Resource Problems

What then are some of the water resources problems in Canada?

A first difficulty relates to the size of Canada and the inaccessability of many of its regions. Water resources cannot be intelligently developed before reliable information on streamflow, precipitation and other factors is available. In Canada, much of this information must be obtained by means of automatic instruments required to operate in very severe environments. Not available at reasonable price at the present time, the development of such instruments, capable of functioning reliably under harsh climatic conditions with little attention for servicing and maintenance, would not only fulfill a real need in Canada but would also be useful in other regions of the world.

Canada's environment is being encroached upon by the waste products of an increasing population, by a growing industrialization, by leaching of fertilizers into streams and lakes and by many other side-effects of its accelerating economic development. Increasingly, conflicts arise between the social and physical use of our water resources on the one hand and the demands of municipal and industrial development on the other. A host of problems related to these conflicts is being posed, problems which are in part technical and in part social and economic in nature. Inland fisheries, recreation, wildlife, and municipal water supplies are being threatened by increasing pollution of waters in heavily populated regions. Methods must be found to make different water uses compatible. The rates at which pollutants diffuse and are purified by nature in our rivers and lakes must be examined more thoroughly to take maximum advantage of natural processes. Less expensive methods of waste treatment must be developed and better methods of sharing costs for pollution abatement must be found. The effect of specific waste components on the water environment and its plant and animal inhabitants must be determined, and so on.

Much of Canada's water supply derives from snow and ice. The conditions and processes causing snowmelt and ice break-up are only partially understood. Similarly, the factors influencing the formation of ice are not well enough known to predict accurately and possibly postpone freeze-up and accelerate break-up. The ability to extend the shipping season on the Great Lakes and Hudson Bay would be of great benefit to the nation, as would the partial control of rates of snowmelt in the mountainous areas of Canada, in Alberta and British Columbia.

The St. Lawrence River, the Great Lakes, the Columbia and other waters are shared by Canada and the United States. In negotiations between the two countries on water apportionment and pollution abatement it is imperative that the Canadian representatives bargain from a position of knowledge. This knowledge will in many instances be available only after conducting intensive research programmes.

Water transfers may take place from basin to basin, province to province, or indeed, from country to country. Whatever the case may be, extensive studies are necessary on water transfer. Our knowledge of how much water Canada possesses is inadequate, but our evaluation of water requirements and techniques for estimating future requirements are in much worse state. Only by concentrating much more effort in these areas of research can the advantages and disadvantages of water transfers be determined in a rational manner.

Much work remains to be done in the field of hydrology. Due to the complex inter-relations between the different phases of the hydrologic cycle, hydrology is to a large extent still empirical in nature. This implies, for a large country such as Canada with widely varying climatological and hydrological conditions, that similar studies must be performed in a number of regions. Since hydrology attempts to supply the designers and operators of a tremendous number of costly water control and water conveyance structures with criteria for design and operation, it is difficult to overstate the economic importance of research in this field. Under the impetus of the International Hydrological Decade, research in hydrology has increased substantially throughout the world during the past few years. Watershed research in experimental and representative basins has intensified markedly and emphasis in future years on the analysis of the data currently being gathered will, it is hoped, greatly improve our knowledge of regional design values.

Traditionally, the whole field of water resources has been of interest mainly to engineers and natural scientists. In an increasingly complex society, a greater involvement of social scientists is mandatory. Problems of federal and provincial jurisdiction must be faced; with increased competition for water, the field of water law becomes more important. Guidelines must be set for inter-basin, inter-provincial and international transfer of water. The whole human dimension of water resource development requires study since decisions on water and sewer servicing affect where and how people live and can be a powerful tool for controlling and shaping residential and industrial developments. Questions have been raised as to the ability of social science to cope with these problems. But certainly this is no excuse for not tackling them. On the contrary, social scientists must face the challenge of developing means of coping with socio-economic aspects of present and emerging problems.

In the foregoing section a few of the water problems facing Canada at the start of its second century, have been outlined. Since the welfare of the country is closely related to the wise development of its water resources, research leading to wise management will be increasingly needed. Accelerated urbanization and industrialization will strain our abilities to cope with the new problems if a sound research program is not developed. Increases in agricultural production, for example, through irrigation will be necessary if Canada is to contribute its share in aiding the unfortunate hungry of the developing countries while feeding its own growing population.

All indications are that a well-designed program of water resources research will be of enormous benefit to Canada and its future. More specific potential benefits and recommended levels of research effort are discussed in later chapters of this report.

I.4 Definition and Function of Water Resources Research

Research activities may be categorized by discipline or by purpose. Water resources research falls clearly into the latter category. It requires workers from a great variety of disciplines, such as engineering, physics, biology, chemistry, ecology, geography, economics, sociology, and many others. All these specialists share, however, a common purpose, the furtherance of knowledge of water resources and how they may be managed optimally. The goals of water resources research have been well stated by the Committee on Water Resources Research of the U.S. Federal Council for Science and Technology[3]: ". . . the aim of the Federal research program should be:

1. To develop methods for conserving and augmenting the quantity of water available.
2. To perfect techniques for controlling water so as to minimize erosion, flood damage, and other adverse effects.
3. To develop methods for managing and controlling pollution so as to protect and improve the quality of the water resource.
4. To develop and improve procedures for evaluating water resource development and management so as to maximize net socio-economic benefits.
5. To understand the nature of water, the processes which determine its distribution in nature, its interactions with its environment and the effects of man's activities on the natural processes. This is basic to the successful prosecution of items 1 through 4.

[3] Committee on Water Resources Research. Federal Council for Science and Technology. *A Ten-Year Program of Federal Water Resources Research,* Washington, D.C.: U.S. Government Printing Office, 1966, 88 Pages.

6. To develop techniques for efficient, minimum cost design, construction, and operation of engineering works required to implement the water resources development program. Overriding considerations of effectiveness and safety, and of economy in connection with the already huge and mounting costs of executing and operating water resource developments that are rapidly growing in number, size, and complexity, require the best efforts we can bring to bear on these problems.
7. To develop new methods for efficient collection of the field data necessary for the planning and design of water resource projects. . . ."

The study of components that lead to the attainment of these goals are herein considered as water resources research for the purpose of this report.

From a practical point of view it is, in many instances, difficult to distinguish between what does or does not constitute water resources research. Many research projects contain an element of "water activity" but are predominantly oriented towards other purposes (e.g. fisheries, agriculture, etc.). In the analysis of water resources research activities only those projects were included that could be related to the water resources research categories (see Questionnaire Survey, *infra,* II.3) which arise from the seven purposes stated above.

There is a further problem in defining water resources research. Being primarily an applied field of science, the distinction between applied research on the one hand and design work on the other was difficult to draw in some instances. In making such distinctions the definition of research that was used was that adopted by the Organization for Economic Co-operation and Development (OECD).[4] Research is work undertaken primarily for the advancement of scientific knowledge, with or without a specific application in mind. Work, in which the element of innovation was lacking, such as in the regular collection of scientific data, was *not* considered to be research.

[4]OECD, *Proposed Standard Practice for Surveys of Research and Development,* DAS/PD/62.47 (3rd Revision), Paris (also known as "The Frascati Manual").

Chapter II

ORGANIZATION OF STUDY

II.1 Development of Study

It is obvious that wise development and management of Canada's water resources require the kind of knowledge that a balanced research program will produce. However, our knowledge of the scope and nature of the Canadian effort in water resources research has been fragmentary. For example, prior to the present survey a good estimate of the total expenditures in water resources research in Canada was not available to permit comparison of the level of research effort in water with that in other fields and with that needed for intelligent development and management of the resource. This lack of comprehensive information on water resources research activities, as a basis for developing improved policies in this field, was a matter of concern at the several levels of government, in universities, and in the private sector.

In recognition of this situation, the Science Secretariat decided to make an inventory of water resources research activities in Canada and, based on this inventory, to assess the gaps in the nation's research efforts and the areas of research which will require greater emphasis in the future. To implement this study, the Science Secretariat requested the senior author of this report to draft a procedure for carrying out this task, with the following specific objectives:

1. To make an inventory of existing and planned water resources research programs in government, universities, research institutions and private companies of Canada.
2. To identify water resources research needs in the light of present and emerging water problems in Canada, and suggest ways of meeting these needs if they are not being filled.
3. To examine manpower implications arising from the study and suggest ways of developing the required manpower.

The survey was endorsed and actively supported by the Federal Department charged with co-ordination of water policies (Department of Energy, Mines and Resources), by the federal-provincial Canadian Council of Resource Ministers and by the Canadian National Committee for the International Hydrologic Decade. The Science Council of Canada approved the study at its meeting of May 9, 1967 and subsequently formed a Committee on Water Resources Research under the chairmanship of Dr. J. T. Wilson, Principal, Erindale College, University of Toronto. The Science Council reviewed the present report of the Study Group, other material on research activities in Canada, and the report of its Committee on Water Resources Research and has published its recommendations in this field as Science Council Report No. 3.

II.2 Advisory Committee

It was realized in the early stages of the study that the success of an undertaking of this kind would depend to a large extent on the advice and co-operation of prominent individuals in the field of water resources. A group of people drawn from different levels of the various governments and the universities, knowledgeable of conditions in different regions of the country and of the wide variety of technical fields in water resources research, served on an Advisory Committee to the Study Group. A list of members of the Committee and their affiliations is given in Appendix I.

During the course of the survey the Committee held two meetings, each of two days duration. The first meeting was devoted to discussion of the scope and the basic methods of the study. The following procedure was adopted:

Phase 1: Undertake a basic inventory of activities in water resources research by means of a questionnaire survey, which would be followed up by personal interviews as necessary.

Phase 2: (To be conducted concurrently with Phase 1). As a means of assisting in objective assessment of Canadian research needs, to engage consultants to assess the potential economic benefits of various types of water resources research (see section II.4 below) and to report on activities and needs in special fields which are particularly difficult to survey by means of questionnaires.

Phase 3: Make a synthesis of the study, using results of the questionnaire survey and consultant studies, resulting in a report on water resources research and research needs in Canada.

The second meeting of the Committee was concerned with a review and analysis of the questionnaire results and a discussion of the consultants' reports. From these discussions a set of guidelines was provided, which formed the basis for the recommendations presented in this report. It should be recognized that the guidelines represented a consensus of the views of the Committee but were not completely endorsed by every member of the Committee. In addition, the authors of this report have had to interpret the guidelines and fill in many details, a task certainly performed in the spirit of the guidelines but without seeking complete endorsement of details by the full committee. In short, the authors assume full responsibility for the views expressed in this report but have attempted to follow as much as possible the guidelines established by the Advisory Committee.

II.3 Questionnaire Survey

A large number and variety of organizations are involved in water resources research and it is characteristic that engineers and scientists of many different disciplines are active in the field. To obtain information concerning research from such a diverse population, two questionnaires were designed, eliciting information from both individual researchers and administrative heads of research centres.

The two questionnaires were entitled "Project Questionnaire" and "Reporting Unit Questionnaire". The questionnaires are reproduced in Appendix II.

It was, of course, necessary to categorize water resources research. To facilitate comparisons with research activities in the United States, the system of categories used by the U.S. Committee on Water Resources Research of the Federal Council for Science and Technology was adapted to Canadian needs. This system delineates the different categories by purpose. Although excluding activities that are not usually considered part of the water resources field, it is comprehensive and has been successfully applied in similar studies for a number of years.

For the purposes of this study then, water resources research was taken to include research in the following main categories:

1. Nature of Water—fundamental research on the water substance.
2. The Water Cycle—natural distribution in space and time of water and processes affecting atmospheric, surface and underground waters.
3. Water Supply Augmentation and Conservation—applied research devoted to methods of augmenting and conserving available water supplies.
4. Water Quantity Management and Control—research on the management of water, exclusive of conservation, and effects of related activities, (e.g. land management, urbanization), on water supplies and floods.
5. Water Quality Management and Protection—methods of identifying, describing and controlling water pollution.
6. Water Resources Planning—research to develop planning techniques and on the social, economic, legal, and institutional aspects of water resources planning.
7. Resources Data—research on methods of determining the kinds and amounts of basic water resources information needed, and on improved methods of collecting this information.
8. Engineering works—research on design, materials, and construction methods, specifically applicable to water control.

To obtain more detailed information the above eight main categories were divided into sub-categories. This system of sub-categories was common to both questionnaires, and is given with the questionnaires in Appendix II.

The Project Questionnaire was directed to individual researchers and leaders of small research groups. The information requested concerned individual projects, their manpower requirements, operating and capital costs, sources of funds, etc. In addition, three questions were included, encouraging the respondent to comment on research priorities and on the application of research results to water resources management in Canada.

The Reporting Unit Questionnaire, on the other hand, sought information on water resources research from the "cost centres" of government departments, university faculties and departments, industry, research councils, etc. Not only was an attempt made to determine current effort and emphasis of research, but also the organizations were asked to estimate the future level of effort, both in terms of financing and manpower requirement. In addition, respondents were requested to supply data on current and future personnel requirements by specialization or training and level of education. The final questions asking for comment on research needs and priorities, and application of research results, were identical to those in the Project Questionnaire.

Sets of questionnaires were mailed initially to addresses obtained from mailing lists of the Canadian Council of Resource Ministers and the Canadian National Committee for the International Hydrologic Decade.

Federal Government Departments were canvassed through liaison staff members in each department. In addition, members of the Advisory Committee and other persons added names to the mailing lists. In all, slightly less than a thousand sets of questionnaires were sent out.

II.4 Consultants

Although much valuable information may be obtained by means of questionnaires, it was recommended by the Advisory Committee that studies in depth of three important fields would benefit the survey greatly. For this reason consultants were engaged to assess the potential economic benefits, research activities and research needs in three main categories. The consulants were asked to address themselves to the following three fields respectively:

1. Improved design of water control and water conveyance structures.
2. Water pollution control and abatement.
3. Social, economic, and institutional aspects of water resources research.

The first study on the potential benefits to be derived from research on improved design of water control and conveyance structures was performed by H. G. Acres Limited, Consulting Engineers, Niagara Falls, Ontario. The water pollution control and abatement study was made by Dr. P. H. Jones of the University of Toronto, and Dr. D. R. Stanley, President of Stanley Associates Engineering Limited, Edmonton, Alberta.

The social, economic and institutional aspects of water resources research presented a special problem. Although it is likely to be a very important field of research for solution of water problems in Canada, little is known at this stage of the extent and nature of research efforts in this field. Hence, a team of consultants was asked to undertake a study in this field. The team was headed by Dr. W.R.D. Sewell of the University of Victoria, and co-operating with him were M. Michel Chevalier, University of Montreal, Dr. R. W. Judy, University of Toronto, and Professor L. Ouellet, Laval University.

Each group of consultants undertook a study with the following objectives:

1. To identify research needs in the special field in relation to current and emerging water resource problems and issues in Canada.
2. To establish what research has been undertaken to date in the field.
3. To determine the constraints that prevent increase of research efforts in the field and methods of overcoming these constraints.
4. To recommend priorities for research in the field in the light of the problems and of the constraints.
5. To identify, as far as possible, potential economic value of research in the various aspects of the field.

The findings and recommendations of the three study sub-groups were submitted in reports to the Study Group before the end of 1967. The reports formed the basis of discussions and guideline recommendations by the Science Secretariat Advisory Committee on Water Resources Research.

Chapter III

PRESENT ACTIVITIES IN WATER RESOURCES RESEARCH

III.1 Results of Questionnaire Survey

To determine the significance of the data presented in this section, three questions must be answered. The first question relates to the distribution of questionnaires and more specifically asks: do the data give a reasonably complete picture of the on-going work in the country? As was indicated in the previous chapter, a total of slightly fewer than 1,000 agencies, organizations, and institutions were surveyed, a number considerably larger than the number of organizations actually involved in water research. In other words, the mailing list used was conservative in that many questionnaires were sent even to organizations that would not be expected to be greatly involved in research in this field. In addition, an attempt was made by means of visits to all provinces and discussions with knowledgeable individuals to become aware of work that had been overlooked and might now be included. In all, it is believed that the figures presented in this section do include essentially all work that was being performed during the fiscal year 1966-67.[1]

The second question to be answered is: What types of work should be included in the tabulations as water research activities, and what kinds should be excluded as being scientific data collection, or design work, or as being research not directly related to water resources? All completed questionnaires were scrutinized with a view to distinguishing, firstly, between research and other activities (scientific data collection, surveys, etc.) and, secondly, between water resources research and other research. The first judgment was made with the aid of the definitions set out in the Frascati Manual.[2] Thus, research is work undertaken primarily for the advancement of scientific knowledge, with or without a specific application in mind. Only work that contained an element of innovation was included in the tabulations; routine collection of data, carrying out of surveys, etc. were excluded. The second judgment, whether or not a project was to be considered *water resources* research, was made by simply checking to what extent each project fitted the

[1] Fiscal year 1966-67 does not cover the same period of time for all organizations. Not to complicate unduly completion of the questionnaires, respondents were asked to supply data on the year most closely corresponding to a fiscal 1966-67. In some instances, this year runs from July 1, 1966 to June 30, 1967, in others January 1, 1966 to December 31, 1966, etc. However, the length of the period was in all instances one year.

[2] OECD, *Proposed Standard Practice for Surveys of Research and Development, op. cit.*

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Table 2.—Number of Water Research Projects Performed in Each Province (and Ottawa)

Code	Sub-categories	B.C.	Alta.	Sask.	Man.	Ont.	Ott.	Que.	N.B.	N.S.	P.E.I.	Nfld.	Total
101	Properties of Water	—	—	—	—	—	—	—	—	—	—	—	—
102	Aqueous Solutions and Suspensions	—	1	—	—	—	1	3	1	—	—	—	6
201	Water Cycle, General	6	12	12	—	20	1	7	2	1	—	—	61
202	Precipitation	1	—	2	—	4	—	5	—	—	—	—	12
203	Snow and Ice	—	3	—	1	2	17	12	—	—	—	—	35
204	Evaporation and Transpiration	—	5	4	—	7	1	1	—	—	—	—	18
205	Streamflow	2	1	2	—	2	1	2	—	2	—	—	12
206	Groundwater	2	21	7	—	4	15	2	—	1	—	—	52
207	Water in Soils	2	5	3	—	2	2	—	—	—	—	—	14
208	Lakes	—	—	2	1	9	4	—	—	—	—	—	16
209	Water and Plants	—	1	7	—	2	—	—	—	1	—	—	11
210	Erosion and Sedimentation	1	6	1	—	2	—	3	1	—	—	—	14
211	Chemical Processes	—	1	—	—	5	—	1	—	—	—	—	7
212	Estuarine Problems	—	—	—	—	—	3	3	—	—	1	—	7
301	Saline Water Conversion	—	—	1	—	2	—	—	—	—	—	—	3
302	Water Yield Improvement	—	1	1	—	—	—	2	—	—	—	—	4
303	Use of Water of Impaired Quality	—	—	—	—	—	—	1	—	—	—	—	1
304	Conservation in Domestic Use	—	—	—	—	1	—	—	—	—	—	—	1
305	Conservation in Industry	—	—	—	—	1	—	—	—	—	—	—	1
306	Conservation in Agriculture	2	2	4	—	—	—	—	—	—	—	—	8
307	Weather Modification	—	—	—	—	2	—	—	—	—	—	—	2
401	Control of Water on the Land	—	9	—	—	3	—	3	—	—	—	—	15
402	Groundwater Management	—	1	—	—	—	—	—	—	—	—	—	1
403	Effects of Man's Activities on Water	2	1	—	—	1	—	—	1	—	—	—	5
501	Identification of Pollutants	1	—	—	—	7	4	—	1	—	—	—	13
502	Sources and Fate of Pollution	1	—	1	—	9	3	—	2	—	—	—	16

503	Effects of Pollution	2	2	1	1	9	—	1	1	—	—	1	18
504	Waste Treatment Processes	1	4	2	1	29	4	6	4	—	—	—	51
505	Ultimate Disposal of Wastes	—	—	—	—	6	—	—	—	—	—	—	6
506	Water Treatment	—	1	—	—	3	2	1	—	—	—	—	7
507	Water Quality Control	1	—	—	—	7	—	2	1	1	—	—	12
601	Planning	—	1	—	1	1	2	—	—	—	—	—	5
602	Evaluation Processes	1	2	1	6	—	—	—	—	—	—	—	10
603	Cost Allocation, Sharing, Pricing	—	1	—	—	—	—	—	—	—	—	—	1
604	Water Requirements	2	1	—	—	1	—	—	1	—	—	—	5
605	Water Law	—	—	—	2	—	—	—	—	—	—	—	2
606	Institutional Aspects	1	1	—	1	2	—	—	—	—	—	—	5
607	Sociological and Psychological Aspects	2	—	—	1	1	—	—	—	—	—	—	4
608	Ecologic Impact of Water Development	—	—	—	—	—	—	—	—	—	—	—	—
701	Network Design	1	—	—	—	1	2	—	—	—	—	—	4
702	Data Acquisition	—	—	2	—	2	7	1	—	—	—	—	12
703	Evaluation, Processing and Publication	—	1	1	—	3	2	—	—	—	—	—	7
801	Specifications and Design	5	—	5	—	4	1	14	—	1	—	2	32
802	Materials	—	1	4	—	1	2	—	1	1	—	—	10
803	Operations	—	—	—	—	—	—	1	—	—	—	—	1
	Total	36	85	63	15	155	74	71	16	8	1	3	527

description of one of the sub-categories of research. Projects that had their main emphasis on other than water resources were also excluded from the data.

The third question requiring an answer is: How meaningful are the figures on expenditures provided by the respondents? This question is considerably more difficult to answer than the previous two. Individual scientists, responding to the project questionnaires were requested to give information on operating costs, such as salaries, travel, and expendable equipment, and capital costs, such as instruments and observing platforms. There is evidence that not all of these items were always included, resulting in figures that tend to be low. For example, university respondents did in many cases include only the value of grants in aid received from NRC and other granting bodies, excluding their own salaries. By means of the Reporting Unit Questionnaire, an attempt was made to estimate the "overhead" cost. The great majority of responding organizations did not have reasonable estimates of overhead cost readily available and therefore did not report them. Consequently, the figures stated in this report must be thought of mainly as project support. This is true for both the historical figures given in this chapter and proposed figures given in Chapter V and VI. Costs for space, power, administration, etc., are additional to the figures given here, and these costs may be not inconsiderable. Overhead costs, in the opinion of some observers, may be in the order of 100 per cent of the direct cost.

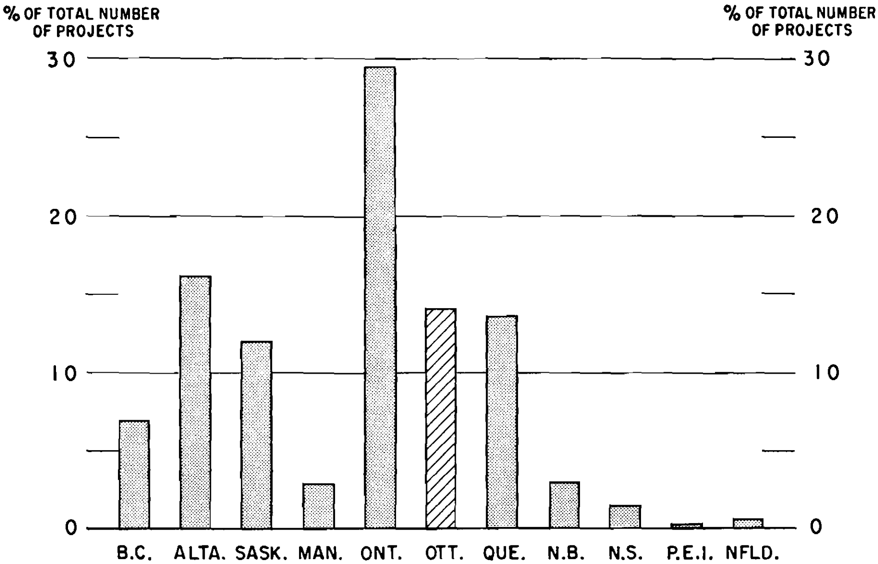
Table 2 shows the distribution of research projects in the different sub-categories of research by province of performance of the research. A separate column has been used for Ottawa, so as not to distort the figures for the Province of Ontario. By no means all Federal Government projects are included in the Ottawa column. Rather, only those projects are included that were either performed in Ottawa Federal laboratories as having national significance, or were unidentifiable as to the location of performance. Apart from the Ottawa exceptions, federal agency research projects performed in the various provinces were included in the totals for those provinces. No research projects in water resources were reported from the Yukon and Northwest Territories, although some federal research is closely related to Northern interests. Whether in fact no water research is being conducted in the Territories is not known, but the effort is certainly too small to be satisfactory.

The bulk of projects is in the Categories 200 and 500, the water cycle and water quality management and control, respectively. It is interesting to note that Alberta and Saskatchewan devote the major share of their effort to what might be called hydrology (the water cycle category), whereas in Ontario the largest number of projects falls in the water quality category. This clearly reflects the applied nature of water resources research. To a major extent it means that the research is problem oriented.

Figure 1 shows the percentage distribution of the total number of projects in the different provinces. Ontario has the highest percentage (29.4) of projects followed by Alberta with 16.1 per cent. The Alberta effort is relatively high in proportion to population and reflects the concentrated effort of a few agencies (Research Council of Alberta, University of Alberta, Department of Forestry and Rural Development, and Department of Agriculture) in the water resources field.

FIGURE-1

WATER RESEARCH PROJECTS BY PROVINCE



The number of research projects classified by the type of agency or institution performing the research is shown in Table 3. The provincial figures include the provincial research councils (British Columbia Research Council, Research Council of Alberta, Saskatchewan Research Council, and Ontario Research Foundation). In fact, close to 40 per cent of the provincial effort takes place in these organizations. Private consultants and consulting engineering firms have been included under industry. The largest number of projects are carried out by the Federal Government and in the universities. The wide range of expertise available in the universities shows up in the great variety of sub-categories represented in the university column.

Table 3.—Number of Research Projects Classified by Sector or Agency of Performance

Code	Sub-categories	Fed.	Prov.	Mun.	Indy.	Univ.	Non-Prof.	Total
101	Properties of Water	—	—	—	—	—	—	—
102	Aqueous Solutions and Suspensions	2	—	—	—	1	3	6
201	Water Cycle, General	9	29	—	3	20	—	61
202	Precipitation	4	5	—	—	3	—	12
203	Snow and Ice	21	5	—	3	6	—	35
204	Evaporation and Transpiration	14	—	—	—	4	—	18
205	Streamflow	4	3	—	—	5	—	12
206	Groundwater	18	26	—	1	7	—	52
207	Water in Soils	4	2	—	—	8	—	14
208	Lakes	8	2	1	—	5	—	16
209	Water and Plants	7	1	—	—	3	—	11
210	Erosion and Sedimentation	2	3	—	2	7	—	14
211	Chemical Processes	1	1	—	1	4	—	7
212	Estuarine Problems	4	—	—	1	2	—	7
301	Saline Water Conversion	—	1	—	—	2	—	3
302	Water Yield Improvement	2	—	—	2	—	—	4
303	Use of Water of Impaired Quality	—	—	—	1	—	—	1
304	Conservation in Domestic Use	—	1	—	—	—	—	1
305	Conservation in Industry	—	—	—	1	—	—	1
306	Conservation in Agriculture	4	2	—	—	2	—	8
307	Weather Modification	2	—	—	—	—	—	2
401	Control of Water on the Land	9	1	—	1	4	—	15
402	Groundwater Management	1	—	—	—	—	—	1
403	Effects of Man's Activities on Water	2	1	—	—	2	—	5
501	Identification of Pollutants	5	4	—	1	3	—	13
502	Sources and Fate of Pollution	5	2	—	3	6	—	16

503	Effects of Pollution	3	6	—	1	8	—	18
504	Waste Treatment Processes	4	8	1	16	20	2	51
505	Ultimate Disposal of Wastes	—	1	—	—	5	—	6
506	Water Treatment	2	2	—	—	3	—	7
507	Water Quality Control	8	1	—	2	1	—	12
601	Planning	2	1	—	—	2	—	5
602	Evaluation Processes	1	1	—	—	8	—	10
603	Cost Allocation, Sharing, Pricing	—	1	—	—	—	—	1
604	Water Requirements	—	2	—	—	3	—	5
605	Water Law	—	—	—	—	2	—	2
606	Institutional Aspects	—	1	—	2	2	—	5
607	Sociological and Psychological Aspects	—	—	—	—	4	—	4
608	Ecologic Impact of Water Development	—	—	—	—	—	—	—
701	Network Design	2	1	—	1	—	—	4
702	Data Acquisition	8	—	—	1	3	—	12
703	Evaluation, Processing and Publication	2	2	—	—	3	—	7
801	Specifications and Design	10	—	—	8	14	—	32
802	Materials	7	—	—	—	3	—	10
803	Operations	—	—	—	—	1	—	1
	Total	177	116	2	51	176	5	527

Table 4.—Research Funds Classified by Source

$,000

Code	Sub-categories	Fed.	Prov.	Univ.	Indy.	Foreign	Other	Total
101	Properties of Water	—	—	—	—	—	—	—
102	Aqueous Solutions and Suspensions	24.0	—	1.5	17.0	—	—	42.5
201	Water Cycle, General	434.4	417.7	25.8	12.6	—	—	890.4
202	Precipitation	98.5	39.2	22.4	—	7.5	—	167.6
203	Snow and Ice	464.0	67.2	20.0	11.0	7.5	—	569.7
204	Evaporation and Transpiration	261.1	3.5	5.9	1.9	—	—	272.5
205	Streamflow	74.9	27.5	5.3	—	—	16.0	123.7
206	Groundwater	508.6	222.1	4.8	—	—	1.0	736.5
207	Water in Soils	120.6	14.6	11.5	—	8.8	0.8	156.3
208	Lakes	327.3	73.6	5.7	—	—	5.0	411.7
209	Water and Plants	69.1	9.0	7.3	—	—	—	85.4
210	Erosion and Sedimentation	93.8	66.2	89.3	—	—	—	249.3
211	Chemical Processes	25.2	2.1	1.5	—	—	—	28.8
212	Estuarine Problems	218.0	—	—	—	—	—	218.0
301	Saline Water Conversion	42.0	30.0	—	—	—	—	72.0
302	Water Yield Improvement	90.9	—	—	—	—	—	90.9
303	Use of Water of Impaired Quality	5.3	—	—	—	—	—	5.3
304	Conservation in Domestic Use	3.0	—	—	—	—	—	3.0
305	Conservation in Industry	—	—	—	4.5	—	—	4.5
306	Conservation in Agriculture	65.8	11.6	2.1	—	—	—	79.5
307	Weather Modification	173.0	—	—	—	—	—	173.0
401	Control of Water on the Land	120.9	4.9	0.8	2.0	—	—	128.6
402	Groundwater Management	1.4	—	—	—	—	—	1.4
403	Effects of Man's Activities on Water	105.0	65.4	—	—	—	—	170.5

501	Identification of Pollutants	38.9	64.9	3.5	6.7	—	—	114.1
502	Sources and Fate of Pollution	108.6	29.8	14.6	14.0	15.1	85.0	267.1
503	Effects of Pollution	323.2	75.0	—	50.0	26.6	—	474.8
504	Waste Treatment Processes	205.7	79.3	17.6	614.9	7.0	8.0	932.5
505	Ultimate Disposal of Wastes	15.4	17.9	5.5	2.0	—	—	40.8
506	Water Treatment	17.5	8.0	5.0	—	—	—	30.5
507	Water Quality Control	630.1	15.3	—	13.0	—	—	658.4
601	Planning	42.4	7.0	1.4	—	—	—	50.8
602	Evaluation Processes	44.3	7.2	7.6	—	—	—	59.1
603	Cost Allocation, Sharing, Pricing	0.8	1.2	—	—	—	—	2.0
604	Water Requirements	35.5	18.5	0.7	—	—	0.3	55.0
605	Water Law	—	—	2.8	—	—	—	2.8
606	Institutional Aspects	6.1	2.0	3.0	—	—	70.0	81.1
607	Sociological and Psychological Aspects	10.3	—	1.3	—	17.0	—	28.6
608	Ecologic Impact of Water Development	—	—	—	—	—	—	—
701	Network Design	10.0	22.6	—	10.4	—	—	43.0
702	Data Acquisition	207.0	—	1.0	—	—	—	208.0
703	Evaluation, Processing and Publication	87.0	41.0	—	—	43.0	5.0	176.0
801	Specifications and Design	314.4	7.0	5.0	77.1	—	—	403.5
802	Materials	54.2	—	2.3	15.0	—	—	71.5
803	Operations	9.0	—	—	—	—	—	9.0
	Total	5,487.3	1,451.3	275.4	852.1	132.5	191.1	8,389.7

Table 5.—Project Expenditures Classified by Sector or Agency of Performance

$'000

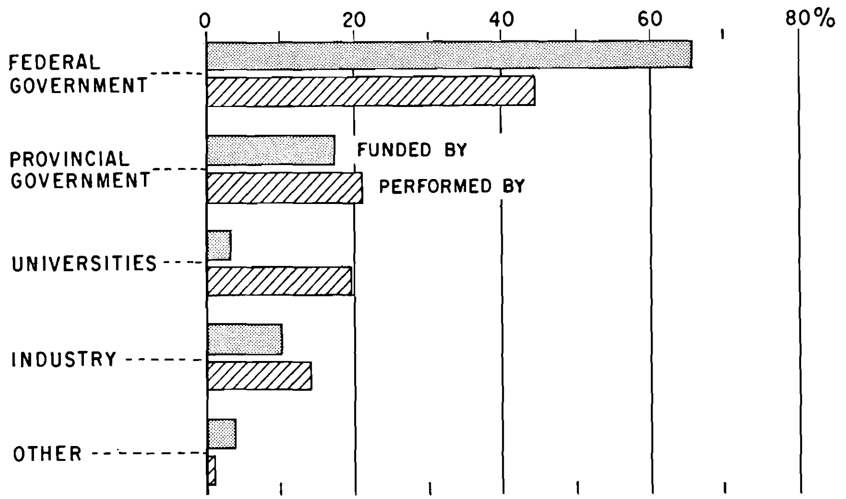
Code	Sub-categories	Fed.	Prov.	Mun.	Ind.	Univ.	Non-Prof.	Total
101	Properties of Water	—	—	—	—	—	—	—
102	Aqueous Solutions and Suspensions	22.5	—	—	—	3.0	17.0	42.5
201	Water Cycle, General	150.6	584.0	—	22.0	133.8	—	890.4
202	Precipitation	46.1	53.6	—	—	67.9	—	167.6
203	Snow and Ice	383.0	67.2	—	27.0	92.5	—	569.7
204	Evaporation and Transpiration	236.7	—	—	—	35.8	—	272.5
205	Streamflow	70.7	25.0	—	—	28.0	—	123.7
206	Groundwater	364.0	276.0	—	9.5	87.0	—	736.5
207	Water in Soils	89.0	15.0	—	—	52.3	—	156.3
208	Lakes	240.7	37.0	5.0	—	129.0	—	411.7
209	Water and Plants	56.4	9.0	—	—	20.0	—	85.4
210	Erosion and Sedimentation	9.1	76.2	—	20.0	144.0	—	249.3
211	Chemical Processes	12.0	0.5	—	7.0	9.3	—	28.8
212	Estuarine Problems	192.0	—	—	16.0	10.0	—	218.0
301	Saline Water Conversion	—	60.0	—	—	12.0	—	72.0
302	Water Yield Improvement	10.9	—	—	80.0	—	—	90.9
303	Use of Water of Impaired Quality	—	—	—	5.3	—	—	5.3
304	Conservation in Domestic Use	—	3.0	—	—	—	—	3.0
305	Conservation in Industry	—	—	—	4.5	—	—	4.5
306	Conservation in Agriculture	57.6	16.0	—	—	5.9	—	79.5
307	Weather Modification	173.0	—	—	—	—	—	173.0
401	Control of Water on the Land	102.1	3.0	—	13.3	10.2	—	128.6
402	Groundwater Management	1.4	—	—	—	—	—	1.4
403	Effects of Man's Activities on Water	32.0	130.0	—	—	8.5	—	170.5
501	Identification of Pollutants	28.9	55.0	—	6.7	23.5	—	114.1

502	Sources and Fate of Pollution	81.8	11.0	—	110.0	64.3	—	267.1
503	Effects of Pollution	228.7	105.0	—	10.0	131.1	—	474.8
504	Waste Treatment Processes	31.0	108.3	0.5	576.1	144.6	72.0	932.5
505	Ultimate Disposal of Wastes	—	15.0	—	—	25.8	—	40.8
506	Water Treatment	10.0	7.0	—	—	13.5	—	30.5
507	Water Quality Control	626.1	4.3	—	24.0	4.0	—	658.4
601	Planning	16.0	14.0	—	—	20.8	—	50.8
602	Evaluation Processes	33.0	5.0	—	—	21.1	—	59.1
603	Cost Allocation, Sharing, Pricing	—	2.0	—	—	—	—	2.0
604	Water Requirements	—	25.0	—	—	30.0	—	55.0
605	Water Law	—	—	—	—	2.8	—	2.8
606	Institutional Aspects	—	2.0	—	70.0	9.1	—	81.1
607	Sociological and Psychological Aspects	—	—	—	—	28.6	—	28.6
608	Ecologic Impact of Water Development	—	—	—	—	—	—	—
701	Network Design	10.0	13.0	—	20.0	—	—	43.0
702	Data Acquisition	173.3	—	—	11.2	23.5	—	208.0
703	Evaluation, Processing and Publication	35.0	43.0	—	—	98.0	—	176.0
801	Specifications and Design	150.3	—	—	145.4	107.8	—	403.5
802	Materials	50.0	—	—	—	21.5	—	71.5
8C3	Operations	—	—	—	—	9.0	—	9.0
	Total	3,723.9	1,765.1	5.5	1,178.0	1,628.2	89.0	8,389.7

Table 4 provides information on the source of funds. The amounts shown do not indicate whether the funds were spent intramurally or outside the agency, but merely the amounts devoted to different sub-categories by the different sectors. Table 5 on the other hand shows in what sector the research in fact was performed and how it was distributed over the different sub-categories. The information of Tables 4 and 5 is summarized in Figure 2.

FIGURE-2

SOURCE OF FUNDS AND SECTOR OF PERFORMANCE



Total project expenditures in water resources research in fiscal year 1966 were $8.4 million. The great majority of these funds (82.7 per cent) was of government (Federal and Provincial) origin. If these figures are viewed in terms of the sector of performance, the Federal Government percentage drops considerably, basically due to the major contribution that federal government agencies make to university research. The flow of funds from one sector to another is shown in more detail in Table 6. The Federal Government in 1966 was both the major contributor to, as well as major performer of research. Provincial Government expenditures were mainly for in-house research, although a small portion was transferred to universities. An approximately equal amount of federal funds was, however, used for provincial research, so that the amounts funded and spent by the provinces were nearly the same. Universities, of course, were basically recipients of funds, whereas industry was in a position similar to the provinces, in that it provided funds to other sectors and at the same time. was the recipient of funds for research. The percentage distribution of expenditures in the different categories of research have been summarized in Figure 3.

FIGURE-3

DISTRIBUTION OF WATER RESOURCES RESEARCH

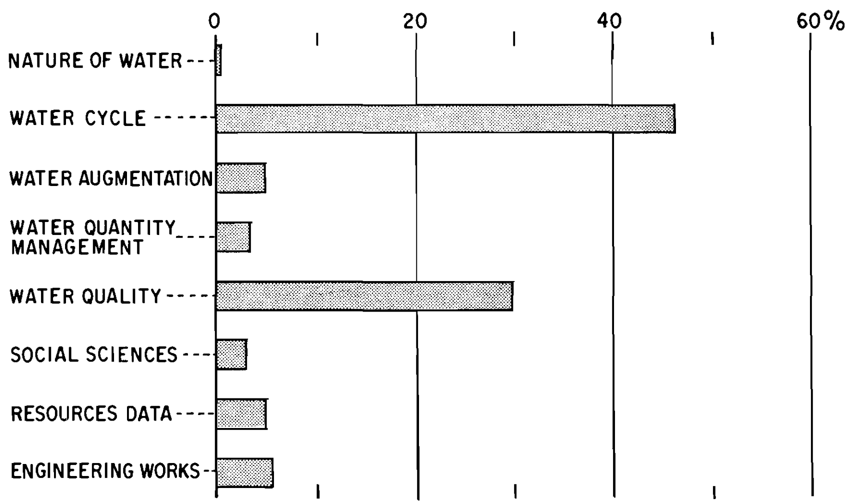


Table 6.—Source (↓) and Destination (→) of Research Support

$'000

Source	Fed.	Prov.	Mun.	Indy.	Univ.	Non-Prof.	Total
Federal..........	3,692.9	463.0	—	333.4	989.8	9.0	5,488.1
Provincial......	19.0	1,232.0	—	65.0	132.6	3.0	1,451.6
University......	2.4	—	—	—	273.3	—	275.7
Industrial.......	—	62.4	—	617.1	95.6	77.0	852.1
Foreign..........	8.8	7.0	—	—	116.7	—	132.5
Other..............	0.8	1.0	5.5	162.5	21.3	—	191.1
Total......	3,723.9	1,765.4	5.5	1,178.0	1,629.3	89.0	8,391.1

Most of the funds were allocated to two categories of research: the water cycle with 46.4 per cent and water quality management and control, 30 per cent. The smallness of the expenditures in Category

100, Nature of Water, reflects the strongly applied nature of water resources research in Canada. This category was difficult to survey since relevant work may be done in physical and chemical laboratories not usually associated with water resources research. The totals in Category 100 are thus likely on the low side. Water Supply Augmentation (Category 300) and Water Quantity Management and Control (Category 400) received 5.1 and 3.6 per cent respectively of the total funding, reflecting perhaps the relative abundance of water in most of Canada. Only 3.3 per cent of the total was spent on research in Category 600, economic, social and institutional aspects, pointing to a need for much greater involvement of social scientists in this field. Similarly, research on better methods of collecting resources data is carried out on a very modest scale compared to the importance of this category in water resources development and the large expenditures on data networks in Canada. Finally, the 800-category, research on Engineering Works, may well appear considerably lower than it was in actuality, since research to improve existing structural materials and to develop new materials for use in water control and conveyance structures (sub-category 802) is often equally applicable to "non-water" structures, and for that reason may not have been completely reported in this survey.

Although Federal and Provincial Government Agencies, and the universities are represented in most sub-categories, the emphasis in the three sectors is quite different. For example, fully one third of the provincial effort was directed towards research in sub-category 201, which pertains to studies involving two or more phases of the water cycle, whereas the Federal Government devoted considerable amounts to a number of sub-categories (203, 204, 206, 208, 503 and 507). Since the universities are not mission oriented, there was less emphasis on any one particular sub-category. Industrial effort was concentrated in the 500-category, water quality management and protection, with particular emphasis on waste treatment processes.

Table 7 shows the distribution of research project expenditures in the provinces. After excluding the expenditures in the Ottawa column, the percentages of total expenditures in the different provinces were calculated. These percentages are compared with the population distribution as shown in Figure 4. Alberta, Saskatchewan, and Ontario, showed the highest per capita total expenditures in water research in Canada. Although comparisons between population and expenditure distribution are not very significant, they point again to the problem-oriented nature of Canadian water resources research. Alberta and Saskatchewan, both with major water-short areas, emphasized research in the water cycle category, whereas Ontario devoted a large proportion of funds to pollution problems.

The manpower effort in water resources research is set out in Table 8, with a total reported effort in 1966 of 700 man-years. Professional manpower (doctor, master, and bachelor) totals 351.6 man-years. With 8.4 million dollars in total expenditures, the cost per professional man-year is $23,900.

Table 7.—Research Expenditures in Each Province

$'000

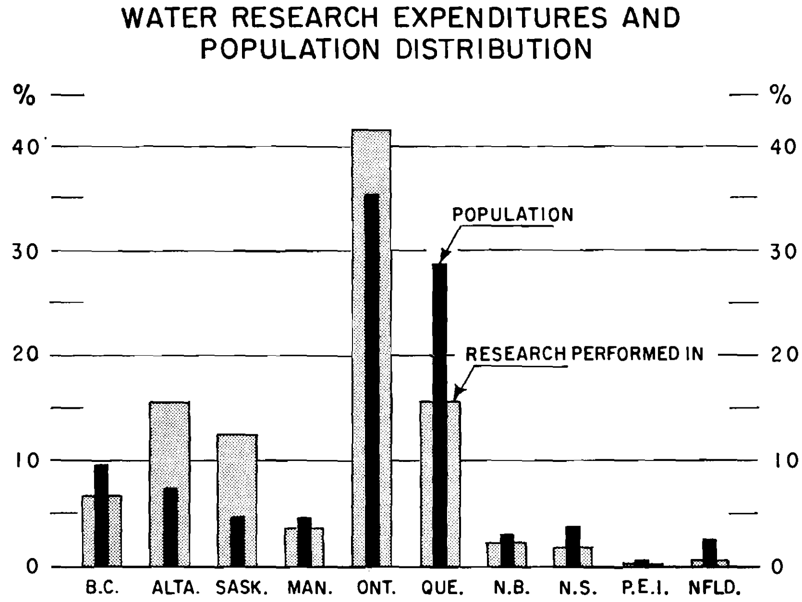
Code	Sub-categories	B.C.	Alta.	Sask.	Man.	Ont.	Ott.	Que.	N.B.	N.S.	P.E.I.	Nfld.	Total
101	Properties of Water	—	—	—	—	—	—	—	—	—	—	—	—
102	Aqueous Solutions and Suspensions	—	12.5	—	—	—	10.0	17.0	3.0	—	—	—	42.5
201	Water Cycle, General	56.0	131.7	223.7	—	256.1	28.0	158.9	15.0	21.0	—	—	890.4
202	Precipitation	.4	—	5.0	—	50.1	—	112.1	—	—	—	—	167.6
203	Snow and Ice	—	32.5	—	11.0	20.5	316.0	189.7	—	—	—	—	569.7
204	Evaporation and Transpiration	—	59.0	36.5	—	138.2	30.0	8.8	—	—	—	—	272.5
205	Streamflow	26.0	6.0	6.5	—	14.0	39.0	4.5	—	27.7	—	—	123.7
206	Groundwater	24.0	174.0	131.0	—	34.5	336.0	12.0	—	25.0	—	—	736.5
207	Water in Soils	15.5	57.0	11.5	—	10.3	62.0	—	—	—	—	—	156.3
208	Lakes	—	—	37.0	5.0	206.5	163.2	—	—	—	—	—	411.7
209	Water and Plants	—	1.5	70.2	—	11.2	—	—	—	2.5	—	—	85.4
210	Erosion and Sedimentation	8.0	199.6	1.5	—	11.0	—	26.2	3.0	—	—	—	249.3
211	Chemical Processes	—	.5	—	—	27.3	—	1.0	—	—	—	—	28.8
212	Estuarine Problems	—	—	—	—	—	177.0	26.0	—	—	15.0	—	218.0
301	Saline Water Conversion	—	—	60.0	—	12.0	—	—	—	—	—	—	72.0
302	Water Yield Improvement	—	7.9	3.0	—	—	—	80.0	—	—	—	—	90.9
303	Use of Water of Impaired Quality	—	—	—	—	—	—	5.3	—	—	—	—	5.3
304	Conservation in Domestic Use	—	—	—	—	3.0	—	—	—	—	—	—	3.0
305	Conservation in Industry	—	—	—	—	4.5	—	—	—	—	—	—	4.5

Table 7.—Research Expenditures in Each Province—(Concluded)

Code	Sub-categories	B.C.	Alta.	Sask.	Man.	Ont.	Ott.	Que.	N.B.	N.S.	P.E.I.	Nfld.	Total
306	Conservation in Agriculture	7.1	21.0	51.4	—	—	—	—	—	—	—	—	79.5
307	Weather Modification	—	—	—	—	173.0	—	—	—	—	—	—	173.0
401	Control of Water on the Land	—	89.1	—	—	4.2	—	35.3	—	—	—	—	128.6
402	Groundwater Management	—	1.4	—	—	—	—	—	—	—	—	—	1.4
403	Effects of Man's Activities on Water	32.0	130.0	—	—	4.5	—	—	4.0	—	—	—	170.5
501	Identification of Pollutants	2.0	—	—	—	83.2	24.8	—	4.1	—	—	—	114.1
502	Sources and Fate of Pollution	7.0	—	10.0	—	167.3	74.7	—	8.1	—	—	—	267.1
503	Effects of Pollution	55.0	6.1	10.0	190.0	165.0	—	10.0	28.7	—	—	10.0	474.8
504	Waste Treatment Processes	13.0	79.0	9.2	.5	632.3	31.0	105.5	62.0	—	—	—	932.5
505	Ultimate Disposal of Wastes	—	—	—	—	40.8	—	—	—	—	—	—	40.8
506	Water Treatment	—	2.0	—	—	17.0	10.0	1.5	—	—	—	—	30.5
507	Water Quality Control	69.0	—	—	—	521.3	—	24.0	4.1	40.0	—	—	658.4
601	Planning	—	14.0	—	2.8	18.0	16.0	—	—	—	—	—	50.8
602	Evaluation Processes	5.0	5.0	33.0	16.1	—	—	—	—	—	—	—	59.1
603	Cost Allocation, Sharing, Pricing	—	2.0	—	—	—	—	—	—	—	—	—	2.0
604	Water Requirements	19.0	3.0	—	—	18.0	—	—	15.0	—	—	—	55.0

605	Water Law	—	—	—	2.8	—	—	—	—	—	—	—	2.8
606	Institutional Aspects	1.5	2.0	—	7.6	70.0	—	—	—	—	—	—	81.1
607	Sociological and Psychological Aspects	17.0	—	—	6.6	5.0	—	—	—	—	—	—	28.6
608	Ecologic Impact of Water Development	—	—	—	—	—	—	—	—	—	—	—	—
701	Network Design	13.0	—	—	—	20.0	10.0	—	—	—	—	—	43.0
702	Data Acquisition	—	—	22.5	—	1.4	172.9	11.2	—	—	—	—	208.0
703	Evaluation, Processing and Publication	—	8.0	50.0	—	83.0	35.0	—	—	—	—	—	176.0
801	Specifications and Design	89.4	—	52.5	—	12.0	6.0	211.8	—	1.8	—	30.0	403.5
802	Materials	—	14.0	21.0	—	.5	15.0	—	6.0	15.0	—	—	71.5
803	Operations	—	—	—	—	—	—	9.0	—	—	—	—	9.0
901	Data Collection	—	—	—	—	—	—	—	—	—	—	—	—
	Total	459.9	1,058.8	845.5	242.4	2,835.7	1,556.6	1,049.8	153.0	133.0	15.0	40.0	8,389.7

FIGURE-4



As was indicated on page 18, although all respondents were requested to include in the cost of projects such items as salaries, travel, instruments, and observing platforms, there is evidence that this was, in fact, not always done. This means that the $23,900 figure is the project cost per professional man-year and excludes much of the overhead costs. There is a considerable difference, however, between the cost per professional man-year in the separate categories of research. For example, the figure for water quality management and protection turns out to be $28,400, and for the water cycle category $23,100, whereas the cost for social science research (category 600) is considerably lower, at $13,900. Although the sample size for most categories is too small to permit use of the resulting professional man-year costs as definite figures, they are indicative of the fact that some types of research are more expensive than others.

The reported manpower was distributed over 116 specialties as defined in the "Major Field and Specialties List," of the Canada Department of Manpower and Immigration. The four most common specialities are hydrology, geo-hydrology, sewage and sewage treatment, and fluid mechanics. Combining the specialties by major disciplines, the following distribution is obtained: Engineering 56 per cent, Physical Science 26 per cent, Life Science 9 per cent, Social Science 2 per cent, Interdisciplinary 5 per cent, and Other 2 per cent.

Table 8.—Man-Years of Research Effort Classified by Educational Level

Code	Sub-categories	Doctor	Master	Bachelor	Student	Technician	Total
101	Properties of Water	—	—	—	—	—	—
102	Aqueous Solutions and Suspensions	.7	.2	—	3.5	.6	5.0
201	Water Cycle, General	8.4	11.3	18.5	9.8	28.0	76.0
202	Precipitation	1.0	2.2	1.9	1.3	7.5	13.9
203	Snow and Ice	3.1	13.0	13.5	3.5	8.9	42.0
204	Evaporation and Transpiration	5.0	3.1	2.2	4.3	7.7	22.3
205	Streamflow	2.0	1.9	4.2	1.3	6.6	16.0
206	Groundwater	11.8	10.3	13.9	3.1	15.3	54.4
207	Water in Soils	3.1	5.0	.2	2.6	5.9	16.8
208	Lakes	2.9	5.2	1.4	6.0	11.9	27.4
209	Water and Plants	.8	2.5	.5	1.7	3.3	8.8
210	Erosion and Sedimentation	4.6	6.2	1.4	5.1	11.9	29.2
211	Chemical Processes	.9	1.1	.1	.8	.6	3.5
212	Estuarine Problems	1.1	3.5	1.2	2.6	6.3	14.7
301	Saline Water Conversion	4.7	5.0	.9	1.0	3.4	15.0
302	Water Yield Improvement	.2	1.2	.7	.1	.6	2.8
303	Use of Water of Impaired Quality	.1	.5	.2	—	—	.8
304	Conservation in Domestic Use	—	—	.2	—	—	.2
305	Conservation in Industry	—	.5	—	—	—	.5
306	Conservation in Agriculture	—	2.0	2.4	2.1	3.5	10.0
307	Weather Modification	—	2.0	1.0	—	3.0	6.0
401	Control of Water on the Land	1.4	3.3	2.7	2.5	6.6	16.5
402	Groundwater Management	—	.2	—	—	.3	.5
403	Effects of Man's Activities on Water	—	1.7	1.1	.5	6.3	9.6
501	Identification of Pollutants	2.4	1.0	.6	1.3	2.1	7.4
502	Sources and Fate of Pollution	2.3	2.9	6.3	4.1	2.4	18.0

Table 8.—Man-Years of Research Effort Classified by Educational Level—(Concluded)

Code	Sub-categories	Doctor	Master	Bachelor	Student	Technician	Total
503	Effects of Pollution	6.0	5.0	10.0	5.5	12.4	38.9
504	Waste Treatment Processes	6.0	6.3	19.0	15.0	27.6	73.9
505	Ultimate Disposal of Wastes	1.3	3.5	1.4	1.5	1.1	8.8
506	Water Treatment	.3	1.5	.7	1.2	.1	3.8
507	Water Quality Control	1.6	4.1	6.6	2.6	32.7	47.6
601	Planning	.5	.7	1.5	.5	.8	4.0
602	Evaluation Processes	.5	.4	3.7	—	2.3	6.9
603	Cost Allocation, Sharing, Pricing	—	.3	—	.4	.2	.9
604	Water Requirements	1.7	.3	.4	1.6	3.0	7.0
605	Water Law	—	.2	—	—	—	.2
606	Institutional Aspects	.3	4.3	3.3	—	.1	8.0
607	Sociological and Psychological Aspects	.5	—	1.5	.3	—	2.3
608	Ecologic Impact of Water Development	—	—	—	—	—	—
701	Network Design	.1	1.7	.5	—	.1	2.4
702	Data Acquisition	3.3	2.8	3.7	.3	1.6	11.7
703	Evaluation, Processing and Publication	.4	1.7	3.1	1.1	4.5	10.8
801	Specifications and Design	1.3	7.2	12.2	7.2	20.8	48.7
802	Materials	.3	1.4	.6	1.0	2.2	5.5
803	Operations	—	.5	—	.5	.3	1.3
	Total	80.6	127.7	143.3	95.9	252.5	700.0

III.2 Organization and Recent Developments in Water Research

Water resources research in the Federal Government is carried on in a number of Departments and Agencies. The most important of these are the Departments of Agriculture, Energy, Mines and Resources, Fisheries, Forestry and Rural Development, National Health and Welfare, and Transport, the Fisheries Research Board of Canada and the National Research Council. The orientation of research in the different Departments is of course dependent to a great extent upon the responsibilities with which the Departments have been charged. Whereas, for example, the Departments of Agriculture and Fisheries have rather specific missions, as far as water is concerned, the Department of Energy, Mines and Resources has been charged with the responsibility for co-ordinating, promoting and recommending national policies and programs with respect to water. The research program in the latter Department is therefore naturally more diverse and covers more categories of research than is the case in the former two. The recent formation of the Inland Waters Branch and the Policy and Planning Branch in the Department of Energy, Mines and Resources has given and will continue to give a real impetus to the search for knowledge in the water resources field. Much of this work will be in addition to the continuing research programs in the other Departments and Agencies.

Although a portion of the Federal research is carried out in the Ottawa region, most of the research is done in establishments throughout the country. For example, in the Department of Agriculture, water research is performed at the Central Experimental Farm at Ottawa, and in addition at Research Stations and Experimental Farms at Beaverlodge and Lethbridge, Alberta, Nappan, N.S., L'Assomption and LaPocatière, Quebec, Harrow, Ontario, Melfort, Scott, Saskatoon and Swift Current, Saskatchewan. Most of the research in the Meteorological Branch, Department of Transport, is based at Toronto. The Fisheries Research Board has stations at St. Andrews, N.B., Winnipeg, Manitoba, Dartmouth, N.S. and Nanaimo, B.C., and the Department of Fisheries is involved in water resources research in Vancouver, B.C., St. John's, Nfld., Sault Ste. Marie, Ontario, and Halifax, N.S. Water oriented research in the Department of Forestry and Rural Development is also predominantly carried on outside the Ottawa region, the main projects being at Calgary, Alberta, Amherst, N.S., and Chalk River, Ontario. On the other hand, the National Research Council performs most of its research in its establishments at Ottawa. The Department of Energy, Mines and Resources has regional laboratories in Calgary and Moncton and district offices for the Water Survey of Canada in most provinces. With its establishment of the Canada Centre for Inland Waters at Burlington, Ontario, much of the effort of this Department will be further decentralized.

The Canada Centre for Inland Waters, while led and co-ordinated by the Department of Energy, Mines and Resources, will involve substantial program contributions of the Fisheries Research Board, the Department of

National Health and Welfare, and the university community for whom special laboratories and office facilities are being provided. An advisory committee to the Centre is being formed and will consist of university, industry and government representatives.

Most Federal departments and agencies involved in water research carry on projects in the water cycle category. Particularly, work in the Department of Agriculture, the National Research Council and the Meteorological Branch, Department of Transport, is directed towards research in the 200-category. The particular emphasis in each department is naturally dependent on the mission of the department. For example, the Department of Agriculture stresses research in sub-categories 207 and 209, water in soils and water and plants, respectively, whereas the Meteorological Branch is more concerned with meteorological aspects of water resources research such as precipitation and evaporation.

On the other hand the Departments of National Health and Welfare, Fisheries and the Fisheries Research Board devote a substantial portion of their effort to research in water quality management and protection. The Department of Forestry and Rural Development conducts research in the 400-category, with particular emphasis on control of water on the land (effects of land management on run-off), in addition to that in the water cycle category. The Department of Energy, Mines and Resources has research programs in all main categories of research with special emphasis on general hydrology, lakes, environmental pollution research and economic and planning studies.

As was indicated in the first section of this chapter, the impact of the Federal program of research on the whole effort is very large. Forty-four per cent of the expenditures in water resources research are used for intramural programs of the Federal Government. Reported five-year programs of the Federal departments indicate that this effort is going to increase substantially over the coming five years, although likely not as rapidly as the various departments have proposed, due to general budgetary restrictions.

It was pointed out above that the Federal Government, besides being a major performer of research, is also a major source of funds for the other sectors. The universities received almost one million dollars of support from Federal Government departments and agencies in 1966, the major Federal source of funds for the universities being the National Research Council. During 1967-68, the National Research Council awarded 95 operating grants to individual university investigators for a total of $621,000.[3] In addition, the Council awarded Major Equipment Grants, and gave support to the Great Lakes Institute of the University of Toronto and the Marine Sciences Centre at McGill University. Besides the National Research Council, other Federal departments also lend support to universities. The Department of

[3] Courtesy of Awards Office, NRC.

Energy, Mines and Resources has now established a National Advisory Committee on Water Resources Research. The membership of the Committee is planned to be drawn from several Federal departments, the provinces, universities and industry. The terms of reference of the National Advisory Committee are:

1. To provide continuing advice to the Minister of Energy, Mines and Resources on needs and priorities for research on water resources in Canada, including water pollution research.
2. To assist in the co-ordination of water resources research.
3. To review and make recommendations on applications for grants in aid of research from the Department of Energy, Mines and Resources.

The main committee will be assisted by three sub-committees: one dealing with social science research, another with natural science and engineering research, and a third serving as an advisory committee to the Canada Centre for Inland Waters at Burlington, Ontario.

Two other committees of importance to the water resources research field are the Associate Committee on Geodesy and Geophysics with its Sub-Committees on Hydrology and Snow and Ice, and the Associate Committee on Water Pollution Research, both of the National Research Council. The Sub-Committees on Hydrology and Snow and Ice are appointed by the Associate Committee on Geodesy and Geophysics; their membership is drawn from the Federal and provincial governments, universities and industry. These Sub-Committees have been active in collecting and distributing information on hydrology and snow and ice research. They publish at regular intervals a bibliography of the Canadian work in hydrology and organize symposia on selected topics in their fields. The Sub-Committee on Hydrology also acts in an advisory capacity to the Canadian National Committee for the International Hydrologic Decade.

The Associate Committee on Water Pollution Research was established for the stimulation and promotion of research in the water pollution field. The Associate Committee was particularly interested in graduate training, with liaison between the National Research Council and other organizations engaged in water pollution abatement research. Since the Committee was also charged with duties very similar to those of the recently established National Advisory Committee on Water Resources Research in the Department of Energy, Mines and Resources, it was recently recommended that the Associate Committee be disbanded and be replaced by a committee dealing with the broader field of environmental pollution research.

The International Hydrological Decade (I.H.D.) has been a major influence on the expansion of water research in Canada, particularly in the water cycle category. In 1967, 97 countries and 16 international organizations were participating in the program which started in 1965. The Canadian program is co-ordinated by a National Committee, chaired by Major-General

H. A. Young, consisting of representatives of the Federal and provincial governments and the universities, and is supported by a fulltime Secretariat provided by the Inland Waters Branch, Department of Energy, Mines and Resources.

The importance of the Canadian Decade program in relation to overall water research activities in 1966 can be judged by the fact that of the 185 active I.H.D. projects in 1967, only 50 were started prior to the Decade. Most of these projects are multi-disciplinary and co-operative, each involving from 3 to 14 agencies and as many as 20 sub-projects. This allows maximum use of the data collected by the expensive instrument installations.

While it is impossible to obtain exact costs for this program from all the federal, provincial and university agencies involved, a study of 1966 figures[4] shows the source of financial support was as follows: Federal departments, $1,555,000, National Research Council (mostly in grants to universities) $261,000, and provincial agencies $376,000, for total minimum expenditures of $2,192,000.

The provincial effort in the whole field of water resources research accounts for 21 per cent of the work done and a total of approximately $1.75 million. It was indicated earlier that nearly 40 per cent of this effort was performed in four provincial research councils (B.C., Alta., Sask., and Ont.). Although the Councils are not generally considered to be part of provincial governments, in this report they have been categorized in this manner, in part to prevent a proliferation of sectors, and in part because the water research in the Councils is funded predominantly by provincial governments. The water resources research programs of the Councils, particularly in Alberta and Saskatchewan, have provided a real focus for regional research in this field.

Two other provincial agencies with major programs in water research are the Quebec Department of Natural Resources and the Ontario Water Resources Commission, both of which are mission oriented. Both have responsibility for the management of water resources with the emphasis in the latter on pollution control and abatement. Both are active in research in the water cycle category and, in addition, the Ontario Water Resources Commission has a considerable research program in Category 500 (water quality management and protection). The remainder of the provincial research is distributed among a number of mission-oriented provincial agencies, which carry on research programs closely related to provincial management responsibilities.

One is tempted in a report of this kind to pass judgment on the "quality" of the work going on, to make comments on the stature of Canadian water research scientists in the world community, and to attempt to measure the effectiveness of research performed in the different sectors. The

[4] Courtesy of I. C. Brown, Secretary, Canadian National Committee, International Hydrological Decade.

authors are well aware that to do so will enable the critic to accuse them of unfair bias or to question their competence to make these judgments, or even to question the possibility of making such judgments at all. Nevertheless, a few observations are passed on to the reader.

The first observation is that very few Canadian projects operate at the fringe of world knowledge, or attempt to search for generalized theories useful to water resources development. More specifically, most projects are adaptations to specific Canadian regions of theories, methods and techniques originated elsewhere. It is not known whether this is true as well for other countries besides Canada, but it is thought that in the international research community, Canada is not looked upon as being in the forefront of water resources research. If indeed the level of research is not as high as it might be, the question naturally arises as to the reasons for this.

A first obvious reason is the very low level of support prior to the mid-1960s. It was indicated above that research in hydrology got started at some reasonable scale only with the advent of the International Hydrological Decade in 1965. Similarly research in the water pollution field has grown only during very recent years, under the impact of public concern for water pollution.

A further reason relates to the state of university research in water resources. Since the universities are, by and large, the major suppliers of manpower in the field, strong programs of research at these centres are a prerequisite for good performance in other sectors. Table 5 shows that support of universities in 1966 amounted to approximately $1.6 million. This support is distributed over 20 universities for an average of $80,000. Of course some universities (Univ. of Alberta, Univ. of Toronto and Univ. of Saskatchewan, for example), are considerably above this average. None of the universities, however, seems to have reached "critical size" as far as water resources research is concerned.

A few universities have, with limited means, developed a reputation in specific disciplines, such as the University of Guelph in hydrology and the Ecole Polytechnique in hydraulics, but on the whole not one university in the country has a large diversified interdisciplinary program in water resources research. A beginning of such a program has now been made at the University of Manitoba, and several other universities are in the process of setting up similar programs. The fact that large specifically water-oriented programs are non-existent is a reflection of inadequate financial support for water research and of difficulties in organizing interdisciplinary programs in the universities.

The smallness of university programs mentioned above cannot but have a deleterious effect on programs in Government. Most of the present generation of research workers in the water field, have been trained in the basic disciplines (physics, civil engineering, biology) and have entered water research with the delightfully unbiased view of the blind man, whose eyes will be opened by on-the-job exposure. While this sort of "preparation" has had advantages in many cases in the past and will continue to be of importance, there is a great need for more specifically oriented training.

A third reason for the relatively slow flowering of water research in Canada has been the absence of serious problems. With the increase in the past decade of regional water shortages, increasing flood problems, water pollution and other water related problems, more research effort has recently been devoted to Canada's water resources.

Another observation relating to the stature of the water resources field is the absence of a journal in Canada in which results of water research can be published. Although a few Canadian journals carry articles on water resources engineering, the majority of articles must be published outside of the country, in American or international journals, to reach the eye of scientists with related interests. Indeed, the non-existence of a water resources journal in Canada may be one of the reasons for the fact that a substantial part of the research carried out appears not to result in published papers.

III.3 Research Activities in Other Countries

A country such as the United States can afford, both financially and technologically, to consider its research efforts in a given field almost independently of activities in other countries. Canada cannot afford to do so. It is most important in the field of water resources research to concentrate limited manpower and financial resources in Canada on those subjects in which scientific knowledge and technology cannot be readily imported due to lack of applicable research in other countries. In particular, it is necessary to review the nature and magnitude of the water research effort of the United States before making recommendations concerning the potentially most profitable subjects for Canadian research.

In the United States, very good analyses, appraisals and projections of the federal government's research efforts on water have been published by the President's Office of Science and Technology through the Committee on Water Resources Research of the Federal Council for Science and Technology (Nos. 1, 2 and 3)[5]. Unfortunately, accurate information is not available on water resources research sponsored by other levels of government, by universities, by foundations and by industry in the United States. Thus, there are difficulties involved in comparing the *total* Canadian effort, in *all* sectors (given in Tables 2-8) with similar U.S. activities.

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[5] No. 1—U.S. Office of Science and Technology—"A Ten-Year Program of Federal Water Resources Research"—Feb. 1966, 88 pp.

No. 2—U.S. Office of Science and Technology—"Federal Water Resources Research Program for Fiscal Year 1967"—April 1966, 20 pp.

No. 3—U.S. Office of Science and Technology—"Federal Water Resources Research Program for Fiscal Year 1968"—April 1967, 28 pp.

An attempt was made to assess the non-federal U.S. expenditures on water resources research, through information on the number of research projects in water, available from the Science Information Exchange (SIE) of the Smithsonian Institution, Washington. They have registered 4,193 projects in the water field for the year 1967. Of these, 743 or 18 per cent are supported wholly by non-federal agencies. Another 989 projects are supported partially by federal funds and partly by non-federal money. Many of these are in a federal-state matching grant program which requires the state to pay for at least 50 per cent of the cost of the grant, but many others receive only small contributions from non-federal agencies. If we assume that one third of the costs of these projects is borne by non-federal support, then, 26 per cent of the projects listed by the SIE can be considered to have non-federal support. Whether these projects are, on the average, more or less costly than federally sponsored projects was impossible to determine. However, practically no industrial research and development in this field is listed with SIE. No figures are available on the magnitude of industrial research on waste treatment processes, water purification, instrument development, materials for water structures, etc., but several Washington authorities think that these expenditures may be large.

From these indications it would seem to be a conservative estimate that approximately the same percentage of non-federal support for water research, i.e. 32 per cent, applies in the United States as was found from the comprehensive survey in Canada. If this is assumed, then comparisons of federal expenditures in the two countries can be thought to apply to the whole effort as well. Comparative federal expenditures by sub-category are given in Table 9 for fiscal year 1966-67. It should be noted that there is a three-month discrepancy in federal government fiscal years, the Canadian being from April 1 to March 31 and the United States from July 1 to June 30.

A few major short term changes are evident in comparing the U.S. federal budgets for fiscal year 1966-67 given in Table 9 and fiscal year 1967-68. In the water cycle category (200) a major increase in the study of lakes is indicated, from $0.6 million to $1.7 million. A decrease of expenditures is saline water conversion (301) from $27.7 million to $24 million is budgetted. However, the largest changes are in the field of water quality management and control (500) where total investment is going from $13.6 million to $33.6 million in one year with the largest increases in waste treatment processes (504) from $1.1 million to $5.9 million.

The longer-range plan for United States federal investment in water resources research envisages continued expansion in all fields except saline water conversion. For 1970-71, projected total intramural research would involve expenditures of $145 million with an additional $42 million going to grants-in-aid of research and research contracts. The research contract and

Table 9.—Canadian and U.S. Federal Intramural Expenditures (FY 1966-1967)

Code	Sub-categories	Canada $'000 (Can.)	United States $'000 (U.S.)
101	Properties of Water	—	367
102	Aqueous Solutions and Suspensions	22.5	1,488
201	Water Cycle, General	150.6	2,574
202	Precipitation	46.1	704
203	Snow and Ice	383.0	607
204	Evaporation and Transpiration	236.7	1,044
205	Streamflow	70.7	2,055
206	Groundwater	364.0	2,034
207	Water in Soils	89.0	1,122
208	Lakes	240.7	644
209	Water and Plants	56.4	1,113
210	Erosion and Sedimentation	9.1	2,315
211	Chemical Processes	12.0	1,298
212	Estuarine Problems	192.0	650
301	Saline Water Conversion	—	27,707
302	Water Yield Improvement	10.9	2,890
303	Use of Water of Impaired Quality	—	865
304	Conservation in Domestic Use	—	7
305	Conservation in Industry	—	7
306	Conservation in Agriculture	57.6	970
307	Weather Modification	173.0	3,000[a]
401	Control of Water on the Land	102.1	1,747
402	Groundwater Management	1.4	252
403	Effects of Man's Activities on Water	32.0	742
501	Identification of Pollutants	28.9	1,891
502	Sources and Fate of Pollution	81.8	2,020
503	Effects of Pollution	228.7	3,197
504	Waste Treatment Processes	31.0	3,293
505	Ultimate Disposal of Wastes	—	1,338
506	Water Treatment	10.0	774
507	Water Quality Control	626.1	1,121
601	Planning	16.0	302
602	Evaluation Processes	33.0	1,588
603	Cost Allocation, Sharing, Pricing	—	20
604	Water Requirements	—	167
605	Water Law	—	103
606	Institutional Aspects	—	141 (606 and 607 combined)
607	Sociological and Psychological Aspects	—	
608	Ecologic Impact of Water Development	—	1,583
701	Network Design	10.0	115
702	Data Acquisition	173.3	1.161
703	Evaluation, Processing and Publication	35.0	350
801	Specifications and Design	150.3	2,128
802	Materials	50.0	954
803	Operations	—	3,008
	Total	3,723.9	81,456

[a]Estimated from: National Atmospheric Sciences Program, Interdepartmental Atmospheric Sciences Program, Report No. 10, Jan. 1966, Washington, D.C. This includes only water resources oriented research, as does the Canadian figure.

grants program is thus expected to remain as a nearly constant or slightly declining proportion of the overall federal expenditures, changing from 24.5 per cent of the total in 1966-67 to 22.5 per cent in 1970-71.

The major trend in the United States government intramural program will continue to be to devote a greater proportion of the effort to water quality, anti-pollution studies, with the totals in this field increasing from $13.6 million in 1966-67 to $33.6 million in 1967-68 and $53.8 million in 1970-71. Thus anti-pollution research is expected to rise from 17 per cent of the total effort in 1966-67 to 37 per cent in 1970-71. Research on techniques of water resources planning (600) is also expected to undergo major expansion from $3.9 million (4.9 per cent of total in-house expenditures) in 1966-67 to $13.5 million (9.3 per cent of total) in 1970-71. These trends reflect an emphasis on those problems which become most acute with high population densities, i.e. pollution and conflicting water uses.

Regrettably, no comparable statistics on activities and emphasis on water resources research in other countries are available. Both France and Britain have extensive programs of water resources research. Besides the regular on-going programs of research, France has its "Actions Concertées" with the purpose of encouraging research in a number of basic and applied fields of science. Twenty of these programs have been started as part of the Fifth Plan, for which total expenditures are expected to reach about $155 million. One of the programs is devoted to water resources, with particular emphasis on the improvement of inventory methods of water resources and anti-pollution studies. In Britain a well known centre for hydraulics research is at Wallingford, Berkshire. The Natural Environment Research Council in Britain has a Hydrological Research Unit established at the Hydraulics Research Station at Wallingford. The Water Resources Board is also actively concerned with water research by both sponsorship and actual performance. The Board is interested in river regulation, generation of synthetic flow data, hydrologic mathematical models and automatic hydrometric instrumentation.

The lack of comparable statistics on water research activities in countries other than the United States makes comparison between the Canadian effort and those of other countries difficult. It also enhances the possibility of undesirable duplication of effort in the different countries. The direction of research in each country will, in part, be influenced by the scope and size of programs in other countries. The recommendations in the present report, for example, were materially influenced by knowledge of the proposed programs in the United States. It is therefore proposed that the Canadian Delegation to the Organization for Economic Co-operation and Development explore the possibility of having member countries conduct similar surveys in the water resources field. The results of such surveys would be invaluable for future studies of this kind.

Chapter IV

BENEFITS OF WATER RESOURCES RESEARCH

IV.1 Introduction

In basic fields of science, such as astronomy, the benefits of research are often intangible or at best very difficult to evaluate economically. Such basic research is supported by society as an important way of satisfying man's quenchless thirst for knowledge and understanding of the universe and of his role in relation to the phenomena around him. A report by the U.S. National Academy of Sciences to the Committee on Science and Astronautics of the House of Representatives, Washington 1965, on "Basic Research and National Goals",[1] argues that "scientific research can be viewed as itself a desirable end-product . . . it is an aesthetically and morally desirable form of human activity, and the increase of this activity is itself a proper measure of social and national health". However, there have also been such important long-term economic advantages derived from basic research in the past that there has been little questioning of the need for countries to sponsor basic research activities.

In applied fields of research the assessment of likely benefits is perhaps slightly less difficult, although it is obvious that a major difficulty in assessing potential benefits of all research activities is inherent in the unpredictable nature of the results. For if the results were predictable the element of innovation which characterizes research would be missing. Thus any assessment of potential benefits of research must be to quite an extent speculative and based on experience in the application of past results. Water resources research is, almost by definition, a field of applied research in which, consequently, some reasonably direct economic benefits are relatively less difficult to establish. Thus some guides to the level of research effort which appears to be economically justifiable can be established, at least in an approximate way. No attempt has been made, however, to perform a rigorous benefit-cost analysis for water resources research. As Maass[2] has pointed out:

> ". . . The major limitation of benefit-cost analysis, as it has been applied to public investments . . . , is that it ranks projects and programs in terms only of economic efficiency. . . . But the objective of most public programs is not simply, not even principally, economic benefits . . . . Thus, benefit-cost analysis may be largely irrelevant, or relevant to only a small part of the problem of evaluating public projects and programs . . . ."

The emphasis in this chapter on financial benefits should not obscure the fact that water resources research is like all other kinds of research in that it, too, helps to satisfy man's needs for knowledge and understanding of a vital part of his environment. In addition, the aesthetic, recreational and even moral benefits of research to curb water pollution, and otherwise to make optimum

[1] U.S. Government Printing Office, Washington, 1965.

[2] A. Maass, "Benefit-Cost Analysis: Its Relevance to Public Investment Decisions". *The Quarterly Journal of Economics,* Vol. LXXX, May, 1966, No. 2.

use of this natural resource, without destroying its value to other users and to future generations, probably outweighs the importance of economic benefits.

IV.2 Design and Operation of Water Control and Water Conveyance Structures

One of the most obvious ways in which the results of water resources research can be applied is in designing and operating the structures that engineers use to control the level and flow of water and to convey water from one location to another. Such structures range from multi-purpose, billion dollar dams, to eavestroughs for carrying water from roofs, and include, in addition, city storm sewer systems; ditches, culverts and bridges for draining excess water from and under highways, railroads and airport runways; irrigation systems; piers, breakwaters, locks and harbour facilities built in lakes and rivers; water pipelines for municipalities; and so on. Each one of these structures, be it a farm pond spillway or massive dam and reservoir system, must be designed on the basis of analyses of technical data. Optimum design requires both good basic data in the project region, and sound techniques to make maximum use of these data. Research provides the guidelines for the type of data that should be collected and the methods by which these observations can be made accurately and economically. Research also provides the constantly improving analysis techniques that may be applied to the basic data. Analyses then form the basis for design criteria for the structures. For certain types of structures, such as dams, application of research results can also lead to operation of the control facility to maximum advantage.

Some examples of the types of economies that can be achieved will clarify the above points. Evaporation estimates for a major reservoir built in Canada in the past decade appear on the basis of more recent techniques and data to have been initially over-estimated, to a net cost of $2 million. On the same project the initial spillway design flood was found on the basis of later research to be too conservative (i.e. too big) for Canadian conditions, having been based initially on United States techniques. Reduction in the spillway design flood, based on more refined adaptation of the techniques to Canadian conditions, resulted in a saving of $1 million. On another northern project, doubts concerning the relationship between channel flow velocities and likely ice formation cost $500,000, or 2 per cent of the water conveyance structure costs, to make the design conservative. In all of these cases the reduced capital costs on the projects that either resulted from new research or could very likely be achieved with additional research ran from 1 to 5 per cent of the costs of the structure.

In connection with the operation of dams, it has been estimated that each 1 per cent improvement in inflow forecasts to the huge new reservoir behind Bennett Dam on the Peace River, B.C., would result in $1 million[3] per year increase in revenue through improved operating efficiencies. There is

[3] F. Sampson, "Peace River Project with Specific Reference to Reservoir Filling and Runoff Forecasts", *Proc. Western Snow Conf., 29th Annual Meeting,* 1961, pp. 20-24.

little reason to doubt that improved hydrologic forecasts would result in significant increases in operating efficiencies of many Canadian dam and reservoir systems.

The consultants (H.G. Acres and Co. Ltd.) who studied this matter, obtained information on total expenditures in Canada on water resources structures and projected these expenditures to 1980. The results of this analysis are shown in Table 10. Expenditures in 1966 totalled $1,061 million and are expected to rise to $3,035 million by 1980.

The consultants reviewed their own very extensive experience in design of many hydraulic structures and undertook analyses of the role of research results in a number of individual projects. They came to the conclusion that a very conservative estimate of the direct financial benefits that would result from research in the water cycle (Category 200) and engineering works (Category 800) would decrease capital expenditures on water control and conveyance structures by an average of ½ to 1 per cent for each sub-category of research applicable to the structure. Since in each case knowledge of a number of factors are important, the total potential average improvement resulting from research on all factors affecting a structure was estimated by Acres to be about 3 per cent.

To compare the potential benefits of research with the costs in any rigorous way is difficult if not impossible. Methods developed for economic evaluation of research are not easily applied to the water resources research situation. In such methods (see, for example, Quinn, J.B., "How to Evaluate Research Output", *Harvard Business Review,* April 1960) the economic advantages of beginning a particular R & D project are assessed by determining the likely cost of the R & D work, charging a realistic rate of interest on this investment until such time as the R & D is expected to result in a salable product, or a reduction in production cost or some other financial benefit is achieved. Benefits can be evaluated by estimating the sales of the new or improved product during its likely salable lifetime, deducting the costs of production and distribution. The industry can then evaluate whether the investment in the research would likely pay off over the period of production.

It is not so simple to apply such methods to a broad field such as water resources research, since the time interval is not discrete. That is, we are not here dealing with investment in a particular two or three-year research project but with a continuing program involving expenditures each year. In addition, the benefits in terms of improved design of water control and conveyance structures can also be considered to accrue to new construction and operation year by year for an indefinite period.

Another serious difficulty is to estimate the lag time between completion of research and implementation of results. In some types of water projects, usually the very largest ones, outstanding consultants are engaged who often apply very recent research results, within a year or two, to problems they

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Table 10.—Construction and Repair Expenditure Projected by Category, 1959-1980

$'000

Categories	1959	1960	1961	1962	1963	1964	1965	1966	1967	1970	1975	1980
Docks, Wharves, Piers and Breakwaters	61,675	71,540	77,080	57,831	37,517	46,309	55,575	69,838	80,904	101,000	138,000	200,000
Rivers and Canals	7,364	10,974	12,762	12,213	9,218	10,920	31,777	26,358	43,393	52,500	73,000	100,000
Dredging and Pile Driving	51,390	31,590	23,928	11,192	7,706	5,614	11,959	16,100	19,051	23,300	32,400	45,000
Sewage Systems and Connections	112,674	113,367	122,685	122,430	132,340	143,180	163,266	194,065	197,815	247,000	315,000	400,000
Water Supply Systems	99,104	98,294	93,385	99,751	108,766	117,708	166,810	172,798	167,224	205,000	285,000	400,000
Dams and Reservoirs	45,693	76,295	60,018	72,547	60,680	146,183	266,814	172,825	199,783	260,000	320,000	430,000
Irrigation and Land Reclamation	17,542	15,742	19,414	21,486	26,382	24,232	25,312	52,450	70,042	90,000	125,000	175,000
Water Control Structures for Electric Power	105,100	83,800	128,100	141,400	143,500	110,800	123,800	260,600	278,400	340,000	470,000	650,000
Bridges, Culverts, Aquaducts, etc.	183,110	196,396	207,566	166,886	202,342	211,757	215,693	227,142	235,807	287,000	398,000	550,000
Drainage and Storm Sewers	13,929	21,122	7,082	5,434	25,224	24,226	31,218	42,174	44,309	52,000	66,000	85,000
Totals	697,581	719,120	752,020	711,170	753,675	840,929	1,092,224	1,061,525	1,336,728	1,657,800	2,222,400	3,035,000

encounter. On the other hand, thousands of small projects are designed by municipal engineers or local consultants who do not have as much opportunity to keep up to date with research in all of the fields with which they are called upon to deal. In such cases the lag between research results and practice may be very long, in the order of decades.

A third difficulty lies in knowing how much research and what kind is needed to achieve the magnitude of benefits that are considered possible. The consultants estimate that cost reduction of 3 per cent could be achieved in construction of water control and conveyance structures; but how much research is needed and what kind to achieve this improvement? Some judgments can be made, and have been made, in Chapter 5 on the types of research most likely to yield optimum benefits, but there appears to be no way of specifically quantifying the overall level of research in the appropriate categories which would be required to achieve optimum benefits.

However, given these difficulties, it is still possible to do some calculations that are suggestive of the potential economic returns from water cycle and engineering works research. If one assumes that research results in this field take, on the average, seven years[4] to be put into practice and, if one assumes (for simplicity) that the research done in 1966 affects the desired design improvements in 1973 only, and that 1967 research affects construction only in the year 1974, and so on, then one has an easy if only very approximate way of comparing costs to potential benefits. This approach is likely just as accurate (or inaccurate) as adding up the costs of research for 15 years say, and comparing the likely total benefits over a similar period with a seven-year lag.

If these rather sweeping assumptions are made, one sees that the $4.4 million invested in water cycle and engineering works research in 1966 would, at 6 per cent interest, amount to $6.6 million in 1973, and would affect construction costs of $1,997 million in that year. If the 3 per cent improvement figure is accepted, this suggests potential benefits of the order of $60 million, or nearly nine times the investment. Similarly, the proposed expenditure of $8.7 million on the water cycle and engineering works categories of water resources research in 1970 (see Chapter V) becomes $13.1 million by 1977, at 6 per cent, and would affect construction expenditures of about $2,550 million. A 3 per cent improvement in design efficiency in 1977 would amount to $77 million. In both cases the research costs are 0.5 per cent or less of the construction investment affected.

It is obvious, but it should be emphasized, that these figures are not the result of any rigorous benefit-cost analysis which was found to be inappropriate in the present case. However, the figures do make it obvious that, whatever type of assumptions might be made or economic analysis undertaken, the present and projected levels of research investment in the water cycle

[4] Prof. W. Bennis, *Conference on Change and The Dynamic Organization*, University of Toronto, November 1967.

and engineering works fields are only a very small percentage of the construction expenditures affected, and of the potential benefits from improved design efficiencies.

It should also be emphasized again that this discussion has considered only the obvious, direct benefits. There are many other benefits of research in these two categories (the water cycle and engineering works) that were not considered in the argument above. For example, studies of water movement and turbulence in lakes and rivers (sub-categories 208 and 205) are very important in connection with movement and diffusion of pollution in streams and lakes. Knowledge of groundwater is vital to optimum development of municipal water supplies in many areas, yet this knowledge does not greatly affect the design of water structures. Studies in the field of the water cycle, augmented by improved observing networks, will permit one better to assess the magnitude of the resource in various regions of Canada, its fluctuations with time and its accessibility. Such knowledge is vital to intelligent allocation of the resource between local users, between provinces, and perhaps even between countries.

In other words, while the investment and expenditure figures give some measure of *one kind* of direct financial benefit of research in the two categories, they by no means convey the *full* economic benefits of research in these fields. They should be thought of as minimum identifiable benefits of such research.

IV.3 Benefits of Anti-Pollution Research

It is even more difficult to set even approximate minimum values on potential benefits of research in water pollution control. However, some measures of the economic aspects of pollution can be obtained. One such measure is the cost of construction of water treatment plants and sewage treatment plants for municipal wastes. Table 11 gives figures on costs of water and sewage treatment plant construction in Ontario from 1963 to 1967. The amount of money spent in each region of Canada on such facilities is related not so much to the total population but rather to the urban population, i.e. the numbers living in cities and towns requiring sewage treatment facilities. Projections of urban population are given in Table 12 which indicate that between 1966 and 1980 Ontario's urban population will continue to be about 38 per cent of that for Canada as a whole. Water use per capita in urban areas is expected to rise from 125 gal. per day to 200 gal. per day between 1966 and 1980. Using these figures, it is estimated that in 1966 capital construction expenditures only, on municipal water and sewage treatment plants in Canada, were about $400 million and that these are expected to rise to $870-900 million annually by 1978. The total annual *operating* costs of water and sewage treatment plants across the country must be enormous, but no figures were available. An estimate of the total

Table 11.—Expenditures on Water and Sewage Treatment Plants, Ontario 1963-1967[a]

$'000,000

Year	Expenditures
1963	114.9
1964	134.6
1965	140.4
1966	152.9
1967	176.0 (approx.)

[a]Courtesy Ontario Water Resources Commission (A. J. Harris)

Table 12.—Urban Population Growth Projections, 1961-1980[a]

Year	Total Pop. '000	%[b] Urban	Urban Pop. '000
Ontario			
1961	6,236	77	4,801
1966	6,871	79	5,428
1970	7,454	81	6,038
1980	9,008	86	7,747
Canada			
1961	18,201	70	12,741
1966	19,870	72	14,306
1970	21,249	75	15,937
1980	25,057	81	20,296

Ontario's Urban Population as a per cent of Canada's Urban Population, 38

[a]Economic Council of Canada, "The Canadian Economy from the 1960's to the 1970's", *Fourth Annual Review*, Queen's Printer, Ottawa, Sept. 1967.

[b]Urban centres are those with population 1,000 or more.

costs to industries is not available but, to give some indication of the magnitude, one pulp and paper manufacturer alone estimates that its capital expenditures for pollution control exceeded $17 million in the period 1960-67.

The costs of construction and operation of water and sewage treatment plants are of course only the obvious costs of attempting to control pollution of our waters. Another way of looking at pollution costs is to examine the "nuisance" costs to our society. For example, when a resident of an urban area wants to fish or swim but cannot do so in the lake or stream nearby, he must at some cost to himself drive some distance to some relatively unpolluted body of water. Other social costs include decrease in property values adjacent to bodies of water which become seriously polluted, the extra costs of cleaning and repairing pleasure boats, etc. It is obviously very difficult to estimate the magnitude of these "pollution costs" to the people of Canada, although one brave soul made an estimate of $400 million per year, which was widely quoted at the recent national Conference on Pollution and Our Environment.

Present (1966) expenditures on research in water quality management and protection (Category 500) total $2.8 million, or less than 1 per cent of the annual capital costs of municipal water and sewage treatment plants alone.

If municipal operating costs, industrial waste treatment costs and nuisance costs were added in, the research investment would appear to be extremely small, especially in view of the projected increases in expenditures in pollution control which today's research must serve.

It is especially clear in this field that successful major innovation could make a tremendous difference in the potential benefits. For example, if a new chemical secondary sewage treatment process were found which is say 20 per cent cheaper to build than the present biological systems, the *annual* capital saving to municipalities would be about $180 million per year by 1978. If it were found that the tolerance level of aquatic life to certain pollutants is much greater than now suspected or that self-purification rates of streams and lakes is more rapid under some conditions than hitherto expected, or that certain self-sustaining biological processes in lakes and streams could help control levels of pollution, then very large financial savings on treatment plants might be possible. Here one is confronted with questions of unpredictability of the results of research which makes a realistic assessment of the financial benefits very difficult.

IV.4 Social, Economic and Institutional Aspects

The difficulties of assessing, in financial terms, the potential benefits of research in the natural sciences pale into insignificance in the face of the problem of assessing potential economic benefits of social sciences research. This is not so say that the benefits are not real; they are very real indeed. For example, systems analysis techniques, economic and social analyses can permit selection of the optimum scheme for development of a basin. The best scheme may be many millions of dollars less costly than the others. Better methods of quantifying the benefits of water resources projects, especially the indirect recreational or social benefits, will lead to selection of schemes that will give the greatest benefits to the citizens who pay for them. One experienced U.S. worker in the water resource field puts the potential benefits of economic and social research at about 10 per cent of all the nation's expenditures on water programs although there is little except personal experience to support such a figure.

In Canada, many water developments have been frustrated not by lack of funds but by jurisdictional problems preventing the necessary co-ordinated planning. For example, several decades elapsed between initial conception and the recent final agreement to proceed with co-ordinated planning studies of the Saskatchewan-Nelson River system by the three Prairie Provinces and the Federal Government. It is impossible to know in this case whether some dispassionate research on optimum institutional or legal arrangements for planning would have hastened the final agreement. However, there is no doubt that such inter-governmental agreements would be easier to achieve if results of research on the full range of possible institutional and legal arrangements were made available to the administrators and politicians concerned. In addition, if economic assessments of the "shadow-price" of inefficient institutional arrangements could be made, political leaders would have better information on which to seek improvements.

The social and ecological impact of water developments are almost impossible to predict with currently available knowledge. Concern for preservation of social values and natural ecological conditions has resulted in cancellation of several recent major reservoir programs in the United States, including the proposed Bridge Canyon Dam in the Grand Canyon. Close to home, a recent controversy raged in New Brunswick over the construction of the Mactaquac hydro-electric development. Those naturalists and farmers who loved that portion of the beautiful St. John River valley and worked the land that was to be flooded by the reservoir were understandably concerned about the effects of the reservoir on vegetation, wildlife, the way of life of local residents, and the aesthetic values of the valley. Good forecasts of the social and ecological and regional economic impact of such developments would help agencies and citizens to see the complete picture and select optimum solutions for resolving conflicting uses of our water resources.

The amounts of money that taxpayers are prepared to spend on pollution abatement depends on their perception of the problem and its seriousness. In order to develop efficient but politically realistic plans, planners should know something about how far Canadian citizens are prepared to go in paying for a cleaner environment.

Many other examples are given by Sewell,[5] of the kinds of problems which face Canadian water managers and which require social and economic research for solution. The above examples are intended only to give the reader some idea of the far-reaching potential benefits of an expanded research effort in this field. The benefits are impossible to measure accurately, but they are, nevertheless, very important to efficient management of Canada's water resources.

[5]W.R.D. Sewell, The Contribution of Social Science Research to Water Resource Management in Canada (see *infra*, pp. 111-169).

IV.5 Other Benefits

Sections IV.2 and IV.3 contained discussions of hydrologic, water engineering and pollution research in improved design, construction and operation of water projects. These are, of course, not the only potential benefits of research in these fields.

One of the most important values of water cycle research (Category 200), and research on water requirements (604) is to permit informed decisions to be made on water apportionment and water transfers. Many provincial agencies are faced with the problem of whether to grant permits to those who wish to take more river water or well water from a nearby source. In many such cases, further drawdown of a well might affect the flow of a nearby stream and thus the use of the stream's water by many people downstream. Conversely, reduction of streamflow in some areas may result in lowering of the groundwater table in the vicinity and the drying up of some wells. While the basic theory of water flow through porous media is well enough known to help solve many such problems, in most regions local research on permeability of the various soil and ground strata and on groundwater-streamflow interrelationships has been insufficient to allow application of the general theories. Yet, the decisions must be made.

Perhaps, one of the most important political problems in the water field in the next decade will be in formulating public policies on water transfers. In all cases of change in the natural drainage patterns one must know much more than one now does about the quantity and quality of the resource in the source region and its variability from season to season and year to year. One must also know much more about the foreseeable water needs of the source region. Much of the work required here is of a survey nature, but traditional survey techniques need refinement to meet Canadian needs and some special engineering, hydrologic, water quality, economic and social problems must be solved, for which few precedents and guidelines exist. It is certain, however, that for international negotiations on water transfers and on joint use of shared water resources such as the Great Lakes and many international rivers, Canadian negotiators must be equipped with the best physical, chemical, biological, economic and engineering knowledge possible, to ensure that any international agreements are in the best interests of Canada's citizens. If our political and administrative leaders cannot count on this support from the scientific and engineering community, and count on it soon, potentially valuable opportunities for agreements may be lost, and the chance will remain of entering into agreements which would turn out to be second best for our citizens. This applies not only to possible international agreements but to inter-provincial and inter-regional developments as well.

IV.6 Summary of Benefits

In this chapter an attempt has been made to review some of the potential benefits to Canada of a balanced program of water resources research. In sections IV.2 and IV.3, some of the more easily identified direct economic benefits were cited. Canada is now making a capital investment of about 2.5 per cent of its Gross National Product, or about $1.5 billion per year, on works to control, convey or treat water. This sum will rise to about $4 billion by the late 1970s. Estimates of the potential improved efficiencies in design and operation of these structures are difficult to make but appear to be of the order of 3 per cent of construction costs.

However, some of the less easily identifiable benefits of water resources research are more important than the more obvious ones. Of special importance are the advantages that would accrue through being able to make fully-informed decisions, on engineering and economic and social grounds, of the best alternative of various possible water development options. In addition, advantageous agreements on inter-regional, inter-provincial and international development of water resources must rest on much better knowledge than now available, on many aspects of Canada's waters. Finally, the moral imperative to manage Canada's natural environment for present and future generations, in the face of increasing population pressures, requires Canadians to support the development of the technological means for doing so. The economic and social well-being of the citizen will rest in no small measure on the success of water resources research programs.

Chapter V

RESEARCH NEEDS AND PRIORITIES

V.1 The General Level of Research Required

One of the difficult problems to which the Study Group Advisory Committee addressed itself was whether the total effort in water resources research in Canada, as reported in the survey, is adequate, more than adequate or less than adequate to meet the country's foreseeable needs. This difficulty is compounded by the fact that the present study is the first in renewable resources undertaken by the Science Secretariat. This results in a lack of perspective, which makes a rational judgment more difficult than would be the case if other studies in renewable resources had been completed. Future studies by the Science Secretariat will, it is hoped, correct this deficiency.

As noted in Chapter IV, it would be helpful if a rigorous economic analysis of benefits and costs could be developed to provide the main input to such a decision. This has proven to be impossible and undesirable and hence economic considerations, such as those in Chapter IV, could only serve as a guide to the Committee. However, the Committee had, through its members, the advantage of first-hand knowledge of water problems in all parts of the country, and of the potential applicability of research results.

The Committee had also the benefit of the recommendations of knowledgeable consultants in specific fields. For example, the consultants on social, economic and institutional aspects of water resources research recommended that to provide some of the key solutions to Canada's water development, research in this field should be increased so that university support reach an annual level of about $300,000 within a few years time.

Another perspective was provided by viewing water resources research in the context of overall research and development expenditures in Canada. The $8.4 million spent on water research in 1966 was about 1.2 per cent of the country's total R & D expenditure of $720 million. From the point of view of manpower, only about 2 per cent of the scientist and engineer man-years devoted to research and development in Canada were working in the water field. The Committee then considered whether this was an appropriate portion of the nation's R & D effort in the light of (a) the importance of water resources to Canada's development and (b) the potential benefits of research in this field.

One of the factors considered in attempting to evaluate the importance of water in the Canadian economy was that the total 1966 construction expenditures on water control and conveyance structures and on water and sewage treatment plants was $1.46 billion. This amounted to 2.5 per cent of the G.N.P. of $58 billion. Projections in Chapter IV suggest that the percentage of the G.N.P. spent to control, convey and treat water will remain about the same, at least until 1980. This of course is not a true measure of the value of the resource to Canada, but simply the direct, easily identifiable cost to control the resource. It is reasonable to assume that the *value* of water to Canada's economy far exceeds these costs.

In short, the Committee had to make an informed judgment based on all of these considerations. It concluded that Canada has seriously underemphasized water resources research, and that research institutions of governments and industry should recognize water research as a main field into which research efforts should be channeled during the next decade. More specifically, the Committee recommended that, in view of the importance of water to Canada's economy and the major potential benefits of research results, the percentage of the total R & D effort devoted to water research should be approximately doubled to 2.5 per cent rather than the present 1.2 per cent. This increase must be accomplished over a period of 10 to 12 years.

The implication, in financial terms, of an increase in the level of research funding from 1.2 to 2.5 per cent of the total R & D effort of the country depends on the growth of the overall level of research support. If it is assumed that the total R & D effort of the country is increased to about 2.2 per cent of the Gross National Product (current U.S. Level is about 3.5 per cent), Canada will be spending $2.8 billion (current dollars) on R & D in 1978 (assuming a G.N.P. of 128 billion current dollars in 1978). The water resources research component, if increased to 2.5 per cent of the total, would be about $70 million. This corresponds to an average annual increase in project expenditures of 20 per cent which was judged to be the most rapid rate of expansion that could be achieved without reducing the quality and efficiency of the research effort.

A further consideration of the Committee was that those categories of research contributing directly to efficiency of design and operation of structures to control, convey and treat water (categories 200, 500 and 800) totalled $6.9 million in 1966 or less than one half of 1 per cent of 1966 investment in such structures. In order to raise this to 1.5 per cent of the annual investment by 1978, research expenditures in these categories alone would have to reach about $60 million by that time.

In summary, it is extremely difficult to develop in an objective manner specific recommendations on the level of expenditures a country should devote to a major field such as water resources research. However, in this case, several indicators including optimum rate of growth, reasonable percentage of capital investments, and an appropriate proportion of total R & D efforts, pointed towards similar recommendations. These are that an average annual increase of approximately 20 per cent in water resources research be achieved to reach an overall level of about $25 million by 1972-73 and $75 million by 1978-79.

It should be noted that these projections are in current dollars which include a 2 per cent implicit price increase (general inflation factor) consistent with the goals of the Economic Council. The possibility of inflation at a more rapid pace should be taken into consideration by any agencies that may use these proposals as guidance in preparing budgets. Also excluded from the recommended levels of expenditure is the increased cost per scientist of doing research, the sophistication factor.[1] In the absence of information on the sophistication factor in water resources research it is estimated that sophistication of research in this field, i.e. the cost for better and more complex instruments and facilities is proceeding at a rate of about 4 per cent per annum. While a 4 per cent sophistication factor may be a reasonable average for water research, in some categories requiring extensive instrumentation, the rate may be considerably higher, and in other categories the rate may be much lower. For this reason, this factor has not been incorporated in the projections of expenditures. However, agencies using this report as a guideline for projected expenditures should take into account a sophistication factor appropriate to their field of work.

V.2 Needs in Various Research Categories

Introduction

In the previous section, an assessment was given of the overall level of effort in water resources research that is needed in the country and would be appropriate for Canada to undertake in view of the role of water resources in its economy and activities. In this section, a statement on the factors that influenced the detailed recommendations on expenditures in the eight main categories and 45 sub-categories of research in the field is followed by a summary of these recommendations. The final section of this chapter is devoted to a more detailed discussion of needs and level of effort by individual category and sub-category. It is hoped that the reader will gain perspective by having the summary precede the detailed treatment of the individual categories and sub-categories.

Factors Influencing Recommendations

Four main factors were considered by the Advisory Committee in arriving at recommendations concerning the relative importance of the various categories of water research in Canada. The first was relevance of

[1] A. V. Cohen and L. N. Ivins, *The Sophistication Factor in Science Expenditure*, Science Policy Studies No. 1, London, H.M.S.O., 1967.

research in this field to existing and emerging problems in the management of water resources in Canada. Some types of research are very important in countries where conservation of a very limited supply is of paramount concern, but in Canada the types of research needed at this stage of our development are mostly those which will allow us to capitalize to an optimum extent on the relatively abundant resource available. For example, it is not proposed to put as great an emphasis on research on conservation of water in domestic use and in industry as is the case in the U.S.A., although it will no doubt be necessary to increase our efforts in these fields as the country's economy develops in the 1970s.

The second main consideration was the possibility of importing highly relevant scientific and technical solutions. An example will illustrate this point. In 1967, the United States spent about $28 million on research into saline water conversion and will continue to spend large sums on developing and improving techniques in this field. Even relatively large expenditures in this field in Canada are unlikely to have a significant impact on the overall state of knowledge and technology, in view of the very extensive efforts in the United States and some other countries. Consequently, to meet Canadian requirements for saline water conversion, techniques that have been developed elsewhere can no doubt be applied with only minor modifications in Canada. However, it should be kept in mind that in order fully to exploit imported research and technology it is necessary to develop and maintain some competence in the field, and this is done best by having a few research workers supported in that field, who can speak the language of persons engaged in similar research abroad. This problem has been clearly described by Bergmann[2] who stated:

> "The question of whether it is preferable to buy what one needs or to make it instead is another problem for any but the most highly developed countries. Probably it is always cheaper to buy ready-made goods than to develop the knowledge and techniques required to produce them; however, there are certain drawbacks in following this path of least resistance. You cannot determine the value of what you want to buy without having the same knowledge as the seller, and you cannot utilize what you have bought without having the technical expertise. Moreover, there comes a point where for any number of reasons you can no longer buy what you need. Then the existence of an excellent body of scientists and engineers—men with ideas and experience—becomes a vital necessity and every penny spent on the creation of such a body has been well spent. In the end, dependence because of ignorance is intolerable for any country."

For these reasons, even in those categories where much of the research results are readily importable, a certain minimum level of effort is recommended. On the other side of the coin, it is obvious that Canada must do much of its own research on subjects such as lakes, water law, and environmental aspects of pollution.

[2] E. D. Bergmann, "Technical Strength for a New Nation," *Science and Technology* No. 72, pp. 62-69, December 1967.

A third factor considered in assessing the relative distribution of effort in each sub-category, measured in dollars, was the cost of doing research on a particular subject. For example, research on large lakes is very costly per scientist because of the expense of research vessels and of suitable observational techniques and platforms. On the other hand, much of the research on economic, social and institutional aspects requires little more than pencil, paper and perhaps some computer time.

The fourth factor influencing the Committee's proposals for the level of research required in each category and many sub-categories was an assessment of potential economic benefits of research in the various fields. In cases where they could be reasonably assessed, the direct, readily identifiable benefits were those that were taken into account. However, appraisals of indirect benefits and social benefits also influenced the recommendations.

V.3 Summary of Research Needs and Priorities

Considering the factors outlined in section V.2 above, the Advisory Committee and the authors considered research needs in each category and sub-category. These needs are discussed in some detail in the following section (V.4), but a summary is presented in this section to give the reader a broader perspective for review of the detailed recommendations to follow.

Table 13 summarizes the recommendations outlined for each of the main categories and sub-categories. It will be seen that the recommendations reflect the basic idea that Canada is and will continue to be for the next decade a country with a relatively large water resource for a relatively small population. However, the trend is towards more intensive development, and pollution of prime resources such as the Saskatchewan-Nelson and Great Lakes-St. Lawrence systems will become of increasingly greater importance. The research proposals are directed mostly towards capitalizing on this major resource advantage for stimulating economic development. This is in sharp contrast to the United States water research allocations which will be increasingly great in the fields of conservation, re-use and renovation of limited water resources. This contrast is shown in Table 13 which shows the projected U.S. Federal *intramural* distribution of expenditures in comparison with the proposed *total* Canadian expenditures.

In a sense this puts Canada in a very advantageous position—that of learning a great deal from its southern neighbour about methods of coping with problems now appearing on the Canadian horizon, but of not having in the next decade to devote very large amounts of its own limited research funds and staff to these problems. Canada can then concentrate its efforts on appraising the extent, magnitude and quality of the resource, and on optimum use of the resource for municipal and industrial development. It should be borne in mind that the recommendations reflect ideas on the rate of development in Canada which are consistent with projections of the

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Table 13.—Comparison Beween Distribution of United States Federal Intramural and Proposed Canadian Total Expenditures

Code	Categories	U.S. Projected Distribution of Federal Intramural Expenditures 1970-1971 (Per cent)	Proposed Canadian Distribution of Total Expenditures 1972-1973 (Per cent)
100	Nature of Water	2.7	1
200	Water Cycle	17.1	40
300	Water Supply Augmentation and Conservation	18.2[a]	6
400	Water Quantity Management and Control	5.8	5
500	Water Quality Management and Protection	37.0	28
600	Economic, Social and Institutional Aspects	9.3	6
700	Resource Data	2.8	6
800	Engineering Works	7.1	8
	Total	100.0	100

[a]Does not include water oriented weather modification research, for which no realistic projections were available.

Economic Council of Canada. However, if industrial and population development proceeds at a more rapid pace than anticipated, a changing emphasis in water research would be necessary. For this reason it is recommended that a complete re-appraisal of these priorities be made in 1972 at the latest.

Particular fields singled out for major increases in emphasis and expenditures (5-fold increase or more by 1972-73 where present expenditures exceed $50,000) are precipitation (202), streamflow (205), identification of pollutants (501), sources and fate of pollution (502), planning (601) and construction materials (802). Some other sub-categories of research on which only small sums (less than $50,000) are now being spent are also proposed for 5-fold or greater increases by 1972-73. These sub-categories are properties of water (101), use of water of impaired quality (303), conservation in domestic use, and industry (304, 305), groundwater management (402), water treatment (506), cost allocation (603), water law (605), ecologic impact of water development (608), network design (701), and engineering works operations (803).

On the other hand, substantially lower than average rates of increase in expenditure are proposed in some other sub-categories of research. For example the sub-categories of water cycle-general (201), snow and ice (203), groundwater (206), and estuarine problems (212), receive at this time relatively very considerable support and, although these sub-categories are of great importance, it would be unrealistic to increase their levels as rapidly as the overall average annual rate of 20 per cent.

Table 14.—Proposed Increase in Research Expenditures by Sub-Category

$'000,000

Code	Categories	1966 Expenditures[a]		Proposed 1972-73 Expenditures		Target Expenditures for 1978-79	
101	Properties of Water	—		.1			
102	Aqueous Solutions and Suspensions	0.04		.15			
	Total	0.04	(0.5%)	.25	(~1%)	.8	(1%)
201	Water Cycle, General	0.89		1.71			
202	Precipitation	0.17		1.00			
203	Snow and Ice	0.57		1.00			
204	Evaporation and Transpiration	0.27		.86			
205	Streamflow	0.12		.86			
206	Groundwater	0.74		1.43			
207	Water in Soils	0.16		.43			
208	Lakes	0.41		1.43			
209	Water and Plants	0.08		.28			
210	Erosion and Sedimentation	0.25		.57			
211	Chemical Processes	0.03		.14			
212	Estuarine Problems	0.22		.29			
	Total	3.91	(46.6%)	10.00	(~40%)	28.5	(38%)
301	Saline Water Conversion	.07		.11			
302	Water Yield Improvement	.09		.40			
303	Use of Water of Impaired Quality	.01		.07			
304	Conservation in Domestic Use	—		.07			
305	Conservation in Industry	—		.10			
306	Conservation in Agriculture	.08		.34			
307	Weather Modification	.17		.41			
	Total	.43	(5.1%)	1.50	(~6%)	4.5	(6%)
401	Control of Water on the Land	.13		.42			
402	Groundwater Management	—		.28			
403	Effects of Man's Activities on Water	.17		.55			
	Total	.30	(3.6%)	1.25	(~5%)	3.7	(5%)

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Table 14.—Proposed Increase in Research Expenditures by Sub-Category—(Concluded)
$'000,000

Code	Categories	1966 Expenditures[a]		Proposed 1972-73 Expenditures		Target Expenditures for 1978-79	
501	Identification of Pollutants	.11		.58			
502	Sources and Fate of Pollution	.27		1.59			
503	Effects of Pollution	.47		1.59			
504	Waste Treatment Processes	.93		1.74			
505	Ultimate Disposal of Wastes	.04		.15			
506	Water Treatment	.03		.15			
507	Water Quality Control	.66		1.30			
	Total	2.51	(30.0%)	7.10	(~28%)	22.5	(30%)
601	Planning	.05		.25			
602	Evaluation Processes	.06		.25			
603	Cost Allocation, sharing, Pricing	—		.13			
604	Water Requirements	.06		.25			
605	Water Law	—		.13			
606	Institutional Aspects	.08		.25			
607	Sociological and Psychological Aspects	.03		.12			
608	Ecologic Impact of Water Development	—		.12			
	Total	.28	(3.3%)	1.50	(~6%)	4.5	(6%)
701	Network Design	.04		.30			
702	Data Acquisition	.21		1.00			
703	Evaluation, Processing and Publication	.18		.20			
	Total	.43	(5.1%)	1.50	(~6%)	4.5	(6%)
801	Specifications and Design	.40		1.00			
802	Materials	.07		.57			
803	Operations	.01		.43			
	Total	.48	(5.8%)	2.00	(~8%)	6.0	(8%)
	TOTALS	8.39		25.1		75.0	

[a]Numbers do not necessarily add up to total due to rounding.

Saline water conversion (301), waste treatment processes (504), water quality control (507) and evaluation, processing, and tabulation of resources data (703) are important fields of research in themselves, but the Advisory Committee considered that a more modest rate of increase in these fields combined with use of research results from other countries would meet Canadian needs.

One other point should be stressed. There are no known ways of uniquely defining the amounts of money that should be spent in any particular category of research. It is a matter of informed judgment, making use of whatever economic and social indicators appear to be relevant. This the Advisory Committee has done. In writing this report the authors thought it better to put the recommendations in the form of specific figures, rather than outlining recommendations in vague terms. This has been done while recognizing the danger that any one individual figure can be attacked as being too low or too high and recognizing that these figures are simply an attempt to give some concrete definition to recommendation which are by their nature imprecise. Hence the figures should be viewed only as a guide to the levels of research support recommended and not as precise recommendations.

V.4 Major Research Needs and Levels of Effort by Sub-Category

Category 100—Nature of Water

This is the only category used in this survey which could be classified as "pure" or fundamental research and for which it is neither possible nor desirable to estimate the potential direct benefits. However, it is obvious that knowledge of the nature of pure water and behaviour of very dilute solutions is the starting point for better understanding of waste removal, pollution control, ice formation and many other processes and subjects dealt with in the categories of applied water research. In 1966 only about one professional man-year was reported as being devoted to studies in the two sub-categories, properties of water (201) and aqueous solutions and suspensions (202). In order to capitalize on developments in this basic field to benefit Canada, it will be necessary to increase research efforts in Category 100 to support at least 8 or 9 full-time research workers in this field by 1972-73. This will require allocation of about $250,000 by Fiscal Year 1972-73. This is about 1 per cent of the proposed total 1972-73 water research effort and compares with projected Federal expenditures of $3.9 million for 1970-71 in the United States. The expenditure of $250,000 could be looked upon as an excellent investment since it would help to produce the expertise needed to determine applicability to Canadian problems of a many times larger basic research effort in United States, to say nothing of similar research in other parts of the world.

Category 200—Water Cycle

This category of research covers much of the field known as hydrology, the science concerned with the distribution, occurrence and movement of water on and under the earth's surface. Hydrology involves the study of the natural processes affecting water, and the effects that moving water has on the land, through erosion and sedimentation. A thorough understanding of the extent and variability of Canada's water resources, both on a national scale and locally, is of utmost importance in ensuring optimum management of these resources. All structures built to control and convey water should be built with full knowledge of the flows of the water courses, the currents and waves in lakes, the ice forces, the sediment deposition pattern, and all of the other physical factors which must influence the design of the structure. A fairly substantial research program in this category has been developed in Canada, although much of it began only in the past two years under the impetus of the International Hydrologic Decade. Expenditures in Category 200 totalled $3.9 million in 1966, 46.6 per cent of the total expenditures in water resources research.

To put the effort in some perspective, past research in Category 200 significantly influenced nearly $900 million worth of construction in 1966. Given a 7-year lag between completion of research and engineering use of the results, 1966 research results would affect construction expenditures of about $1.7 billion in 1973. (See Table 10).

The Advisory Committee argued that substantial improvements in knowledge of the water cycle as it affects Canada are both potentially profitable and capable of achievement, and thus recommended a continuing major effort in this category. However, in view of the present substantial base from which research programs can be developed in this category, the Committee recommended a slightly slower rate of expansion of efforts in this field than the 20 per cent per annum rate proposed overall. The proposal is that research in this category become about 40 per cent of Canada's total effort rather than nearly 47 per cent. If this adjustment is made within the next 6 years this implies a total expenditure of about $10 million in Category 200 by 1972-73 with target expenditures in 1978-79 being approximately 28.5 million (38 per cent of total). In the United States, research policies reflect an increasingly water-short economy where the emphasis will be on water conservation and pollution. The water cycle category is expected to account for only 17 per cent of the total U.S. federal water research effort by 1970-71.

Sub-Category 201—General

This is considered to be the most important sub-category in the Water Cycle Category. It deals with two or more phases of the hydrologic cycle and their interactions, including development of rainfall-runoff relationships, computer models of the hydrologic cycle in river and lake basins, surface and groundwater inter-relations and geomorphology. As a part of the International Hydrologic Decade program, which began in 1965, more than 30 small, representative basins in Canada have been instrumented to provide data on all aspects of the water cycle within the basins. A substantial proportion of the $890,000 research expenditure in this sub-category is involved in the representative basin program. One of the main objectives of this program is to learn how to predict run-off output from river basins without stream gauges from meteorological data as input. If the necessary relationships can be determined from the instrumented representative basins in the various climatic, soils and geologic zones of the country, it may be possible to develop generalized relationships by computer, which would permit prediction of the run-off regime and thus hydrologic design criteria for any small basin in the country. Data could be profitably used from other representative basins in the world, instrumented under the I.H.D. program.

However, while the program to establish and instrument these basins is well developed, there has been to date no proportionate effort to analyze the results and begin development of the types of generalized equations and relationships needed. Establishment of such comprehensive analysis projects should have a very high priority in the research programs of the Federal Government and universities to make maximum use of Canada's substantial investment in the instrumentation and observation phases of the program. Of special importance to Canada is the development of suitable mathematical models of snowmelt and of the contribution of melting snow to streamflow and lake levels.

The Advisory Committee proposed that about 17 per cent of 200-category funds be devoted to this sub-category which would imply an increase in annual expenditures to about $1.7 million by 1972-73.

Sub-Category 202—Precipitation

Precipitation falling in the form of rain or snow is the source of all of our fresh water resources, yet Canada is spending a relatively small amount ($168,000) on research on space and time variations of precipitation, time trends, and methods of estimating extremes of low and high rainfall amounts which produce droughts and floods. Knowledge of the frequency of occurrence of rains of various intensities over small drainage basins is important for establishing design criteria for drainage and storm sewer systems. These designs are now often based on frequency analyses of rainfall measured at a station or "a point", but what is really required is an estimate of rainfall frequencies over an area from say one acre to 25 square miles. Construction costs in this category were more than $42 million in 1966 and are expected to rise to $85 million per year by 1980. However, very little research effort has been put into determining the representativeness of point rainfall values and into studies of small scale areal variability of rainfall in various Canadian climatic zones.

In British Columbia, it is a matter of real urgency to develop methods of determining precipitation amounts at higher altitudes from the easily collected valley station data. Again, some research on this matter has been started under the I.H.D., but the program needs major expansion. Estimates of precipitation extremes, and probable maximum precipitation, affect the design of many major dams in Canada. In 1966, more than $430 million was spent on such structures and by 1980 the annual investment will have passed the $1 billion mark. Most of the research in this field in Canada has been adaptive in nature, making use of techniques derived originally in the United States. In the future more basic research into the structure of storms in Canada and the methods of estimating the upper limits to storm precipitation must be undertaken. Precipitation and climatic trends should also be taken into account in designing water development projects but cannot for lack of ability to predict trends. Very little research is underway on this subject.

In view of these considerations, a six-fold increase of research effort in this field by 1972-73 and a continuing increase thereafter to 9-10 per cent of the total effort in the 200 Category is recommended. This should be spearheaded by the Federal Government and actively supported by the provinces and universities.

Sub-Category 203—Snow and Ice

Rather understandably, Canada spends a much larger proportion of its water research effort on snow and ice studies than does the United States. To give a typical example, illustrating the hydrologic importance of snowmelt, more than 40 per cent of the annual run-off of the Fraser River comes from melting snow and ice. Canada devoted about 15 per cent of water cycle category research in 1966 to investigations of formation and dissipation of ice, thermodynamics of snow and ice, glaciers, ice forces, permafrost, etc. The comparable figures for U.S. federal research was about 3 per cent. It is obvious that this is a field of research in which Canada cannot depend on importing research from its southern neighbour, although studies in Scandinavia and USSR are valuable to Canada. Earlier research in this field influenced the design of more than $.5 billion worth of docks, wharves, dams, channels, etc. in 1966. Some potentially valuable areas of further research are: (i) in predicting and modifying freeze-up and break-up for navigation, especially in the Great Lakes-St. Lawrence system, (ii) better understanding of snowmelt thermodynamics and prediction methods at Canadian latitudes, (iii) effects of permafrost on groundwater and hydrologic regimes, (iv) glacial fluctuations as indicators of long term climatic trends, (v) development of satellite techniques for snow and ice cover evaluation and (vi) improved methods of prediction of floods due to ice jams.

In view of the very substantial activities already underway in Canada in this field, the Advisory Committee recommended a slower than 20 per cent annual average growth rate for this field and propose an expansion of the effort from about $570,00 in 1966 to $1 million or 10 per cent of the Water Cycle Category, by 1972-73. In addition it should be noted that a significant proportion of research in the general water cycle (201) will include snowmelt studies as related to other phases of the hydrologic cycle.

Sub-Category 204—Evaporation and Transpiration

Evaporation has been called the "most desperate branch of that desperate science" (meteorology). Perhaps because of the intellectual challenge it has attracted a reasonable amount of attention from Canadian researchers. About 7 per cent of the 200-Category effort in 1966 or $273,000 was devoted to studies in this field, which is about the same percentage as in the United States where evaporation rates and losses are substantially higher. However, the United States is proposing a relatively faster expansion of effort in this field than in other Water Cycle categories. Most of the Canadian research has been devoted to studies of evapotranspiration, to aid in estimating irrigation water requirements. It was only in 1967 that the first maps giving estimates of free water evaporation, from lakes and reservoirs, were published in Canada and these were called "preliminary" and were based on very limited data. Very limited knowledge is available on the applicability of various evaporation estimation techniques in Canadian climates. Several IHD projects to evaluate evaporation estimation methods for small and large lakes have been started or are planned and should be strongly supported.

The Advisory Committee proposes an approximate tripling of the research effort in this field from 1966 to 1972, which is about the average rate of annual growth of 20 per cent proposed in water resources research in general. Much of the increased effort should be devoted to evaporation from water, snow and ice surfaces. Research in evaporation and transpiration reduction is discussed in Category 300.

Sub-Category 205—Streamflow

It is remarkable that a country which spends about $10 million annually on collection of streamflow observations, invested only $124,000 in 1966 in research on the data collected, on improved methods of analyzing these data for various uses and on the physical processes of river flow. In 1966, federal agencies in the United States spent 11 per cent of their Water Cycle research on streamflow studies. Canada spent only 3 per cent. In discussions of sections 201 and 202 it was pointed out that better knowledge of precipitation distributions and of precipitation run-off relationships would be most valuable in estimating design floods for very small and for large watersheds. For middle sized basins, and perhaps small ones also, a more direct approach in many cases is to analyze regional streamflow characteristics in relation to weather, soils, geology, stream characteristics, basin cover, etc. and thus derive from gauged basin data, methods of estimating flood and drought frequencies for the millions of small basins which can never be gauged and on many of which water control or conveyance structures must be built. Some $700 million worth of structures were built in 1966, and by 1980 the annual capital investment will be about $1.7 billion. Perhaps one of the best investments Canada could make in water research would be to undertake extensive physical-statistical analyses of the great library of streamflow data now on file. Other types of streamflow research needing attention in Canada include studies of mechanics of flow in rivers particularly under ice cover, turbulence and diffusion in rivers (closely related to sub-category 502—Sources and Fate of Pollution) and studies of hydrograph shapes and characteristics, especially at high flows, and research on methods of making optimum use of once-a-day river water level records for design flood studies.

The Advisory Committee considered that research efforts in this sub-category should be greatly increased to 7 times the present level of effort, by 1972-73.

Sub-Category 206—Groundwater

A few large municipalities, thousands of small communities, and most of Canada's rural residents rely on groundwater supplies. It is estimated that one fifth of domestic consumption in Canada is derived from groundwater supplies. Field research in this sub-category is very costly since drilling costs are high, but in the long run such research can be very profitable since it may frequently lead to easy exploitation of high quality water very close to the user. Much of the research undertaken to date has been related to inventory studies and has been of a fairly descriptive nature. In the future more effort should be concentrated on mathematical and model approaches to flow of water through porous media, and on physical studies of the rate and character of recharge of groundwater aquifers. Salt water intrusion in East coast aquifers deserves special attention. A substantial program of groundwater research is underway in Canada, with very active participation of provincial and federal agencies. In 1966, $737,000 was invested in such research. This was in addition to expenditures on conventional surveys of locations and extent of groundwater resources, which were not considered to be research.

The Advisory Committee recommended a continuing expansion of research in this field but a slower rate of growth than average. It was proposed that a support level of about $1.4 million per annum be reached by 1972-73. A more rapid growth in research into groundwater management and artificial recharge of aquifers is recommended and is dealt with under Sub-Category 402.

Sub-Category 207—Water in Soils

The movement of water into soils and through the soil profile, vertically and laterally, is the key link between the supply of rain and snowmelt water and the useable output, streamflow or groundwater aquifer. In addition soil moisture is the important hydrologic factor related to plant growth, and to scheduling and planning of irrigation of crops. Canadians have undertaken substantial and successful research efforts on estimation of soil moisture from climatic data and other means, but have done much less on infiltration rates and characteristics of Canadian soils and on movement of water within the soil profiles.

Total research expenditures in 1966 were $156,000 and the Advisory Committee recommends an annual growth rate of about 20 per cent or a rate of expansion about the same as the average rate proposed for water research.

Sub-Category 208—Lakes

Canada is a land of lakes. Perhaps the most unique feature of Canada's water resource is the relatively high percentage of water that is found in our lakes, both large and small. In addition to having a major share of the largest group of fresh-water lakes in the world, the Great Lakes, including the largest fresh-water body in the world, Lake Superior, Canada has within its boundaries Great Bear and Great Slave Lakes, both greater than 11,000 sq. mi. in area, Lake Winnipeg of 9,400 sq. mi., Lake Athabaska of 3,000 sq. mi. and millions of smaller lakes. Each major dam, such as the Gardner Dam on the South Saskatchewan River, creates a large new lake. Canadian water research programs have recognized to some extent the importance of studies of lakes in our country and especially, in the past few years, the Great Lakes. This sub-category includes research only on the natural physical and chemical characteristics of lakes including currents, waves, natural chemistry and thermal regime. It is clear that such studies inter-act with studies in other sub-categories.

Expenditures totalled about $412,000 in 1966 excluding data collection costs, and were rising rapidly in 1967 due to a major new federal government program on the Great Lakes. An article by W. C. Ackermann, President of the American Geophysical Union, points out that much water resources research in the United States (and this is true in Canada as well) has been directed towards marginal resources areas and problems, neglecting the prime water resources. He states that "the Great Lakes can be identified as a uniquely valuable resource that has been taken for granted to the point of abuse"[3]. In Canada, in 1966, $70 million was spent on docks, wharves, piers and breakwaters, mostly in lakes, which should be designed on the basis of better knowledge than now available of wave forces and currents; $430 million was spent on creation of reservoirs, i.e. new lakes where thermal and dynamic characteristics, including wind set-up and waves, significantly affect the design of the dams which formed them; $370 million was invested in water supply and sewage systems, many drawing from and emptying into lakes where knowledge of temperatures and currents to diffuse the wastes are very limited. In short, because of the unique importance of lakes in Canada, it should become a world leader in the field of physical and chemical limnology.

Taking these factors into consideration, a more rapid growth rate than average for water research was recommended by the Committee, with expenditures proposed for 1972-73 of about $1.4 million. It should be noted that

[3] W. C. Ackermann, "Research problems in hydrology and engineering" in *Water Research*, John Hopkins Press, 1966.

the universities and government agencies involved in Lakes research programs carry out also substantial amounts of research that fall into many other sub-categories including those dealing with water cycle—general (201), precipitation (202), evaporation (204), snow and ice (203), erosion and sedimentation (210), chemical processes (211), identification of pollutants (501), sources and fate of pollution (502), effects of pollution including eutrophication (503), and operation of engineering works (803). While the Laurentian Great Lakes should obviously be the focus for this research effort because of their economic importance, universities and government agencies should be encouraged to extend their research efforts to provide the understanding required of other large and small lakes and reservoirs in Canada.

Sub-Category 209—Water and Plants

While a considerable amount of research has been done in Canadian agricultural agencies and universities on improving yields of crops by modifying or making optimum use of soil moisture and precipitation, only a small proportion of this effort has been directed specifically towards the water requirements of plants and the interception of precipitation by vegetation. This is a major area of research in the United States and some of the basic concepts and techniques can be adapted to Canadian uses. This field was considered by the Advisory Committee to need strengthening and they recommended that expenditures of $85,000 be increased to about $280,000 by 1972-73.

Sub-Category 210—Erosion and Sedimentation

Erosion of valuable soils is due mainly to moving water. It is estimated that 25 per cent of Canada's usable land has been affected more or less seriously by erosion.[4] An understanding of this process as it applies to Canadian soil types is necessary to devise suitable protection measures. The streams in the Prairies and in agricultural areas, carry sediment loads and deposit the sedimentary materials in reservoirs, thus reducing the useful storage. Erection of structures such as bridges and piers in rivers and lakes changes the patterns of scour and deposition of sediment. If a good knowledge of the process is not available, this can result in undermining of structures and/or need for costly dredging. The Advisory Committee considered this an important but not crucial field for water research in Canada and recommended a somewhat less rapid than average increase to bring the present $250,000 per year expenditure to about $570,000 in 1972-73. Research directed specifically towards control of erosion and sedimentation is considered under Sub-Category 507—water quality control.

Sub-Category 211—Chemical Processes

Research in this field of chemical interactions between water and its natural environments is closely related to fundamental research on aqueous

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[4] A. Leahey, "Appraisal of Canada's Land Base for Agriculture . . .", *Proc. Resources for Tomorrow Conference,* Ottawa, Queen's Printer, 1961.

solutions (102) on the one hand, to groundwater studies (206) and to several categories of water quality management. Rainwater contains some dissolved salts and solids and as it moves over and through soils and rocks, this "universal solvent" dissolves additional materials. The chemical composition of the water can thus be used to help trace its history and to learn more about water movements through the hydrologic cycle. Most work on this subject in Canada has been undertaken by groundwater specialists and very little study has been devoted to the chemical composition of rainwater, the starting point of the processes. Research in this field is of practical importance in predicting and managing the potential accumulation of salts in irrigated areas and in understanding the impact of man-made wastes (pollutants) on the chemical composition of lakes and rivers.

Research in this field should be increased from its present very low level ($29,000 in 1966-67) to about $140,000 by 1972-73.

Sub-Category 212—Estuarine Problems

Estuaries are studied by both oceanographers and water resource specialists, from somewhat different points of view. Exploitation of fresh water resources in estuarine areas presents very special problems. These problems include the effects of tides on river discharge, impact on coastal beaches of upstream reservoirs which trap sediment, and the intrusion of salt water due to depletion of fresh water flows. In addition, movements and dispersals of pollutants are difficult to predict because of the complex current systems in estuaries caused by tides, river flow and winds.

As none of these problems have achieved major proportions in Canada, the Advisory Committee considered it desirable to increase the research program in this field only slightly from the present level of effort ($218,000 in 1966), in order to have the expertise to take maximum advantage of the much larger research efforts in other countries.

Category 300—Water Supply Augmentation and Conservation

Research in this main category is directed towards producing more water available for man's use, and towards reducing the water demands of domestic, industrial and agricultural water users. In Canada, only limited amounts of research in this category have been undertaken, because aside from some Prairie regions, there are few major shortages of water in Canada in a regional sense. However, costs of distribution of water from nearest available supplies are becoming limiting factors in a number of areas in addition to the Prairies, and some increases in research expenditures appear to be warranted in this Category. It is recommended that the percentage of the overall water research effort be increased from 5 per cent to about 6 per cent in this field. This compares with 30 per cent in the United States in 1966. This U.S. figure includes saline water conversion, but does not include precipitation production aspects of weather modification, as does the Canadian figure.

Sub-Category 301—Saline Water Conversion

Most research in Canada on this problem is being conducted on the Prairies, where some major groundwater resources are very brackish. Because of the massive U.S. research program in this field ($28 million in federal expenditures in 1967) it appears that Canada can import most of the science and technology needed to meet requirements such as those on the Prairies. However, as indicated on page 60, in order to do a successful job of importing results of research and technology, Canada must have a few knowledgeable experts in the field. These can best be developed and sustained by a continuing modest research effort.

The Advisory Committee suggested a slight increase in expenditures in this field from $72,000 in 1966-67 to about $110,000 in 1972-73, or enough to support approximately four full-time research workers.

Sub-Category 302—Water Yield Improvement

It has been conclusively demonstrated in Europe, East Africa and United States that forest cutting and snow management practices can increase the yield of rivers by significant amounts, and change the timing of the run-off. The obvious first location to attempt such research and management in Canada is on the east slopes of the Rocky Mountains, in the headwaters of the North and South Saskatchewan Rivers which feed the irrigation, water supply and power production facilities of the water-hungry Prairies. The major research effort in this field in Canada is conducted in Alberta in the East Slopes (Alberta) Watershed Research Program (ESAWRP). The problems arising in attempting to categorize research have caused some difficulty here however. Although the overall ultimate objective of ESAWRP is water yield improvement, much of the multi-disciplinary research effort involved was reported on in this survey in its many parts, under evaporation and transpiration, snow and ice, erosion and sedimentation, rather than in this sub-category, which really calls for a synthesis of the various disciplinary parts. However, it is clear that research results on this subject in Alberta will yield important benefits in increased water yield where they are most required. Similar research would be of special value in British Columbia's interior valleys, in Southern Ontario and on the St. John River Basin, New Brunswick. However, substantial advantage can be taken of research done elsewhere on this subject.

Research on reservoir evaporation suppression by thin films has limited applicability, mainly on small reservoirs in the Prairie Provinces but sufficient research should be supported on this subject to permit us to keep up to date on developments in Australia, United States and elsewhere, in order to adapt promising techniques to help solve Canadian problems.

With these considerations in mind, the Advisory Committee recommended a four-to-five fold increase in research in this sub-category to bring the level of support to about $400,000 by 1972-73. Research in this sub-category is closely related to that in sub-categories 401 (control of water on the land), 403 (effects of man's related activities on water), and 507 (water quality control).

Sub-Category 303—Use of Water of Impaired Quality

Very little research on this subject was reported in the 1966 survey, total expenditures being about $5,000 on one project concerned with industrial use of poor quality water. However, methods of using water of high salinity in agricultural areas and studies of crop tolerance to salinity would be of considerable value on the Prairies, to complement the research on desalination of the brackish groundwater.

Increased research efforts in this sub-category to bring expenditures to the order of $70,000 by 1972-73, to support two or three man-years of research effort, was considered desirable by the Advisory Committee.

Sub-Category 304—Conservation in Domestic Use

The only research in this field in Canada is a study conducted by a province to develop a completely self-sustaining home water system, by continual re-use of a limited supply. Such a development might have important implications for housing in northern regions. United States expenditures are also small in this field but are projected to rise to $500,000 by 1970-71.

The recommendation for Canadian efforts is to invest about $70,000 per year by 1972-73. That is, to spend enough money to sustain two or three professional man-years on research into viable methods of reducing home consumption of water and improved methods of controlling leakage in municipal water supply systems.

Sub-Category 305—Conservation in Industry

In some cases reduction of water demands by industry by process modification and re-cycling of water may not only decrease the volume of water required by the industry but also reduce the pollution load discharged by the plant. Only one project, costing $4,500, was reported in 1966.

Industry should be encouraged to increase its efforts in this direction over the next six years to achieve a level of expenditures of about $100,000 per year to permit Canada to take maximum advantage of the ten-times-larger program proposed in the United States.

Sub-Category 306—Conservation in Agriculture

Under typical conditions irrigation systems deliver to the plants only a little more than one half of the water they take from rivers, reservoirs, and aquifers. Irrigation is characteristic of water short areas, and thus conservation of some of this wasted water for other uses such as power production would be of considerable value. Recent research on uses of chemicals such as "atrozine" to spray leaves of plants and reduce transpiration suggests a further promising avenue for reduction of water consumption by crops in regions of water deficiencies. Techniques for optimum scheduling of irrigation by means of soil moisture observations or estimates can contribute to conservation of water supplies. Research in this field is of course closely related to that under Sub-Category 209—water and plants.

The Advisory Committee recommended that increase in research in this sub-category be about quadrupled between 1966-67 and 1972-73, to reach about $340,000 per year.

Sub-Category 307—Weather Modification

While weather modification can be thought of as a meteorological matter and is dealt with in the Science Secretariat report on *Physics in Canada*[5], two types of weather modification are included in this present survey because of their special relevance to development and management of our water resources. One is precipitation inducement by cloud-seeding and the other is the effect of man-made features such as reservoirs on the local water balance, particularly evaporation. While it is agreed, as is stated in the *Physics In Canada* report, that Canada cannot hope to keep up with the very large United States efforts in this field, it cannot afford not to have knowledge and competence in cloud seeding for precipitation production. First of all, significant increases in precipitation are likely possible in some regions, especially in areas of strong orographic effects. Secondly, since many United States cloud seeding operations are being undertaken close to the Canadian border and on international river basins, Canada must have sufficient expertise to evaluate the effects on the country and its citizens. Canadian research in this sub-category can afford to be of an adaptive kind, but field projects on induced precipitation are very costly.

Changes in the local water balance in areas adjacent to new reservoirs are local phenomena, but may be of considerable importance in these particular areas. This question deserves some research attention.

Taking these factors into account, it is recommended that research on water resources aspects of weather modification be increased at about the same rate as water research in general from a base of $173,000 in 1966-67 to about $410,000 in 1972-73.

Category 400—Water Quantity Management and Control

This category of research is concerned with control and management of water by means other than engineering structures, and with the side-effects on water quantities that are an increasingly worrisome feature of many of man's activities, such as logging, building cities, constructing highways, etc. This category now absorbs less than 4 per cent of the water research effort and it is recommended that the proportion of the overall expenditures devoted to water quantity management be increased slightly to 5 per cent.

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[5] D. C. Rose, and Study Group of CAP, *Physics in Canada—Survey and Outlook*, Special Study No. 2, Science Secretariat (Ottawa: Queen's Printer, 1967).

Sub-Category 401—Control of Water on the Land

There are two closely related aspects of this field of research: (i) the drainage of excess waters from agricultural lands, and (ii) the conservation of water for use close to where it falls, by land management practices. This latter aspect is in turn closely related to water yield improvement (302) but has different objectives. Much of Canada's non-drained farmland would be much more productive if drainage were provided and 2 million acres of potentially productive land could be brought into production by drainage works. To undertake this drainage work requires substantial investment. Research into optimum spacing and depth of drains, cheaper construction methods, etc., in Canadian soil types, considering frost penetration factors, would optimize design of these drainage works.

Conservation practices to improve the water retention capacity of the land can benefit agricultural production, reduce land erosion and the sediment load of streams. Further research is needed into the physical and hydraulic principles involved in reshaping the land surfaces by terraces, vegetation rows, and particularly into methods of doing so that will be compatible with use of modern farm machinery.

Canadian expenditures in this sub-category in 1966 totalled $129,000 and approximate tripling of effort by 1972-73 is recommended.

Sub-Category 402—Groundwater Management

About 20 per cent of the water used by homes in Canada is from groundwater sources. In Sub-Category 206 the need for a major continuing program to permit a basic understanding of groundwater behaviour was emphasized. However, research must also be directed towards management of this extensive and largely untapped resource. Groundwater in aquifers is not subject to evaporation, temperature and quality variations, and other factors which reduce the value of surface reservoirs. Research is especially needed on techniques for artificial recharge of aquifers, to make optimum use of these underground "reservoirs", on joint use of aquifers and surface reservoirs, and on effects of irrigation programs on groundwater recharge.

Only $1,400 was spent in 1966 on research in this sub-category. The Advisory Committee recommended a major increase to approximately $280,000 by 1972-73.

Sub-Category 403—Effects of Man's Related Activities on Water

In 1966, 72 per cent of Canada's population lived in urban centres of 1,000 people or more and 48 per cent in large cities of more than 100,000 population. Urban growth in Canada has been at a greater rate than in any of the other developed countries and the urban population is expected to increase to 81 per cent of the 25 million total population by 1980. The paving of streets and of highways linking the cities, the roofing of buildings and other changes in land cover brought about by urbanization, profoundly affect the regime of streams and watercourses which drain city regions. Flood peaks are higher and more frequent; low flows are lower and more frequent. These changes in turn should affect the design criteria for countless culverts, storm sewers, bridges, etc., built in and over these watercourses. However, little quantitative information is available to optimize these design criteria, affecting $42 million worth of construction in 1966 and a projected $85 million worth in 1980. Similarly, the qualitative effects of logging on streamflow patterns are well known but not enough is known to predict quantitatively the effects on floods and droughts of logging practices in a particular basin.

Research into these inadvertent but profound effects should be increased from the 1966 level of $170,000 at a slightly higher than average rate to reach about $550,000 by 1972-73.

Category 500—Water Quality Management and Protection

Anti-pollution research is perhaps the most difficult category for formulation of suitable recommendations. The Advisory Committee had the benefit of the Proceedings and Recommendations of the National Conference on "Pollution and our Environment" held in late 1966 by the Canadian Council of Resource Ministers. The recommendations made in the present report were materially influenced by the deliberations at this Conference. In addition, the report of the consultants on this subject, Dr. P. H. Jones and Dr. A. D. Stanley, was helpful to the Committee in developing recommendations.

Research in water quality management and protection is on the one hand economically and socially a very important field of water research and one which receives an overwhelming measure of public support. Canada is still at a point where well conceived research and abatement programs can avoid the gross pollution of water resources which afflicts parts of the United States. It is estimated that the United States must spend $26 to $29 billion within the next five years to achieve clean waters.[6] As indicated in Chapter IV, 1966 capital expenditures on waste and water treatment were about $400 million and these will increase to about $1 billion by 1978-79.

At the same time, it must be recognized that the technology is presently available to reduce significantly much of the water pollution that plagues our most densely populated areas. In addition, a very large program of research in waste treatment processes is in progress in the United States and much of the results and technological developments are directly applicable in Canada. U.S. Federal Agency expenditures alone are expected to reach $54 million in this category of research by 1970-71, with $37 million being devoted to the more easily transposed sub-categories of waste treatment processes, ultimate disposal of wastes, water treatment and water quality control. It is, of course, essential that Canada continue major research programs in these sub-categories, to develop the expertise needed to adapt new developments

[6] U.S. Federal Water Pollution Control Administration "Cost of Clean Water" report to U.S. Congress, 1967.

to Canadian conditions and to undertake research related to special problems in Canada due to climate, permafrost and other factors. However, the major expansion of Canada's efforts in this anti-pollution field should be in the environmental aspects, related to sources and fate of pollution in Canadian waters and the effects of those pollutants.

A substantial research program is underway in main Category 500, with expenditures in 1966 totalling $2.5 million. The Advisory Committee recommendation was that research in this field be increased at a rate very slightly less than the average annual 20 per cent to nearly triple the 1966 expenditures by 1972-73, and to reach about $23 million by 1978. Sub-category 501, identification of pollutants and the "environmental" sub-categories 502 and 503 should receive the major share of the expansion.

Sub-Category 501—Identification of Pollutants

It is obviously essential to the maintenance of water quality conditions and enforcement of quality objectives, that reliable methods be available to determine the presence and concentration of pollutants.

Each year sees the introduction of many new chemical compounds for various purposes. Many of these chemicals find their way eventually into our water as new pollutants. New analytical techniques for identifying these pollutants and their concentrations must constantly be developed. In addition, it is necessary to continue to develop improved methods of detecting and measuring concentration of the "traditional" pollutants, especially methods that can be readily used in the field. In this sub-category Canadians can rely heavily on analytical methods developed in other countries, but in view of the importance of the field, we must maintain a substantial research effort in Canada.

It is proposed that research expenditures on identification of pollutants be increased to about $580,000 by 1972-73, from the 1966 level of $114,000. Industries introducing new chemical compounds to the market should be encouraged to undertake the necessary studies to provide suitable analytical techniques for detection of the substance in water.

Sub-Category 502—Sources and Fate of Pollution

Each lake or river into which liquid wastes are poured diffuses the wastes according to the characteristics of the currents and turbulence of the flow. Also of importance is the limited self-purifying power of water bodies. Some experimentation with mathematical models to predict pollution concentrations at any point in a river or lake, given various pollution inputs along the water body, has proven to be promising. Such techniques will permit refinement in setting quality standards, at the place of effluent, which will yield a given standard of quality in the main body of the water. Unfortunately, little research of this type has been undertaken on Canadian waters, and if it is going to be done, as it must, it will have to be done in this country. Some of the sources of pollution are the obvious industrial and municipal outfalls, but others are less well defined and diffuse. How important a source

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of pollution are salts used to improve traction on icy winter roads, fertilizers used on farm lands, gardens and lawns, animal wastes from agricultural areas and septic tanks? Research on the significance and nature of these pollution sources under Canadian conditions must be increased. The effects of lake and river ice covers on pollutant concentrations and dispersal must also be more thoroughly studied.

This sub-category was considered by the Advisory Committee to require the most rapid expansion in the anti-pollution category with an approximate six-fold expansion of effort proposed by 1972-73. In 1966 expenditures were $267,000, with industrial research being the largest contributor to this total.

Sub-Category 503—Effects of Pollution

Many of the water quality standards and objectives towards which industries and municipalities are asked to aim, are set by means of the present limited knowledge of effects of various pollutants on the animal and plant life of receiving water bodies. A better knowledge of these effects would help to refine the quality standards. Pollutants, specially the fertilizing nitrates and phosphates, speed up the natural aging processes, the eutrophication of lakes, but in a manner that is not well understood. Algal blooms which, on decaying, foul beaches and water intakes are due to over-fertilization of water bodies, but the chain of reactions remains only partially understood. In over-fertilized lakes such as Lake Erie, nature is performing an experiment, an experiment one must observe well and learn how to control.

The discharge of very warm water from conventional stream and nuclear power stations into lakes and rivers appears likely to become a significant problem. The Douglas Point nuclear reactor pumps 200,000 gal. per minute into Lake Huron at 20° C warmer than the intake temperature, and this is a very small plant by current planning standards. Potential effects on the receiving waters and their life forms should be a subject of intensive research before the problem becomes a serious one.

Major studies in this field are underway in the Great Lakes Institute, University of Toronto, the Freshwater Institute of Fisheries Research Board, Winnipeg and at the Canada Centre for Inland Waters, Burlington. An increase from $475,000 in 1966-67 to about $1.6 million in 1972-73 is proposed for research in this sub-category.

Sub-Category 504—Waste Treatment Processes

Many smaller municipalities in Canada find the present costs of waste treatment plants a very large burden on the town treasury. Improvement in efficiency of conventional treatment processes or development of new processes to do the old job better and more cheaply, would be of great economic and social value. In addition, many organic and inorganic contaminants resist presently available treatment processes and new techniques must be found to remove these contaminants before the renovated water is returned to lake or stream. Of particular importance is the development of cheaper methods for removing nutrients, such as phosphates and nitrates, which hasten algal growth and eutrophication. Industrial wastes usually require special treatment processes because of their special nature. The development of suitable waste treatment processes should be considered a prerequisite to introduction of new industrial processes which introduce new types of waste. Fortunately for Canadians a great deal of research on waste treatment processes is being undertaken particularly in Europe and the United States. Federal government expenditures in the United States of $13 million in this sub-category are estimated for 1967-68 and these are expected to rise to $21 million in 1970-71. Most of this research is directly applicable in Canada.

Industry has taken a leading role in research in this sub-category in Canada, having invested $576,000 of the $933,000 total expenditures in 1966. Industries and other sectors should be encouraged to increase their efforts in this sub-category, but in view of the possibility of importing the results of research in this field, a modest rate of increase to a total of about $1.7 million in 1972-73 is recommended.

Sub-Category 505—Ultimate Disposal of Wastes

Sewage treatment plants in our large cities are producing huge quantities of solid and liquid wastes which cannot be put back into water courses but must be disposed of in other ways. Methods must be found for ultimate underground disposal that will not permit eventual seepage of contaminants into groundwater bodies or water courses.

While this is an important problem it is not considered to be as pressing as some of the others in the anti-pollution category. Total research expenditures of about $150,000 by 1972-73 were considered to be adequate.

Sub-Category 506—Water Treatment

Water treatment for domestic and industrial use is the other side of the coin of waste treatment. The more efficiently and completely wastes are treated, the less the requirement for water treatment. Water treatment is generally simple and efficient where a good quality resource exists. However, to be realistic, it is unlikely that complete waste water treatment will be achieved in the future and diffuse sources of pollution such as those from agricultural lands will continue to increase. Research on lower cost methods of water treatment with a particular view to removal of exotic contaminants such as pesticides, have a large potential economic benefit since substantial sums are spent each year on water treatment by municipalities and industries.

In this field as well, processes developed elsewhere are readily usable in Canada, but we must expand our research effort to provide the expertise to make optimum use of foreign research and technology. Only $31,000 was spent in this field in Canada in 1966, and it is recommended that a level of effort sufficient to support about five full time research specialists, or about $150,000, be achieved by 1972-73.

Sub-Category 507—Water Quality Control

This is, in a way, the catch-all sub-category for anti-pollution research not covered in the categories 501-506. It includes, especially, research on control of pollution from farm and animal wastes and pesticides, methods of minimizing effects of waste in groundwater supplies, reduction of pollution due to combined storm and sanitary sewer systems (a serious problem in some major Canadian centres such as Toronto), and possible harnessing of biological processes in lakes and reservoirs to "harvest" pollutants or make the effects of pollutants less noxious. Successful innovation in these fields of "non-conventional" techniques for dealing with pollution may save many millions of dollars in conventional treatment plants and help us to cope with those problems that cannot be solved by municipal and industrial treatment plants.

Some of these problems will be solved largely by foreign research and technology, but there are a number that Canada must tackle. A six year total increase of about 100 per cent over the 1966 expenditures of $658,000 is recommended.

Category 600—Economic, Social and Institutional Aspects

In making judgments concerning priorities of water developments and their economic and social impact, Canada has been generally content to rely on the accumulated wisdom of water resources administrators, and has not equipped these administrators with many social science tools to help make the decisions. As the Canadian economy becomes increasingly complex, this approach can no longer be expected to yield decisions in the best interest of taxpayers or corporations. Very little research is underway in Canada on planning, economic, legal, sociological and institutional aspects of water resources development. For this reason, and because of the imperative need to put more precise and subtle tools in the hands of the country's water managers, the Advisory Committee proposed a special study of this field by a team of outstanding experts. The report of this team, headed by Dr. W. R. D. Sewell of the University of Victoria, is published in full following the main body of this report and no extensive discussion is required here. The general recommendations of the Advisory Committee and consultants concerning the level of effort that would be desirable in the field is included for the sake of completeness and to give a perspective on the relative importance attached to this field. It is recommended that research in this main category be increased at about twice the average rate for all categories of water research. This would raise the present (1966) expenditures of $279,000 to about $1.5 million by 1972-73. The consultants recommend that at least $300,000 of this total by 1971-72 be devoted to research in universities.

There might be a tendency to regard this field of research as almost entirely a matter for provincial and federal planning agencies. However, it is important to recognize that fresh insights into legal, institutional and economic matters may in some cases be more easy to achieve in the academic community or by consultants than by research workers within the framework of existing organizations. Special emphasis is recommended on evaluation processes (602), water requirement determinations (604) and institutional aspects (606).

Category 700—Resources Data

The basis of any assessment of water resources, of any water development project and of much analytical research, is a comprehensive basic data collection program. In Canada, an extensive stream gauging and water level observation program has been carried out in a co-ordinated Federal-provincial program for many years. Surface water quality data collection has not been as well developed. For example, only in 1959-60 did any continuing monitoring program begin of the quality, temperature and other factors pertinent to management of that prime resource the Great Lakes. Even this program, undertaken by the Great Lakes Institute, University of Toronto, with support from Federal and provincial governments, is not extensive or comprehensive enough to meet the need, and was augmented in 1966 by monitor surveys conducted by several Federal agencies based at the Canada Centre for Inland Waters, Burlington. The Federal and provincial water quality monitoring programs need considerable strengthening. Groundwater data collection has not been organized as systematically as surface water data, partly because of the less time-variable nature of the groundwater resources. However, some provinces, particularly Alberta and Saskatchewan, have devoted much attention to groundwater surveys and data collection programs. One of the serious deficiences in Canadian data collection programs is in precipitation data. The precipitation networks in Canada are of considerably lower density than in most developed countries; the density corresponds approximately with that of Afghanistan. There are good reasons for this in the tremendous expanse of Canadian lands which are undisturbed by potential precipitation gauge readers, and in the lack of reliable instruments for unattended operation in remote areas. However, this does not help the design engineer or the water resource planner. Data collection on economic aspects of water has been seriously neglected in Canada. Much more comprehensive data are required by water resource planners on water use, flood damages, drought costs, recreational expenditures, etc. A more thorough discussion of Canadian data collection programs and their role in water resource development was given at the Resources for Tomorrow Conference in 1961.[7]

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[7] R. H. Clark, A. K. Watt, and J. P. Bruce, "Basic Data Requirements for Water Management". *Resources for Tomorrow Conference Background Papers* (Ottawa: Queen's Printer), Vol. 1, pp. 191-201.

In this category of research we do *not* include the cost of regular routine data collection, but only the *research* needed to plan intelligently the networks, develop the instrumentation and process and publish the data. Since Canadian government agencies spend well over twice as much money on water data collection as the $8.4 million the country spent on water research in 1966, it is clear that research leading to greater efficiencies in collecting these data, and in extending data networks into regions not easily sampled at present, would be of great value. The Advisory Committee recommended that research in this category, which totalled $427,000 in 1966, be increased somewhat more rapidly than the average rate of increase proposed for water research (20 per cent per annum) to reach an expenditure of about $1.5 million by 1972-73.

Sub-Category 701—Network Design

A leading administrator of streamflow data networks indicated that application of sampling theory and correlation techniques to Canadian streamflow data networks might make it possible to achieve a similar level of useful data availability with reductions of from 10 to 50 per cent in the density of networks in particular regions. If the lower figure was taken to apply to all the country a saving of $1 million to $1.2 million per annum could be achieved. In some areas this might, of course, require establishment of additional, but much less costly, precipitation stations. In 1966 only a small amount of effort was devoted to research on network design, and effectively none to inter-related design of streamflow, precipitation, groundwater and water quality observational programs.

Research in this field is urgent. It has immediate and obvious potential benefit in improving the efficiency of the country's vital basic water data program and should be increased from $43,000 in 1966 to about seven times this amount by 1972-73.

Sub-Category 702—Data Acquisition

Those concerned with data networks in Canada have gone through years of frustration in attempting to adapt instruments developed in the United States or Britain or continental Europe for use in Canada. The lack of suitable instruments which could record, unattended, for long periods of time, water levels, currents, precipitation, evaporation, water quality, etc., under severe climatic stress, has been one of the most serious obstacles to obtaining good assessments of Canada's water resources and their quantitative and qualitative variability in space or time. It is obvious by now that unless Canada develops such instruments to meet its own needs it will continue to be plagued by this problem. Additionally, there are real export possibilities for sensitive, durable instruments for water resources work and if instruments can be designed and built to meet the rigorous requirements imposed by Canadian conditions they will work and can be sold anywhere. This is a field in which Canadian industry should play a major role.

The recommendation is for an expansion of effort by 1972-73 to about five times the 1966 level of $208,000.

Sub-Category 703—Evaluation, Processing and Publication

Data which are left buried in files or musty archives and are difficult for consulting engineers and government agencies to obtain, are hardly worth collecting. A revolution is underway in computer based techniques for quality control, storing, processing, retrieval and publication of all kinds of data. It is essential that the water field participate in and take advantage of the pertinent developments brought about by this revolution, in order to put required water data in the hands of users quickly and efficiently.

Since much research on data handling is going on in other fields of science, and in other countries, it was not considered necessary to propose a major effort in the water aspects. However, it is essential that some research be devoted to adapting techniques developed in other fields and in other countries and to originating techniques to meet particular requirements in water resources. The present level of effort of $176,000 (1966) should be increased slowly to reach a level of $200,000 by 1972-73.

Category 800—Engineering Works

The implementation of a water resources development plan usually requires some structures or engineering works such as dams, channels, culverts, sewers, pumping systems and so on. In Chapter IV, it was pointed out that Canada is now investing at a rate of more than $1 billion per year on water control and conveyance structures, and this total is expected to rise to about $3 billion per annum by the late 1970s. Two main categories of research will contribute to efficient design and operation of these structures. One is hydrology (Category 200) which will help refine the design criteria, i.e. the amount of water, and water and ice forces the structures must be able to store, withstand or convey; the other is Category 800, which will help to increase the efficiency of design and operation of engineering works to meet the hydrologic and other design criteria. The Advisory Committee noted this as a field to which Canada must devote a larger effort. About 8 per cent of the expanded water research program should be devoted to this category, implying an expenditure of $2.0 million by 1972-73 and $6.0 million by 1978-79.

Sub-Category 801—Specifications and Design

Research in this sub-category is mainly in two fields of engineering, hydraulics and structural design. Many special problems in hydraulics arise in Canada because of the need to cope with winter ice. Ice considerations affect or should affect design of channels, water intakes, dam gates, spillways, bridge piers and many other types of structures. Of great importance in development of East and West coast rivers for both hydro-electric and fishing purposes, is the design of fish-passing facilities at dams. Optimum design of riprap protection near spillway crests where wave forces and ice problems both occur, requires further study as do earthquake effects on dams, and a host of other hydraulics and structural problems.

This is a field in which many of the foreign research results can be readily transferred or adapted to Canadian conditions, but one in which a number of problems, particularly those related to ice effects, must be actively studied in this country if useful results are to be obtained. The 1966 investment in research in this field was $404,000 and the effort was about evenly divided between industry, universities and Federal agencies. The Advisory Committee recommended a two and a half times larger effort by 1972-73.

Sub-Category 802—Materials

The temperature ranges to which materials in Canadian water structures are subjected is as great as in any country in the world and very careful selection and development of materials to withstand these and other adverse conditions must be undertaken. While earth, rock and cement will of course remain the main materials in water structures, modifications in materials and material handling which would permit more efficient construction in winter months would be very valuable. Plastics and other new materials might be developed for more extensive use in channels, pipes, valves, gates and structures where light weight, low cost and resistance to corrosion are important. Use of substances such as epoxy resins for repair of concrete should be evaluated. However, research in this field should, in general, be based on greater application of present and future knowledge of the chemical and atomic structural properties of the materials.

In this sub-category it is likely that only a small proportion of the Canadian materials research applicable to water structures was reported in the survey. Agencies and institutions developing and testing new materials primarily for other uses, in buildings, factories, etc., would not be surveyed by the Water Resources Research questionnaires although much of their work may be applicable to water engineering. Nevertheless, the Advisory Committee considered the reported research on materials directed specifically to water structures was very small in view of the importance of the problem and recommended an increase in expenditure from $72,000 to $570,000 by 1972-73. Much of this increased research should be conducted in industrial establishments.

Sub-Category 803—Operations

The operation of the billions of dollars worth of structures built to control water in Canada has been, with rather few exceptions, handled in an even more unsophisticated manner than the economic and social decisions referred to above. Some indications of the economic value of efficient operations was given in Chapter IV where an estimate was quoted of the value of increased hydro-electric production at the Bennett Dam on the

Peace River, B.C. with improvement in inflow forecasting to the reservoir. Each one per cent improvement would result in $1 million annual improvement in operating efficiency. Unfortunately, no comprehensive hydrologic forecasting service has been developed in Canada to provide reliable prediction of river flows and lake levels for operation of such structures across the country. Some provinces have taken the initiative and developed small operational forecasting systems, particularly British Columbia, Saskatchewan and Ontario, but in general Federal-provincial jurisdictional problems have prevented the development of the efficient comprehensive system that many developed nations enjoy, such as U.S.A., U.S.S.R., Australia, Sweden, Poland, etc. The research needed to develop such systems requires major work in the water cycle-general sub-category (201) but the application of river and lake predictions to dam and reservoir operations and the development of suitable communication systems were considered as part of this sub-category. In addition, optimum operation of multi-reservoir systems in river basins is only beginning to be a problem requiring research in Canada. Refinement is needed in methods of predicting sheet ice formation in forebays and frazil ice formation in channels that affect the day to day operation of dams, spillways and water intakes.

The Advisory Committee considered that the $9,000 spent in 1966 in this sub-category indicated that it is hopelessly undersubscribed in Canada. This may be, in part, a reflection of the problem of jurisdiction cited earlier. An increase to $430,000 by 1972-73 was recommended.

Chapter VI

ORGANIZATION OF WATER RESOURCES RESEARCH IN CANADA

In previous chapters appraisals have been given of the current levels of water resources research efforts in Canada and of the potential benefits to be derived from research in this field. In addition, proposals for increasing the overall level of these activities are given in Chapter V, along with an assessment of the ways in which the overall level of research effort should be distributed among the various research categories, to best meet Canada's future needs. The present chapter is concerned with the organization of these research activities, the requirement to train a sufficient number of specialists to carry out the proposed increased level of research in this field, and some ways in which greater benefits of the research can be attained through earlier and more efficient application of research results.

VI.1 Responsibilities for Water Management

The management of Canada's water resources is a shared responsibility between three levels of government, federal, provincial and municipal. The Federal Government has responsibilities for legislation concerning fish and their water environment, for navigation and navigable waters, for international relations concerning boundary waters and international rivers, and, according to the British North America Act, has joint responsibilities with the provinces concerning water for agriculture. In addition, it is generally recognized that the Federal Government should play a major role in undertaking and supporting water research, especially that research which is of a fairly basic nature, and can be applied in many parts of the country.

The provinces have responsibility for management of the resource within their boundaries. While individual municipalities have traditionally provided their own water supplies, water treatment facilities, water-based recreation, storm sewer systems, etc., it is becoming increasingly obvious that development and management of the resource must usually take into account effects of a particular type of management on a region much larger than that within the boundaries of a particular municipality. In some parts of Canada this has resulted in formation of agencies which have representation from a number of municipalities and which are concerned with water resources in a whole river basin or a set of adjoining basins. Perhaps, the most successful agencies of this type have been the Conservation Authorities concerned with river basin flood control and water conservation in Ontario. Even where such developments have taken place they have been sponsored and funded in part by the provinces, and it has been increasingly necessary for the provincial governments to provide major support for municipalities in financing, and in regional planning, including considerations of diversion of waters from basin to basin.

Industry and the private sector of the economy also have important responsibilities in water management. Industries are major users and sometimes major polluters of the country's water resources and in many cases develop their own water supply and water treatment facilities. Canadian industry could be much more active in instrument development for domestic use and export. Consultants, especially the consulting engineering firms, play a major role in designing most structures built to control, convey, purify and treat water and liquid wastes. In only a few cases are the designs made by the government agency or the industry concerned, although, in most cases, sufficient competence is retained in the agency or industry to review and approve the plans intelligently.

Canadian universities and technological institutes are the main source of personnel for both water management and research. While a significant portion of Canada's needs for specialized manpower in this field has been met by immigration from Europe and the United States this latter source of manpower is a very variable one, fluctuating with the relative economic and social advantages of living in the countries concerned. To develop a viable, continuing program of water research and management Canada must become more self-sufficient in producing the specialists required. In addition, the potential for intrinsically valuable water resources research in the universities, generally undertaken as part of the education of graduate students, should be exploited more fully in Canada.

VI.2 Allocation of Effort by Sector

The amounts of research, measured as a percentage of total water research dollars, sponsored by and undertaken by the various sectors of the Canadian economy in 1966, are given in Table 15 and Table 16, along with comparisons of similar levels in the overall research expenditures in the country.

Table 15.—Source of Funds for Research by Sector

<table>
<tr><th></th><th>Fed.</th><th>Prov.</th><th>Univ.</th><th>Indus.</th><th>Foreign</th><th>Other</th></tr>
<tr><td>Percentage of Total Water Research Funding (1966)</td><td>65.4</td><td>17.3</td><td>3.2</td><td>10.1</td><td>1.6</td><td>2.3</td></tr>
<tr><td>Percentage of all R&D Expenditures[a] (1965)</td><td colspan="2">52</td><td>10</td><td>31</td><td>5</td><td>2</td></tr>
</table>

[a] J. L. Orr, "Statistical Data on Industrial Research and Development in Canada", Report of Department o Industry, Ottawa, to Science Council of Canada, March 1967.

Table 16.—Performance of Research by Sector

	Fed.	Prov.	Univ.	Indus.	Other
Percentage of Total Water Research Funding (1966)	44.4	21.0	19.4	14.0	1.1
Percentage of all R&D Expenditures[a] (1965)	36		21	42	1

[a] J. H. Orr, *op. cit.*

The most striking feature of these tables is the fact that in the water research field 83 per cent of the effort is funded by the two senior levels of government and 65 per cent of the research is done by government agencies at federal and provincial levels. This is in striking contrast to R&D efforts in general in which the role of industry in both funding and performing research is very much greater. It is interesting to note that the universities undertake about the same percentage of the research effort in the water field as in the total R&D activities of the country.

In comparing total research and development expenditures for nine developed countries[1] Canada undertakes the highest percentage of the total effort in universities, second highest in government and lowest in industry. However, it must be realized that of the nine countries Canada spends the second lowest percentage of its Gross National Product on research. Internationally there are few comparable figures for water research, except that, as indicated in Chapter III, the federal government in the United States supports about the same percentage of the total water research effort as is the case in Canada, and allocated 24.5 per cent of this support to university research in 1966-67. The federal government in the United States appears to do about the same percentage of water research intramurally as does the Canadian federal government, although lack of good estimates of industrial water research in the United States makes it difficult to give definite figures.

Is there, then, a good reason for the differences in both Canada and the United States, from the average in other fields, in sectoral allocation of research effort in the water resource field? Industrial research and development is directed towards production of a new product or service, or towards improvement of an existing one and it is industry that must exploit the usable results. In order then to develop expertise and new knowledge which can be put to use quickly and efficiently, it is highly desirable that industry undertake a large share of the general research effort. Even in other natural resources fields, such as forestry, agriculture and mining, it is usually the private sector which must put into use the results of research in order to achieve more efficient production.

[1] J. L. Orr, *op. cit.* The countries are Belgium, Canada, France, Germany, Japan, Netherlands, Sweden, United Kingdom and United States.

Water resources development is a very different matter. Nearly all of the structures built to control, convey and treat water are built by governments or their agencies. Even hydro-electric developments are mostly undertaken by provincial power agencies. Management decisions concerning alternative uses of water and allocation of limited resources are also made by governments. International negotiations over shared water resources are conducted by our governments. In effect, governments play the usual role of industry in using research results to optimize the management of water resources. It is not surprising then, that most of the research efforts in this field are financed by governments and that the Federal and provincial governments undertake about two thirds of the total research "in-house".

The Study Group's Advisory Committee dealt with this matter at considerable length. A number of factors which should influence the allocation of resources for water research were discussed by the Committee. Among the most important factors were the following:

1. The need to support an adequate level of research in the universities in order to encourage professors and students from many disciplines to devote their attentions to the field of water resources and thus develop trained manpower.
2. The need to provide opportunities for employment of research minded graduates in water resources research agencies in government and industry, i.e. to create a sizable market for graduates with specialization in water resources fields.
3. The responsibility of industry to expand its efforts in water resources research particularly in the field of industrial waste water treatment (504 to 506), in conservation of water in industry (305), in data acquisition and instrumentation (702), and in structural materials (802).
4. The importance of ensuring a high level of competence among private consulting engineering firms to ensure optimum design of water facilities and more rapid transfer of research results from the laboratory to the drawing board.
5. The responsibility of governments, as the collective agents of the people, to undertake and sponsor the research needed to ensure optimum management of the resource and to protect Canadian interests in international negotiations on shared resources or possible inter-basin or inter-country diversions.
6. The importance of having a number of research institutes, both governmental and in universities, large enough to be truly interdisciplinary and above the "critical size" needed for interplay of ideas and adequate support facilities.

The Committee, while recognizing the above needs and responsibilities, as well as other less important considerations, found it difficult to quantify objectively the level of activity that should be undertaken in the various sectors and funded by various sources. However, their collective views on this matter were as follows:

1. There appears to be no serious imbalance on the general allocation of effort to the various sectors.
2. The level of effort in universities was proportionately slightly low. Additional support to increase the universities share of research from 19.4 per cent to 22-25 per cent should come from both Federal and provincial governments, and from industry.
3. Industry should increase somewhat its contribution to the overall level of research in this field, and especially consulting engineering and planning firms should be financially encouraged to undertake research projects.
4. The provinces, who have a major responsibility for water management, should maintain their current proportional level of in-house research and should finance more applied research at universities.
5. The net effect of the above recommendations would mean a small decrease in the proportion of the total research effort undertaken internally by the Federal agencies.

It should be noted, of course, that if the overall level of research effort in this field is increased at 20 per cent per annum, as recommended in Chapter V, there would be no reduction of effort in any segment. The above recommendations simply imply a slightly higher rate of increase in research in universities and in the private sector and a slightly lower rate of increase in Federal Government intra-mural research.

There are, however, some more specific recommendations concerning the nature of funding of university research which arose out of the Committee's discussions, and they are dealt with in the next section.

VI.3 Manpower Requirements and Support of Universities

One of the main reasons for the recommendation in Section VI.2 of a greater rate of increase than the overall rate of 20 per cent per annum for water resources research in the universities is the need for professional manpower to undertake the research programs. Projections of total engineering and science graduates,[2] and an estimate of 14 per cent as the present percentage of such graduates engaged in research suggest that the total numbers of graduates at Doctors, Masters and Bachelors levels likely to be available in the future will be sufficient to support a very much greater overall research effort than Canada now undertakes. If it is assumed that only 17 per cent of the new science and engineering graduates of the next decade go into research (present comparable figure in U.S. exceeds 30 per cent), and that immigration of research workers balances emigration (there

[2] R. D. Mitchener, "First degrees awarded by Canadian Universities and Colleges projected to 1976/77", Canadian Universities Foundation, Ottawa, 1964.

has in reality been a large net gain to Canada in the past few years) then the total number engaged in R&D in science and engineering by 1977 will be equivalent to about 45,000 professional man-years.

Thus, it seems reasonable to assume that enough scientists and engineers will be available, and the problem is how best to ensure that a sufficient number of these direct their efforts to water research. From the data of Chapter III it is evident that 351.6 professional man-years were devoted to water resources research in 1966 and that expenditures averaged $24,000 per scientist, somewhat lower than average for all types of science. Proposed expenditures suggest the need for 930 professional man-years in the year 1972-73 and about 2,500 man-years by 1978. The results of the Reporting Unit Questionnaire showed that researchers in the water resources field represented no less than 116 specialties as defined by the Major Fields and Specialties List of the Department of Manpower and Immigration. This reflects the extent to which water resources research is a multi-disciplinary field of endeavour. The individual specialties of greatest demand, according to the results of the Reporting Unit Questionnaire, will be in the engineering field for hydrology, sanitary engineering and fluid mechanics and in the physical sciences for geohydrology, although these four specialties, added together, constitute considerably less than half the total demand for new manpower.

However, perhaps the greatest need, as suggested in the brief discussion of the quality of present research in Canada (pp. 38-39) is for more people to be trained at graduate schools in water resources specialties, rather than continuing to rely on in-service and self training of engineers, physicists, chemists, etc. Water resources development and management approached from the viewpoint of a single discipline is fraught with very real dangers. The history of water resource development is replete with examples of fish kills and ecological disturbances due to water pollution and construction of engineering works. On the other hand, by considering conservation a goal in itself, valuable opportunities for economic development and gain may be lost. The important point here is that development of water resources results from and will cause a chain of interacting phenomena. These phenomena may be of a social, biological, chemical, economic, and other nature, and nothing less than a full understanding of the inputs and effects will result in optimum development and management of Canada's water resource. To achieve this will require development of several inter-disciplinary major centres for research and graduate training. However, while such centres are of great importance, it is also essential to continue to support good work wherever it is found in universities outside such centres.

With these concepts in mind, a three-level system of financial support for university research should be carried out. First of all, support of "little science" in water research should continue to expand through grants-in-aid programs designed primarily to support excellent research scientists and engineers interested in water without undue consideration given to the nature of the research project. Secondly, the National Advisory Committee on Water Resources Research should, through its sponsored research program, provide development grants for several water research centres. These might include building grants, if required. Funding for building grants should, however, be additional to the proposed amounts indicated in Chapter V. This Committee should also support research programs of university scientists outside of such centres where the object of the research will be to provide knowledge required in the management of Canada's waters. The selection of the major water research centres should be based on proposals made by the universities. The universities whose proposals appear to offer the greatest hope of truly interdisciplinary work and of a continuing program, should be supported. While the centres should be inter-disciplinary, at least one should emphasize planning and social sciences aspects, one should focus most attention on the water cycle, one should emphasize pollution research, one should concentrate mainly on engineering hydraulics and instrument development and one on cold climate water research. These centres should preferably be regionally distributed, but this requirement should not interfere with insistence on the highest quality.

The third type of financial support should be in the form of purchased research. Some universities are reluctant to become involved in purchased or contract research programs because they are presumed to inhibit academic freedom. However, an increasing number of professors recognize the important contribution that they and their students can make by agreeing to a certain amount of direction, and are prepared to enter into contract arrangements. Federal agencies, provincial governments and industry should allocate larger proportions of their budgets to purchase research from universities to help solve those problems requiring solution, to fulfill the objectives of the agency or need of the industries.

Finally, it is extremely important that the mission oriented agencies which have recently established major institutes on or close to university campuses develop active programs of co-operation with the university community in the area. This should extend to making available laboratory and other facilities to professors and students, purchase of research from universities, assistance as needed on graduate student committees, provision of special lecturers to the universities as required, and co-operation in other ways which can best be worked out by co-ordinating or advisory committees for such institutes. Of particular importance in this connection at the present time are the Canada Center for Inland Waters at Burlington, Ontario, co-ordinated by the Department of Energy, Mines and Resources, and Fisheries Research Board's Freshwater Institute on the campus of the University of Manitoba.

It should be noted that this multi-level support system outlined above offers several possibilities to the university research worker to obtain support

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for his research. The National Advisory Committee on Water Resources Research should co-ordinate matters to ensure that there is no inadvertent duplication. At the same time, this does offer alternative potential sources of support to the research worker whose project or whose personal views are somewhat heretical to one group or another. It also caters to the personal diversity of research people, some of whom are strongly subject-oriented and practical-minded, and some of whom prefer more basic research pursuits.

VI.4 Co-ordination of Efforts

In Chapter III an outline is given of the co-ordinating machinery which has developed in Canada in the past ten years. In the light of the preceding recommendations in Chapters V and VI it is well to examine this machinery to ensure that it will meet Canadian needs for the next few years. It should be noted that the formation and, less commonly, the dissolution of committees and task forces goes on continually in response to changing emphasis and perceived needs. It is wise then to limit the remarks here to the needs foreseen over the next few years.

It appears that the leading co-ordination machinery for water research *policy* will be the newly formed National Advisory Committee on Water Resources Research and its three sub-committees on Grants in Aid of Research in the Natural Sciences, the Social Sciences and that Advisory to the Canada Centre for Inland Waters, Burlington. This Committee and its sub-committees are expected to have representation from Federal agencies, provinces, universities and the private sector and should prove an effective vehicle for policy direction.

There remains a need, however, for liaison and co-ordination at the technical level, as well, with a view to ensuring continued working level co-ordination and to providing a forum for informed discussion of the technical impact of policy decisions—in a sense a counter-balance of the policy committee. There has been a tendency in some quarters to consider that these technical committees may no longer be needed because of the formation of the National Advisory Committee. Indeed, the structure and function of the NRC Associate Committee on Water Pollution Research was being reconsidered in late 1967 in the light of the formation of the National Advisory Committee. It should be noted that the National Advisory Committee and its sub-committees can because of their broad representation contain only a few pollution specialists or specialists in any other single aspect of the overall water research field. It is most important to retain specialist technical committees to sponsor meetings and conferences, to publish bibliographies and to assess the development of research in the specialist fields and the effects of policy decisions on these research activities. Other committees which should continue to serve in this technical co-ordination role are the NRC Sub-committee on Hydrology and the Great Lakes Working Group of the Canadian Committee on Oceanography. To facilitate proper liaison, it would be fruitful to have some overlapping membership between the specialist committees and the National Advisory Committee on Water Resources Research.

VI.5 Publication of Research Results

One of the most important means of disseminating research results in any field and of guarding against unnecessary duplication, is to have suitable scientific journals in which to publish important research findings without delay. While there are several international journals in the water resources field in which Canadians regularly publish, there is no corresponding Canadian journal. Some papers, particularly those on groundwater, are published in the *Canadian Journal of Earth Sciences* while others with biological implications appear in the *Journal of the Fisheries Research Board*. However, no really suitable Canadian publication exists for most papers on hydrology, on aspects of pollution problems especially pertinent to Canada and for research papers on social, economic and institutional aspects of Canadian water problems. However, should research activities in water expand as recommended it will be important to ensure availability of new publication facilities or opportunities, particularly for reporting on research peculiar to the Canadian situation. The newly formed National Advisory Committee on Water Resources Research is therefore urged to explore actively the possibility of establishing a Canadian journal in the field of water resources research.

VI.6 Information Exchange

It is proposed that Canada rely heavily on imported research results in many categories of water resources research. In fact, all aspects of water research will be more productive if Canada takes full advantage of studies done outside the country.

There are a number of governmental and non-governmental international agencies and organizations in which Canadians participate and exchange research ideas and results. Canadians have been especially active in the intergovernmental international organizations concerned with various aspects of water research, especially the Technical Commission for Hydrometeorology of the World Meteorological Organization (WMO), the UNESCO planning meetings and Co-ordinating Council for the International Hydrologic Decade (1965-1974), the International Atomic Energy Agency, the Food and Agricultural Organization (FAO), the World Health Organization (WHO), the Organization for Economic Co-operation and Development (OECD) and the International Commission on Irrigation and Drainage.

Some Canadians have been active participants also in the non-governmental international associations in the water field. These associations include the International Association of Scientific Hydrology of the International Union of Geodesy and Geophysics, the International Association of Hydrogeologists, the International Association on Water Pollution Research, the International Society of Limnology, the International Association of Hydraulic Research, the International Commission on Large Dams, and possibly several others. If Canada is to take maximum advantage of water research done outside its borders it must encourage and strengthen Canadian participation in activities of such associations. More involvement of provincial water agency staff in activities of the non-governmental international associations would likely pay substantial dividends in terms of direct application of the results of foreign research to Canadian water management.

Furthermore, Canada is in a unique position readily to take maximum advantage of the best work in the field of water research and technology in both the English and French-speaking worlds. Any type of information exchange system developed in Canada, such as that suggested here, should take advantage of world developments in both of Canada's official languages and should provide services to both English and French-speaking scientists, engineers and administrators.

A considerable amount of exchange of research results and information can take place through the various national and international journals, and through the conferences and meetings of international agencies and associations. However, in addition, more formal and organized information exchange systems are needed, especially by new researchers in the field and by managers and administrators seeking access to research results applicable to their problems.

With the current expansion of water research in the United States, several new systems for exchange of information have been developed to meet these needs. One is the Science Information Exchange (S.I.E.), sponsored by the Smithsonian Institution, which stores, by computer, data on all U.S. federally-sponsored research projects and on any others on which it can obtain information, in water and in many other fields. For water resources research, S.I.E. publishes an annual catalogue of research projects underway, and will provide a list of projects and their originators, on any special subject, to scientists who contribute their project outlines to the S.I.E. files. A number of Canadian water scientists contribute to and make use of this system on an informal basis. The American Water Resources Association recently announced an abstracting service whereby an individual researcher or an agency can purchase abstracts of all papers published during the year in any one or more of the sub-categories of research listed in our questionnaire (Appendix II).

The most comprehensive system is being developed in the Water Resources Scientific Information Centre (WRSIC) in the U.S. Department of the Interior. The objectives of WRSIC are:[3]

1. To serve as a focal point for national water resource technical information activities.

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[3] National Science Foundation, *Scientific Information Notes*, Vol. 9, No. 6, Dec. 1967-Jan. 1968.

2. To initiate efforts to co-ordinate and complement existing technical information services.
3. To provide central operation of such water resource technical information services as can be best accomplished on a nationwide level.
4. To insure the rapid flow of technical information to interested individuals and agencies.

To the authors' knowledge there are no similar comprehensive systems in other countries of the world.

It is recommended that the National Advisory Committee on Water Resources Research take appropriate action with a view to establishing a Canadian office as a counterpart of WRSIC. Such an office should initiate discussions with WRSIC to investigate whether the Canadian office could develop some sort of co-operative program with the U.S. Water Resources Scientific Information Centre. This would permit Canadian scientists and administrators access not only to information and research results on Canadian water science, but to those of WRSIC as well. At the same time Canadian representatives to all pertinent international agencies should encourage development of an international information exchange system on technical knowledge in water resources.

VI.7 Application of Research Results

In an applied research field, such as water resources research, one must be concerned with information transfer. In the questionnaire survey, respondents were asked whether research results in those aspects of water resources with which they were most familiar were being applied quickly and efficiently. Many respondents replied in the negative and gave a variety of reasons why this might be so. Several methods of ensuring wider dissemination and use of research results were discussed in the previous section.

A further reason for lack of application of research results concerns the design of structures to control, convey and treat water. As indicated earlier in this chapter, much of this initial design work for industries, municipalities and higher levels of government is done by private consulting firms, mostly consulting engineers. A few of these firms are large enough to sponsor their own research programs to enable some of their staff to keep up to date on recent technological developments applicable to their project designs. However, most Canadian projects are designed by a multitude of small firms which cannot afford to support their own research programs and hence suffer the effects of long time lags before useful research results find their way into project designs.

To help reduce this time lag and ensure that useful research results are applied extensively, each major Canadian consulting firm in the water field should be urged to devote some efforts to research. It is therefore recommended that consulting firms be eligible for grants-in-aid and contract-research support from government agencies, both federal and provincial, and be encouraged to submit projects for support by government agencies having water missions.

VI.8 Further Studies of Water Resources Research in Canada

The present study should be thought of not as a conclusion to reviews of Canadian research in this field but as the initiation of a continuing review, to ensure that applied water research continues to meet the country's needs. No doubt much of this continuing review will fall to the new National Advisory Committee on Water Resources Research and its sub-committees. However, the members of these committees will be research workers and water administrators who cannot always afford the time for full-scale assessments of where Canada stands and where it should be going in the field of water resources research.

For these reasons, it is recommended that a further full scale review of water resources research in Canada be undertaken by the Science Council no later than 1972. Some of the questions that should be considered at that time include the following:

1. How well has the development of water resources research kept pace with the proposals of the present report?
2. Has the economic development of Canada proceeded about as predicted by the Economic Council of Canada to permit the apportionment of research by sub-category to continue as proposed in the present report, or has the development been such that more effort proportionately should be expended in some fields, such as pollution and water conservation, and less in the water cycle?
3. Has the proposed sectoral apportionment between universities, governments and the private sector taken place? Is this apportionment providing a vigorous and productive research program, and a balance between production of new qualified manpower and suitable employment opportunities for this manpower?
4. How well have the various types of research institutes developed? A review of the progress of several types of organizations should include: (a) the off-campus government institutes with university and private sector participation, such as the Canada Centre for Inland Waters, Burlington; (b) on-campus government institutes, such as the Freshwater Institute (FRB) at the University of Manitoba; and (c) inter-disciplinary university institutes, such as those proposed in Section VI.3. Such a review would help to provide guidance concerning the most effective ways to organize major research centres in the water field. These should be reviewed from several points of view, including the value of the research output to the country and the contribution of the centres to production of new manpower in water resources.

Appendices

Appendix I

MEMBERS OF THE SCIENCE SECRETARIAT ADVISORY COMMITTEE ON WATER RESOURCES RESEARCH

Atkinson, H. J.	Research Branch, Department of Agriculture, Ottawa.
Ayers, H. D.	Department of Agricultural Engineering, University of Guelph, Guelph, Ontario.
Bailey, R. E.	Alberta Department of Agriculture, Edmonton, Alberta.
Barber, C. E.	Department of Economics, University of Manitoba, Winnipeg, Manitoba.
Brown, I. C.	Canadian National Committee for the International Hydrologic Decade, Ottawa.
Bruce, J. P.* (*Chairman*)	Inland Waters Branch, Department of Energy, Mines and Resources, Burlington, Ontario.
Cavadias, G. S.	Graduate School of Business, McGill University, Montreal, Quebec.
de Laet, C. H.	Canadian Council of Resource Ministers, Montreal, Quebec.
Durrant, E. F.	Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa.
Fisher, C. P.	Public Health Engineering Division, Department of Health and Welfare, Ottawa.
Fletcher, H. F.	Policy and Planning Branch, Department of Energy, Mines and Resources, Ottawa.
Fulton, J. F.	Canadian National Committee for the International Hydrologic Decade, Ottawa.
Gibbons, N. E.	Division of Biosciences, National Research Council, Ottawa.
Harris, A. J.	Ontario Water Resources Commission, Toronto, Ontario.
Jeffrey, W. W.	Faculty of Forestry, University of British Columbia, Vancouver, B.C.
Logie, R. R.	Department of Fisheries, Ottawa.

*At the beginning of the Study, Mr. Bruce was with the Meteorological Branch, Canada Department of Transport.

McIntyre, R. R.	Department of Forestry and Rural Development, Amherst, Nova Scotia.
MacNeill, J. W.	Policy and Planning Branch, Department of Energy, Mines and Resources, Ottawa.
Prince, A. T.	Inland Waters Branch, Department of Energy, Mines and and Resources, Ottawa.
Raudsepp, V.	Water Investigations Branch, Department of Lands, Forests and Water Resources, Victoria, B.C.
Sewell, W. R. D.	Department of Geography, University of Victoria, B.C.
Slivitzky, M.	Department of Natural Resources of Quebec, Quebec.
Tully, J. P.	Fisheries Research Board, Ottawa. (Also Secretary of Canadian Committee on Water Pollution and Secretary of Canadian Committee on Oceanography).

Appendix II

PRIVY COUNCIL OFFICE — BUREAU DU CONSEIL PRIVÉ

SCIENCE SECRETARIAT — CANADA — SECRÉTARIAT DES SCIENCES

WATER RESOURCES RESEARCH
JUNE 1967

Dear Sir:

It has become obvious in the past decade that Canada's water resource is one of our most valuable assets; perhaps, in the long run, our single most valuable physical resource. Wise development and management of this vital resource require the kind of knowledge that a balanced research program will produce. However, to date, our knowledge of the overall scope and nature of the Canadian effort in water resources research is fragmentary. For example we cannot, at present, make a good estimate of total expenditures in water resources research in Canada, to permit comparison of the level of research effort with that in other fields, and with the level of research effort needed for intelligent development and management of the resource. This lack of comprehensive information on water resources research activities is a matter of concern at the several levels of government, in universities and in the private sector.

In recognition of this situation, two federal-provincial committees concerned with water resources have endorsed a survey being undertaken by the Science Secretariat. These committees, the Canadian Council of Resource Ministers and the Canadian National Committee for the International Hydrologic Decade, have also provided lists of individuals, institutions and agencies from whom information is being requested.

The Science Secretariat has developed two questionnaires with the advice and assistance of a 22 man advisory group. A list of members of the group is enclosed.

These questionnaires are named Project and Reporting Unit forms. The Project questionnaire is used to collect information describing individual research projects. Ideally, the scientist leading a particular project will supply the information describing it. The Reporting Unit questionnaire is used to collect overall cost and manpower information from a unit, section or division, typically from the manager of cost centre. In general, the Reporting Unit questionnaire will give overall data concerning several projects.

Both forms have as common content a list of Water Resources research categories (see page 2) and additional questions "Assessment of Research Needs" (see page 4).

If your institution or agency does not conduct water resources research, but is a user of the results of such research, please complete only the Assessment of Research Needs section (and your identification, question 1, page 3).

The answers to the survey will be reviewed, tabulated by computer, and analyzed by the Science Secretariat. The tabulations and analyses will be reviewed by the same advisory group that assisted in drafting the questionnaire. Recommendations arising from the analyses and review will be published in a report, along with summary tabulations of the questionnaire replies. This report will be made available to all respondents to the questionnaire.

The development of research policies in the water resources field will be influenced by the replies to the survey. Your assistance in making this inventory as complete as possible is greatly appreciated.

After completion of pages 3 and 4, please return these to the Science Secretariat in the enclosed envelope. For your response to be taken fully into account in the survey, completed questionnaires should be returned before July 17th, 1967.

Yours sincerely,

F. W. FORWARD,
Director,
Science Secretariat.

Si vous le désirez, un questionnaire français vous sera envoyé sur demande.

WATER RESOURCES RESEARCH CATEGORIES

100. NATURE OF WATER
Category 100 deals with fundamental research on the water substance.

101. Properties of water — Study of the physical and chemical properties of water, including its thermodynamic behavior in its various states.

102. Aqueous solutions and suspensions — Study of the effects of various solutes on the properties of water; surface interactions; colloidal suspensions.

200. WATER CYCLE
Category 200 covers research on the natural processes involving water. It is an essential supporting effort to applied problems in later categories.

201. General. Including: studies involving two or more phases of the water cycle such as hydrologic models; rainfall-runoff relations; surface and ground-water relationships; watershed studies; geomorphology.

202. Precipitation. Including: investigation of spatial and temporal variations of precipitation; physiographic effects; time trends; extremes; probable maximum precipitation; structure of storms; quantitative precipitation forecasting.

203. Snow and ice. Including: studies of the occurrence and thermodynamics of water in the solid state in nature; spatial variations of snow and frost; formation of ice; break-up of river and lake ice; glaciers; ice forces; permafrost and its effects on groundwater and the water cycle.

204. Evaporation and transpiration. Including: investigation of the process of evaporation from lakes, soil, and snow and of the transpiration process in plants; methods of estimating actual evapotranspiration; energy balance.

205. Streamflow. Including: mechanics of flow in streams; flood routing; bank storage; space and time variations (includes high and low-flow frequency); droughts; floods.

206. Groundwater. Including: study of the mechanics of groundwater movements; multiphase systems; sources of natural rechange; mechanics of flow to wells and drains; subsidence; properties of aquifers; saline water intrusion in coastal aquifers.

207. Water in soils. Including: infiltration; movement and storage of water in the zone of aeration, including soil.

208. Lakes. Including: hydrologic, hydrochemical, and thermal regimes of lakes; water level fluctuations; currents and waves.

209. Water and plants. Including: role of plants in hydrologic cycle; water requirements of plants; interception of precipitation.

210. Erosion and sedimentation. Including: studies of the erosion process; prediction of sediment yield; sedimentation in lakes and reservoirs; stream erosion; sediment transport; river-bed evaluation.

211. Chemical processes. Including: chemical interactions between water and its natural environment; chemistry of precipitation.

212. Estuarine problems. Including: special problems of the estuarine environment; effect of tides on flow and stage; deposition of sediments; sea water intrusion in estuaries.

300. WATER SUPPLY AUGMENTATION AND CONSERVATION
As water use increases we must pay increasing attention to methods for augmenting and conserving available supplies. Research in Category 300 is largely applied research devoted to this problem area.

301. Saline water conversion — Research and development related to methods of desalting sea water and brackish water.

302. Water yield improvement — Increasing streamflow or improving its distribution through land management; water harvesting from impervious areas; phreatophyte control; reservoir evaporation suppression.

303. Use of water of impaired quality — Research on methods of agricultural use of water of high salinity; use of poor quality water in industry; crop tolerance to salinity.

304. Conservation in domestic use — Methods for reducing domestic water needs without impairment of service.

305. Conservation in industry — Reduction in both consumption and diversion requirements for industry.

306. Conservation in agriculture — More efficient irrigation practices. Chemical control of evaporation and transpiration; lower water use plants; optimum use of soil moisture; etc.

307. Weather Modification — artificial stimulation of precipitation; climate modification by changes in land and water surfaces; etc.

400. WATER QUANTITY MANAGEMENT AND CONTROL
Category 400 includes research directed to the management of water, exclusive of conservation, and the effects of related activities on water.

401. Control of water on the land — Effects of land management on runoff; land drainage; potholes; etc.

402. Groundwater management — Artificial recharge; conjunctive operation; relation to irrigation.

403. Effects of man's related activities on water — Impact of urbanization, highways, logging, etc., on water yields and flow rates.

500. WATER QUALITY MANAGEMENT AND PROTECTION
An increasing population increases the wastes and other pollutants entering our water supplies. Category 500 deals with methods of identifying, describing and controlling this pollution.

501. Identification of pollutants — Techniques of identification of physical, chemical and biologic pollutants; rational measures of character and strength of wastes.

502. Sources and fate of pollution — Determination of the sources of pollutants in water; the nature of the pollution from various sources; path of pollutant from source to stream or groundwater; prediction of pollution concentrations including prediction by means of mathematical models; effects of ice cover on dissolved oxygen and other pollutants in streams and lakes; etc.

503. Effects of pollution — Definition of the effect of pollutants, singly and in combination, on man, aquatic life, agriculture and industry under conditions of sustained use; eutrophication; influence of prolonged ice-cover on effects of pollutants; etc.

504. Waste treatment processes — Research to improve conventional treatment methods to gain efficiency or reduce cost; processes to treat new types of waste; advanced treatment methods for more complete removal of pollutants including purification for direct reuse.

505. Ultimate disposal of wastes — Disposal of residual material removed from water and sewage during the treatment process; disposal of waste brines; underground waste disposal.

506. Water treatment — Development of more efficient and economical methods of making water suitable for domestic or industrial use.

507. Water quality control — Research on methods to control stream and reservoir water quality such as flow augmentation; stream and reservoir aeration; control of natural pollution; control of pollution from pesticides and agricultural chemicals; control of acid mine drainage; control of erosion and sedimentation; etc.

600. ECONOMIC, SOCIAL AND INSTITUTIONAL ASPECTS
The problems of achieving an optimal plan of water development are becoming increasingly complex. Category 600 covers research devoted to determining the best way to plan, the appropriate criteria for planning and the nature of the economic legal and institutional aspects of the planning process.

601. Planning — Application of systems analysis to project planning; treatment of uncertainty; probability studies; non-structural alternatives.

602. Evaluation process — Development of methods, concepts and criteria for evaluating project benefits; discount rate; project life; methods for economic, social and technological projections; reliability of projections; research on the value of water in various uses; etc.

603. Cost allocation, cost sharing, pricing/repayment — Research on methods of calculating repayment and establishing prices for vendible products; techniques of cost allocation, cost sharing; pricing and repayment policy.

604. Water requirements — Research on the water quantity and quality requirements of various uses.

605. Water law — Studies of provincial and federal water law looking to changes and additions which will encourage greater efficiency in water use.

606. Institutional aspects — Investigation of institutional structures and constraints which influence decision on water at all levels of government; case studies; jurisdictional problems.

607. Sociological and psychological aspects — Attitudes to use of water; perception of responsibilities.

608. Ecologic impact of water development — Effects of water management operations on overall ecology, including human ecology, of the area. Excludes effect of pollution under 503.

700. RESOURCES DATA
Planning and management of our water resources require information. Category 700 includes research oriented to data needs and the most efficient methods of meeting these needs. Basic data collection in itself is not here considered research, but studies of ways to improve data collection are included.

701. Network design — Studies of data requirements and of the most effective methods of collecting the data.

702. Data acquisition — Research on new and improved instruments and techniques for collection of water resources data, including data on water use and water and erosion damage; telemetering equipment.

703. Evaluation, processing and publication — Studies of effective methods of processing data; form and nature of published data; maps of data.

800. ENGINEERING WORKS
To implement water development plans requires engineering works. Category 800 describes research on design, materials and construction which is specifically useful to water management. Works relevant to a single specific goal, such as water treatment or desalination, are included elsewhere if an appropriate category exists.

801. Specifications and Design — Studies of functional requirements of water structures: research leading to improved design of dams, canals, pipelines, locks, fishways and other works required for water resource development.

802. Materials — Research to improve existing structural materials and to develop new materials for use in water control and conveyance structures.

803. Operations — Research on efficient operating procedures, and maintenance procedures for water control systems.

SURVEY OF WATER RESOURCES RESEARCH IN CANADA

REPORTING UNIT QUESTIONNAIRE

This return is to be completed by the manager responsible for a unit, section or division which is considered as a "cost centre" for budgeting purposes. Such a unit characteristically has several research projects active at one time, although sometimes may be devoting its efforts to a single project. (This return is complementary to the PROJECT return on which information on each individual project is requested.)
Opposite, on Page 2, will be found the code list of Water Research categories and sub-categories. Copies of the Department of Manpower and Immigration (D.M.I.) code list of disciplines are also being supplied.

FOR OFFICE USE
.... 1
.... 7

1. **Institution or Agency**.. Address..
....

Include name and address of reporting unit, section or division.

2. **Reporting Year**
Note: The reporting period should be one year in length, either calendar year 1966, or where more convenient, the closest fiscal year (e.g., for federal agencies FY 1966–67).

From .... Month .... Year
To .... Month .... Year

3. **Research Expenditures**, by Water Resource Research sub-category for each year, 1965 to 1969.

Group actual or forecast project costs according to sub-categories (page 2).
For 1965 and 1966 enter also number of projects. If more than four sub-categories are reported, please use additional sheets.

If reasonable estimates of "overhead" costs for space, power, senior administration etc. are readily available, include these in operating costs: Insert H after the entry if overhead charges are included.

Exclude capital depreciation costs capital consumption allowances.

See page 2 for research sub-categories.

Water resource research sub-category Code # ________

Year	1965 [10]	1966	1967	1968	1969
Number of Projects	____ 13	____ 15	×	×	×
Expenditures in thousands $					
Operating	____ 17	____ 20	____ 23	____ 26	____ 29
Capital	____ 32	____ 35	____ 38	____ 41	____ 44
Total	____	____	____	____	____

Water resource research sub-category Code # ________

Year	1965 [48]	1966	1967	1968	1969
Number of Projects	____ 50	____ 52	×	×	×
Expenditures in thousands $					
Operating	____ 54	____ 57	____ 60	____ 63	____ 66
Capital	____ 69	____ 72	____ 75	____ 78	____ 1
Total	____	____	____	____	____

Water resource research sub-category Code # ________

Year	1965	1966	1967	1968	1969
Number of Projects	____	____	×	×	×
Expenditures in thousands $					
Operating	____	____	____	____	____
Capital	____	____	____	____	____
Total	____	____	____	____	____

Water resource research sub-category Code # ________

Year	1965	1966	1967	1968	1969
Number of Projects	____	____	×	×	×
Expenditures in thousands $					
Operating	____	____	____	____	____
Capital	____	____	____	____	____
Total	____	____	____	____	____

4. **Sources of funds 1966**
Enter percentage values (based on 1966 operating & capital = 100)

Canadian: Federal ________ 4 Provincial ________ 6 University ________ 8 Industry ________ 10
Other Canadian ________ 12 (SPECIFY...) Foreign ________ 14

5. **Professional effort**; for reporting period.
For each relevant sub category of research, list the related number(s) of Specialty (Dept. of Manpower and Immigration code) and enter professional effort 1966, by highest earned degree, in man years

If additional space is required, please use additional sheet.

1966: Professional man years (nearest 1)

	Sub-category Code Number (See Page 2)	Specialty Code Number (Use D.M.I. List B)	Doctor	Master	Bachelor
16	____	19 ____	23 ____	26 ____	29 ____
32	____	35 ____	39 ____	42 ____	45 ____
48	____	51 ____	55 ____	58 ____	61 ____
64	____	67 ____	71 ____	74 ____	77 ____
	____	____	____	____	____
	____	____	____	____	____
	____	____	____	____	____
	____	____	____	____	____
	____	____	____	____	____
	____	____	____	____	____
	____	____	____	____	____
	____	____	____	____	____

6. **Additions to professional staff 1967–89**
Enter by Specialty number the annual additions to required professional staff, by highest earned degree.

If additional space is required, please use additional sheet.

1967–8–9: **Additions** to Professional Staff

Specialty Code Number (D.M.I. List B)	Doctor 1967	Doctor 1968	Doctor 1969	Master 1967	Master 1968	Master 1969	Bachelor 1967	Bachelor 1968	Bachelor 1969
01 ____	5 ____	7 ____	9 ____	11 ____	13 ____	15 ____	17 ____	19 ____	21 ____
23 ____	27 ____	29 ____	31 ____	33 ____	35 ____	37 ____	39 ____	41 ____	43 ____
45 ____	49 ____	51 ____	53 ____	55 ____	57 ____	59 ____	61 ____	63 ____	65 ____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____

7. Technician effort in man years
By field of training
For 1966, enter actual values
For 1967–8–9, forecast the required annual addition

Name of Field or Trade	1966	Man years (nearest unit) 1967	1968	1969
67	68	70	72	74
76	77	79	01	3
5	6	8	10	12
14	16	17	19	21

8. In cases where research effort was limited in 1966, to which of the listed factors was this due? (Enter 1 opposite the most serious limitation, 2 for the next most serious etc.).

(1) shortage of professional personnel ☐

(2) shortage of technicians ☐

(3) shortage of funds ☐

(4) inadequate space ☐

(5) inadequate equipment ☐

(6) other (specify)................ ☐ 23

9. Nature of projects planned to begin in 1967:

9.1 Title and/or one-line description..
.... Sub-category of research code number................ 25

9.2 Title and/or one-line description..
.... Sub-category of research code number................ 28

9.3 Title and/or one-line description..
.... Sub-category of research code number................ 31

9.4 Title and/or one-line description..
.... Sub-category of research code number................ 34

9.5 Title and/or one-line description..
.... Sub-category of research code number................ 37

(code from page 2)

ASSESSMENT OF RESEARCH NEEDS

(Please add sheets if space below is insufficient)

1. If manpower and other limitations could be removed, what research projects in addition to those completed, underway or definitely planned, are needed to fully satisfy the objectives of your institution or agency? Please list projects in order of priority and give a rough estimate of likely total costs and manpower requirements.

2. Taking into account your own knowledge of water resources research activities in Canada and elsewhere and the water problems facing Canada, what aspects of water resources research should be emphasized more strongly at this time?

3. Are the available water resources research results with which you are most familiar being applied as effectively as they could be in Canada? If not, what are the main obstacles to effective application?

After completing pages 3 and 4, please return these (and such extra pages as necessary) to the Water Resources Research Survey, Privy Council Office, Science Secretariat, 110 Argyle Ave., Ottawa 4, Ontario. Post paid envelopes have been provided.

SURVEY OF WATER RESOURCES RESEARCH IN CANADA

PROJECT QUESTIONNAIRE

A project is an identifiable unit of research which normally has a single objective and is conducted in a limited period of time, characteristically, a few months to a few years.

1. **Institution or Agency**..........

(Name and Address)..........

....

NOTE: If the institution or agency is large, such as a government department or a university, include the name of the branch, division or department which would be able to provide, directly, further information on the project.

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2. **Reporting Year**
NOTE: The reporting period should be one year in length, either calendar year 1966, or where more convenient, the closest fiscal year (e.g., for federal agencies FY 1966–7).

From .... Month .... Year
To .... Month .... Year

PROJECT DATA

NOTE. Questions 3-13 below should be answered for each project active in the reporting year. This return provides space for up to three projects. For additional projects, either use additional forms or attach sheets with question numbers and answers.

3. **Project Title** (twenty words or less)..........

....

Brief description of purpose..........

....

3. **Project Title** (twenty words or less)..........

....

Brief description of purpose..........

....

3. **Project Title** (twenty words or less)..........

....

Brief description of purpose..........

....

			Project 1	Project 2	Project 3
4. **Sub-category of research** NOTE: Enter the most applicable three digit number from categories on Page 2			11 ____	11 ____	11 ____
5. **Name of project leader**		Family	....	....	....
		Given	....	....	....
6. **Work on reported project in reporting year.** Enter man years (nearest 0.1 man year) for each indicated classification.		Doctor	14 ____	14 ____	14 ____
		Master	17 ____	17 ____	17 ____
		Bachelor	20 ____	20 ____	20 ____
		Undergraduate and post-graduate assistants	23 ____	23 ____	23 ____
		Technicians	26 ____	26 ____	26 ____
7. Was project requested by another agency?		Check	Yes ☐ 29 No ☐ 29	Yes ☐ 29 No ☐ 29	Yes ☐ 29 No ☐ 29
8. Was project co-operative with another agency during the reporting period? NOTE: A co-operative project is one in which two or more institutions or agencies are actively engaged in the research, or a second institution provides instruments and technical advice. If a second institution simply supports the project financially, the project would not be called co-operative.		Check	Yes ☐ 30 No ☐ 30	Yes ☐ 30 No ☐ 30	Yes ☐ 30 No ☐ 30
9. **Duration of project.** This project commenced in		Month	31	31	31 ....
		Year	19.... 32	19.... 32	19.... 32
and is expected to be completed in		Month	34	34	34 ....
		Year	19.... 35	19.... 35	19.... 35
10. **Project cost** in reporting period NOTE: Include only direct costs. Operating costs include salaries, travel and expendable equipment as typical items. Capital costs include instruments and observing platforms. Exclude capital depreciation costs and capital consumption allowances.	Operating	$ Thousands	37 ____	37 ____	37 ____
	Capital	$ Thousands	40 ____	40 ____	40 ____
	Total	$ Thousands	43 ____	43 ____	43 ____
11. **Enter sources** of the funds (total of 10 above) by approximate percentage distribution	Federal		47 ____	47 ____	47 ____
	Provincial		____	____	____
	University		____	____	____
	Industry		____	____	____
	Other Canadian: Specify		____	____	____ ....
	Foreign		57 ____	57 ____	57 ____
12. Using reporting year costs as 100 estimate costs in preceding and following years (For example, if total cost of this project was 20% less in 1965 than in 1966 and the project was completed in 1966, enter 80 for 1965 and 0 for 1967.)		1965	59 ____	59 ____	59 ____
		1967	62 ____	62 ____	62 ____
13. Attach a list of papers, reports and publications resulting from these projects, identifying each list by project title.					

96701—9

SPECIAL REPORT
on
The Contribution of Social Science Research to Water Resource Management in Canada

by

W. R. Derrick Sewell
Department of Economics
University of Victoria

96701—9½

CONTENTS

List of Tables

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of J. Elizabeth McMeiken, R. W. Robertson and Robert Munro in the preparation of this report. The comments and suggestions of the Steering Committee and the Science Secretariat Advisory Committee on Water Resources Research on an earlier draft were invaluable. Responsibility for errors of omission or commission, however, rests with the author. Opinions expressed are his also.

—W.R.D.S.

THE CONTRIBUTION OF SOCIAL SCIENCE RESEARCH TO WATER RESOURCE MANAGEMENT IN CANADA

Section 1

INTRODUCTION

One of the most significant features of the past decade has been the increasing public debate about the management and use of Canada's water resources. Water resource development has often aroused public discussion in Canada, particularly because such development has had important economic, social, and political consequences. What is new is the intensity and the continuousness of the debate. Water problems have now become major issues in political campaigns. They have been the basis of bitter disputes between the provinces and the Federal Government, and between Canada and the United States. In recent years they have claimed an increasing proportion of the time of the House of Commons and the various provincial legislatures as well as a growing amount of attention in the various media of mass communication.

There are several reasons for the recent awakening of public concern about water problems in Canada. One of them is the increasing number and complexity of conflicts in water use.[1] As population has grown, as industry has expanded, and as urbanization has proceeded, competition for the use of particular water supplies has intensified and has sometimes resulted in severe conflicts of interest between water users. A second reason is rooted in the increasing demand for a higher quality environment. Canadians are no longer satisfied with merely increasing their income; they also wish to improve the environment in which they live, work, and recreate. Suddenly an awareness of the effects of urbanization and industrialization has developed. Problems of air and water pollution are now among the most popular topics of public discussion in many parts of the country.[2] At the same time increasing affluence has led to an increase in leisure time and this in turn has given rise to growing demands for outdoor recreation.[3] More and more pressure is being placed on governments to deal with pollution problems and to increase opportunities for outdoor recreation.

[1] For discussions of these problems, see Canadian Council of Resource Ministers, *The Administration of Water Resources in Canada,* Montreal, 1965, and K. Kristjanson and W. R. D. Sewell, "Water Management Problems and Issues in Canada," *Resources for Tomorrow Conference Background Papers* (Ottawa: Queen's Printer, 1961), Vol. 1, pp. 205-210.

[2] See Canadian Council of Resource Ministers, *National Conference on Pollution and Our Environment, Background Papers and Proceedings,* Montreal, 1966.

[3] For a discussion of increasing demands for recreation in Canada, see Lloyd Brooks, "Demand for Recreation Space in Canada," in *Regional and Resource Planning in Canada,* Ralph R. Krueger, F. O. Sargent, A. de Vos, and Norman Pearson (Eds.), Holt, Rinehart and Winston, 1963, pp. 200-211. For a discussion of increasing demands in a region, see J. Howard Richards, "Gross Aspects of Planning and Outdoor Recreation with Particular Reference to Saskatchewan." *Canadian Geographer,* Vol. XI, No. 2, 1967, pp. 117-123.

A third source of public debate relates to the roles that the various levels of government can most appropriately play in developing the nation's water resources. The BNA Act gives the provinces title to the resources within their territory, and apart from the use of such resources for certain purposes (namely navigation, fisheries, and agricultural purposes), and except for those cases in which inter-provincial or international problems arise, it leaves the provinces free to develop them in whatsoever way they wish.[4] It has become increasingly clear in recent years, however, that many water problems by their nature and magnitude are of greater than provincial concern, particularly in those cases where water resources are shared by more than one province, or where provincial financial resources or technical expertise are not adequate to ensure efficient development.

Proposals relating to the diversion of water from Canada to the United States have also been the subject of public discussion. Among the various proposals, the NAWAPA scheme[5] and the Grand Canal scheme[6] have received particular attention. Although it is widely claimed that Canada possesses vast water resources, opinion is divided as to whether, and under what circumstances, the export of water to the United States should be sanctioned.[7] The arguments against export rest mainly on claims that "Canada may need the water in the future" and that "export today may mean higher cost water for Canadians tomorrow." Unfortunately it is not possible to appraise the validity of these claims as data relating to water use in Canada and as to probable costs of developing new sources of supply are presently lacking.

A fifth source of debate about water management in Canada stems from the increasing demands on the public purse to supply goods and services derived from water resource development, particularly those which are not ordinarily supplied through the market mechanism, such as recreation facilities, de-pollution of lakes and streams, and flood hazard reduction. Questions have been raised as to what criteria should be applied in determining how much the public sector should invest in this regard, and in selecting between competing alternative claims on Federal and provincial budgets.[8]

[4] See Bora Laskin, "Jurisdictional Framework for Water Management," *Resources for Tomorrow Conference Background Papers* (Ottawa: Queen's Printer, 1961), Vol. 1, pp. 211-226.

[5] The NAWAPA scheme is described in U.S. Senate, Committee on Public Works, Special Subcommittee on Western Water Development, *Western Water Development*, Washington, D.C.: U.S. Government Printing Office, 1966.

[6] The Grand Canal scheme is described in Thomas W. Kierans, "The Grand Canal Concept and the Great Lakes," in Canada, House of Commons Standing Committee on Mines, Forests and Waters, *Minutes of Proceedings and Evidence*, No. 9, Ottawa: Queen's Printer, March 11, 1965.

[7] For a summary of the various viewpoints, see W. R. Derrick Sewell, "A Continental Water System: Pipe Dream or Practical Possibility?", *Bulletin of the Atomic Scientists*, (September 1967), pp. 8-13. See also Blair Fraser, "Water Crisis Coming," *Macleans*, March 5, 1966, p. 7 and pp. 30-33; T. Lloyd, "A Water Resource Policy for Canada," *Canadian Geographical Journal*, Vol. 73, No. 1, (July 1963), pp. 2-17; and E. Kuiper, "Canadian Water Export," *The Engineering Journal*, July 1966, pp. 3-8.

[8] See P. H. Pearse, "Public Management and Mismanagement of Natural Resources in Canada," *Queen's Quarterly*, Spring, 1966, pp. 86-99.

Debates about the foregoing matters have brought into serious question the adequacy of present policies, laws, and administrative arrangements to deal with the emerging problems of water management in Canada. It is evident, for example, that some past policies have failed to attain their objectives. Flood losses continue to mount despite expenditures on flood protection.[9] Pollution continues to increase despite the enactment of laws and regulations to control it.[10] It is also clear that the objectives of water management are broadening. No longer is it only a matter of finding the best technical and financial means of solving a given water problem. Increasingly it involves the consideration of effects on other water uses, relative costs of alternative solutions, aesthetic values and so on. At the same time the need to accommodate the goals and objectives of several levels of administration in water planning is becoming increasingly apparent. Means must be found, therefore, to co-ordinate policies and functions of the agencies concerned.[11] In the future, economic, social, and political considerations are likely to play a more and more important role in water management decisions. As a consequence, greater emphasis will need to be placed on social science research to provide the necessary information and guidelines for choice-making.

At present, expenditures on social science research in the water management field in Canada are extremely small. From the survey undertaken by the Study Group, and from supplementary data, it appears that such expenditures amount to less than $280,000 a year,[12] about 3.3 per cent of all research expenditures on water problems in Canada. This sum is minute when compared with investment in water development in Canada, some $750 million a year, or expenditures on physical science aspects of water management, estimated by the Study Group to be about $8,110,300 a year.[13] Many of the problems that are now on the horizon can be traced in part to the lack of attention to the human dimensions of water management. It is clear that there must be a vastly increased research effort in this connection. How much more money is needed? What are the questions that are most urgently in need of answers? How can the present obstacles to an expansion of the research effort be overcome? What modifications are needed in existing institutional frameworks to ensure that the results of research efforts will find their way into water resources planning and development?

[9] See W. R. D. Sewell, *Water Management and Floods in the Fraser River Basin,* Chicago, University of Chicago Department of Geography, Research Series No. 100, 1965.

[10] Canadian Council of Resource Ministers, *op. cit.*

[11] See T. M. Patterson, "Administrative Framework for Water Management," *Resources for Tomorrow Conference Background Papers* (Ottawa: Queen's Printer, 1961), Vol. 1, pp. 227-279.

[12] These data relate to expenditures reported under categories 601, 602, 603, 604, 605, 606, 607, 608 and 700 specified in the Questionnaire circulated by the Science Secretariat. They related both to "in house" research undertaken by government agencies, research carried out under contract to such agencies, and research supported by grants in aid to universities.

[13] These data relate to the remaining categories not covered by economic, social, and institutional research. Detailed breakdowns of these expenditures appear above in the Science Secretariat's Special Study No. 5, *Water Resources Research in Canada.*

These questions were addressed to a group of social scientists engaged by the Science Secretariat of the Privy Council Office. Representing the disciplines of economics, geography, planning, and political science, they each prepared a report for the Science Secretariat setting out their individual views on these matters.

The consultants were: M. Michel Chevalier—Institut d'Urbanisme, Université de Montréal; Dr. Richard Judy—Department of Political Economy, University of Toronto; M. Lionel Ouellet—Department of Political Economy, Laval University; Dr. Derrick Sewell (*Chairman*)—Departments of Economics and Geography, University of Victoria.

The group drew upon the advice of a Steering Committee composed of the following people: J. P. Bruce, Special Consultant, Science Secretariat, Privy Council Office; C. de Laet, Secretary-General, Canadian Council of Resource Ministers, Montreal; J. W. MacNeill, Director, Policy and Planning Branch, Department of Energy, Mines and Resources, Ottawa; M. Slivitzky, Director General of Water, Quebec Department of Natural Resources.

In addition, they received advice from a group of experts in the water resources field, at a meeting sponsored by the Science Secretariat in Toronto, 5 June, 1967.

The Consultants gratefully acknowledge the assistance given them during the course of the study by the Steering Committee, the Science Secretariat, those present at the meeting in Toronto, officials of water management agencies and colleagues at universities in various parts of Canada, France, the United States, and the United Kingdom. The opinions expressed in the various reports prepared in connection with this study, however, are those of the authors.

The present report has been prepared by the Chairman of the group. It draws on the reports of the individual members and upon additional information gathered from sources in various parts of Canada, the United States, and the United Kingdom. It deals with four main topics:

1. The major problems and issues in water management in Canada which involve economic, social and political considerations.
2. Needed social science research in this connection.
3. The research effort to date and priorities for future studies.
4. Present constraints on an expansion of the research effort and means of overcoming them.

The report concludes with a number of recommendations for future action to ensure that the needed research is in fact undertaken.

Section 2

MAJOR WATER RESOURCES PROBLEMS IN CANADA: POSSIBLE CLASSIFICATIONS

What are the major water management problems in Canada? Several attempts have been made to answer this question in resources conferences,[14] hearings of the Standing Committee on Mines, Forests and Waters,[15] and various studies undertaken under the auspices of the Canadian Council of Resource Ministers.[16] The reports which have resulted provide a useful though incomplete source of information. An attempt was made by the Secretariat of the Canadian Council of Resource Ministers to update this data for the purposes of the present study. There may still be gaps in the updated listing, but it is believed that it does provide a reasonable starting point for the purposes of this paper.

To facilitate a review of needed social science research the various water problems must somehow be classified. Several classifications are possible and five have been selected for discussion here, namely: emerging issues, geographical incidence, disciplinary or professional interests, phases in the planning and development process, and decision-making elements.

1. Emerging Issues

Water resources problems may be classified according to the extent to which they arouse public concern. There is a broad spectrum of problems ranging from those which arouse little or no concern to those which give rise to intense public debate.

At one end of the spectrum are problems which arise in the day-to-day operations of a water management project, such as a local water supply reservoir. Such problems are usually fairly simple, and responsibility for dealing with them is allocated to the operating agency. There is seldom any need to consult public opinion as to the appropriate course of action. Generally such problems can be solved within the framework of existing policies and agency organization.

At the other end of the spectrum are problems which arouse considerable public debate, particularly where the decision might lead to an irrevocable course of action or preclude the development of other uses or alternatives. Typically such problems excite a questioning of past policies and the adequacy of the existing institutional framework to deal with the problem under discussion. Usually there is great pressure for an immediate decision.

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[14] See, for example, *Resources for Tomorrow Conference Background Papers, op. cit.*; Canadian Council of Resource Ministers, *op. cit.;* and B.C. Natural Resources Conference, *Transactions of the 14th Conference,* Victoria, B.C., 1962.

[15] Canada, House of Commons Standing Committee on Mines, Forests, and Waters, *Hearings,* Ottawa, 1960 and 1965.

[16] Canadian Council of Resource Ministers, *The Administration of Water Resources in Canada,* Montreal, 1966.

Problems of this type might be termed issues. They can be local, regional, provincial or national in scope. An illustration of a national issue in the water management field is the growing pressure for a definition of the responsibilities of the various levels of government. What functions should the Federal Government perform? In what circumstances should it actively participate in development?

In between these two extremes are the other water problems, not yet sufficiently critical to arouse public concern. Decisions can still be made within the existing framework of policies, laws, and administrative organization, or with only minor modifications to it. Flood problems fall into this category. So also does the matter of agricultural rehabilitation and development. Some of the problems now in this category may eventually become Issues. Problems which appear to be on the threshold of becoming issues include water pollution, criteria for the allocation of public funds to water resources development, and the manner in which mounting flood losses should be dealt with.

Types of problems that might be classified as minor or major, or as Issues are noted in Table 1 (*infra,* p. 148).

2. Geographical Incidence

A second type of classification is one based on the geographical incidence of the problem. One might classify problems, for example, on a local, provincial, national or international basis. Another classification would be along "regional" lines, using various criteria for defining a region (such as urbanization, political boundaries, or watersheds). Classifications on a geographical basis have been one of the most frequently used in discussions of Canadian water problems.

For present purposes a classification based upon local, provincial, inter-provincial, national, and international categories has been adopted. Table 2 (*infra,* pp. 149-150) notes the problems that presently exist at these levels and those which are now appearing on the horizon.

For the most part local problems, such as drainage, are of relatively minor importance and can generally be dealt with effectively by either municipal or provincial agencies. There are other problems, however, that are much wider in their incidence, and these sometimes cover a major area of a province and in certain instances two or more provinces. Major floods occur in several provinces and cover vast areas, notably in British Columbia, Manitoba and Ontario. Water scarcity has become a major concern not only in the Prairie Provinces but in certain parts of southern Ontario. Pollution is widespread in several provinces. Problems of this type might be termed "regional". To some extent they can be handled effectively by existing provincial machinery, but it is becoming increasingly clear that innovations in institutional frameworks of laws, policies and administrative arrangements will be needed as these problems grow in magnitude and geographical incidence. New Federal-provincial and inter-provincial agencies and programs will be required for this purpose.

Still other problems can be considered to have national importance. Those which involve the United States are national by definition, such as matters relating to the use and development of international lakes and rivers. Other problems are national in the sense that they are Canada-wide and consequently involve all or most of the provinces. Pollution is becoming a national problem of this type. There are certain problems, however, which, though widespread in incidence, are not clearly national problems. Floods and droughts are cases in point. The effects of these problems are felt far beyond the areas where they occur but there is no indication as to the extent to which losses sustained affect the national economy. Thus far no studies have been undertaken which would help to assess the overall impact of such losses.

3. Disciplinary Interests

A third classification might be based on the assumed interests of various disciplines. Thus matters relating to the evaluation of economic impacts of development, or the financing of such development could be classified as economic problems. Similarly problems relating to the social disruption caused by reservoir construction, or the determination of the rate of adoption of the services which a new project would provide might be classified as sociological problems. Problems of defining jurisdictional boundaries and interpreting the law would be termed legal problems, while matters concerning the inter-action between levels of government or reorganization of administrative structures would be placed in a category of "political considerations," or "institutional problems".

Classifications organized along disciplinary lines generally contain only two or three categories. Engineers, for example, frequently speak of "engineering problems" and "other problems". Economists on the other hand often classify problems as "physical" (or technical), economic, and other (usually implying social, biological, etc.).

Table 3 (*infra,* pp. 151-52) lists problems that would appear to be of interest to various disciplines, namely engineering, economics, sociology, psychology, law and political science. Obviously the number of water-related topics in which researchers in these disciplines would be interested, is much greater than those appearing in this table which does emphasize, however, that many of the problems are of interest to various disciplines. For example, the operation of river development systems is a matter of interest to engineers, economists, ecologists and geographers and doubtless other disciplines too. Similarly the factors underlying water demands are economic, sociological and psychological in nature. The solution of many of the problems that are now on the horizon will require inter-disciplinary research efforts.

4. Phases in the Planning and Development Process

Water problems can also be classified according to their relationship to a particular phase of the development process. Categories that might be included under this classification are research, data collection, planning, financing, implementation, and management. Sometimes research and data collection are included as parts of the planning phase although they may not all be undertaken by the same agency. Similarly financing and management (which is taken to mean the operation of the project once it has been developed), might be included with implementation.

As noted in Table 4 (*infra,* p. 153), one of the principal problems that relate to the research phase is the present lack of research funds for studies of economic, social, and institutional aspects of water management. The amount of money devoted to research in the natural resources field as a whole in Canada is small, but the amount devoted to social science aspects is minute. Of the research that is undertaken in the water resources field, most attention seems to be paid to the physical dimensions, particularly the hydrological and biological aspects (see Table 6, *infra,* p. 156). The present emphasis is in part a reflection of the manner in which funds are made available for research, such as through the National Research Council which has a physical science orientation. Other Federal government agencies when they have been involved in social science research have generally funded it on a very small scale for a limited period of time, and generally with a mission-orientation. Moreover, much of the social science research has been undertaken by the agencies themselves.

The pertinent question is, therefore, what changes in the present research funding process are required to facilitate more social science research in the water management field? Other problems relating to the research phase include those of determining priorities between competing claims for funds, the lack of personnel skilled and available to undertake the needed research, and the lack of communication between those carrying out the studies and those who might be able to use the results.

There is a general lack of data required for studies of economic, social, and institutional aspects of water management. Often the data collected relate to areal units that are too large to be useful for the studies in question, or it is not collected frequently enough to reflect human impacts on water management. Land use surveys, for example, provide a useful indication of land use patterns as of a particular moment of time. The following year they may alter radically due to other changes, for example, cropping patterns.

There are other problems stemming from the lack of uniformity in data collecting procedures, such as in information relating to municipal water supply or industrial water supply. Data collection agencies are not entirely to blame for such deficiencies. Social scientists are sometimes prone to state merely that data are lacking rather than specifying precisely what data they need, in what form, and how often the information should be collected. Nevertheless, it is clear that if social scientists are to provide the advice that is needed on the human dimensions of water problems, data collection and analysis programs must be considerably expanded. Other problems relating to data collection include those of determining the economic gains from additional information, development of more sophisticated techniques of data storage and retrieval, and increasing the usefulness of data by expanding data-analysis programs.

There are numerous problems associated with the planning of water resource development. One of the most important is that of ensuring that economic, social, and institutional studies are undertaken in phase with other investigations rather than as an afterthought once the latter have been completed. Another is that of linking water resources planning to planning for other purposes, such as for regional economic development. There are also problems of co-ordinating planning within and between levels of government. The problem today in North America is not so much the lack of planning but the lack of co-ordination between planning agencies, each of which has its own particular view of what is required. Another source of concern is the fact that so many plans end up on the planner's shelf instead of in the legislator's portfolio for action.

In the field of financing there are problems of determining the manner in which various levels of government ought to participate in water resource development. Should the Federal Government provide funds for development as well as for other phases of water management? If so, on what terms should it do so? Another difficulty is that demands are being made for the investment of federal funds in developments that have hitherto been assumed to be the responsibility of other levels of government.

Problems of implementation and management raise numerous questions about the legal and organizational frameworks. It is evident that there are weaknesses in some of the present laws relating to water management, particularly where they encourage suboptimal uses of water resources or where they facilitate only one course of action to be taken. Confusion as to what are the responsibilities of various levels of government and particular agencies in water management present additional difficulties. Other problems relate to the lack of co-ordination within and between levels of government in the water management field.

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5. Decision-Making Elements

Another approach is to classify problems according to elements that may enter into decisions about water management. Gilbert White has suggested that six main types of considerations can enter such decisions.[17] He designates these as:

(a) the range of choice
(b) the estimate of the resource
(c) available technology
(d) economic considerations
(e) spatial linkages
(f) social guides

(a) *The Range of Choice*

The range of choice relates to the possibilities for using a given water resource for different purposes on the one hand, and to the alternative ways in which these purposes might be accomplished on the other. For example, a given water resource might be used for such purposes, as irrigation, hydro-electric power generation, municipal and industrial water supply, navigation, recreation, flood control or for the support of fish runs. Each of these purposes could be accomplished in a variety of ways. Flood problems, for example, can be dealt with by building protective works, flood proofing structures, taking emergency measures, enacting flood plain zoning ordinances, providing compensation for flood victims, or establishing flood insurance schemes. Typically, however, only a narrow range of possible uses and alternative strategies for development is considered in water management in Canada.[18]

(b) *Estimate of the Resource*

A critical consideration in decisions relating to water resource development is an estimate of the quantity and quality of the water resource and associated land resources, such as soil and minerals. Information on resource availability is important not only to the engineer who designs the structures, but also to the economist who estimates the value of the goods and services that might be derived from development, and the sociologist who examines the possible consequences of various kinds and magnitudes of development.

(c) *Technology of Water Management*

Any assessment of the possible use and development of water resources requires assumptions as to the technology that is likely to be applied in the collection, storage, transport, use, and disposal of water. Can it be assumed,

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[17] This framework of analysis is described in Gilbert F. White, "Contributions of Geographical Analysis to River Basin Development," *Geographical Journal,* Vol. CXXIX, 1963, pp. 412-46. Its application to flood problems is described in Gilbert F. White, *Choice of Adjustment to Floods,* Chicago, University of Chicago, Department of Geography Research Series No. 93, 1964.

[18] This appears to have been the case particularly in connection with floods. See W. R. D. Sewell, *Water Management and Floods in the Fraser River Basin, op. cit.*

for example, that the most advanced techniques of hydraulic and mechanical design will be employed by those who are involved in drawing up plans for structures to control water resources, or that farmers or industrialists will employ the most efficient techniques available for the utilization of the water that will be provided?

(d) *Economic Efficiency*

Economic considerations often play an important role in many decisions relating to water resource development. This role seems certain to grow in the future, particularly as the competition for scarce capital funds intensifies, and as water development is used increasingly as an instrument for promoting economic change. It will become increasingly necessary to determine the economic efficiency of proposals for water resource development, and to trace the economic consequences of various alternatives.

Considerable progress has been made in recent years in developing techniques for the evaluation of water development projects. The concepts of benefit-cost analysis are being refined and procedures for identifying and measuring the various gains and costs are being improved.[19] Increasing use is being made of systems analysis in the evaluation of proposals for water development.[20]

Despite this progress, however, techniques of economic analysis used in the appraisal of proposals for water development in Canada are still fairly crude. *A Guide to Benefit-Cost Analysis*[21] was published as a part of the proceedings of the Resources for Tomorrow Conference. Its major objective was to provide a set of principles that could be used as a basis for the development of techniques of economic evaluation used by government agencies and others in the appraisal of resource development projects. It has been only partially successful in achieving this objective. Some provincial government agencies undertake benefit-cost analyses and so do a few agencies of the Federal Government. Many of those who undertake such analyses, however, do not adhere to the principles set out in the Guide, and in several cases the techniques have been grossly misused.[22] A major problem, therefore, is that of increasing the level of sophistication of methods of evaluation used by government agencies and ensuring that such methods are correctly employed.

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[19] See A. R. Prest and R. Turvey, "Cost-Benefit Analysis: A Survey," *The Economic Journal*, Vol. 75 (December 1965), pp. 683-75; and A. Wildawsky, "The Political Economy of Efficiency: Cost-Benefit Analysis, Systems Analysis and Program Budgeting," *Public Administration Review*, December 1966, pp. 292-310.

[20] See, for example, A. Maass *et al*, *The Design of Water Resource Systems*, Cambridge, Harvard University Press, 1962; and M. Hufschmidt and M. Fiering, *Simulation Techniques for Design of Water Resource Systems*, Cambridge, Harvard University Press, 1966.

[21] W. R. D. Sewell, *et al*, *Guide to Benefit-Cost Analysis*, Ottawa, Queen's Printer, 1961.

[22] See Ian Burton, "Investment Choices in Public Resource Development," *The Prospect of Change*, Abraham Rotstein (Ed.), Toronto, McGraw Hill, 1965.

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(e) *Spatial Linkages*

Another factor that may influence water management decisions is the effects that a given water use may have on other water uses, or the effects that a given water development project may have on activities beyond the project area. The effects of alterations in streamflow patterns resulting from the construction of a dam, for example, may be expressed in significant changes in biological systems and social systems as well as in changes in outputs of goods and services. Analyzing the impact of a given change in a hydrologic system on the other interlocking systems is a highly complex task. Important advances have been made in recent years, however, particularly through the use of high speed computers and the development of systems analysis techniques. Nevertheless, much work remains to be done before the precise effects of a given change in the hydrologic system can be predicted, even within one system.

(f) *Social Guides*

Decision-making in water management is profoundly affected by the encouragement or constraint which society imparts through its customs, attitudes, laws, and organizations.[23] Collectively, these may be referred to as social guides. Knowledge of their influence is essential if water resources planning is to be effective in attaining its objectives. The record is replete with examples of water development schemes, which, although engineered to a high degree of proficiency, have failed because of lack of attention to the potential reaction of those who would be affected by the scheme or attention to the capacity of the existing institutions to implement it effectively. Thus flood control schemes may fail to reduce flood losses unless measures are also taken to restrict further occupance of the flood plain; the provision of electric-power may not result in predicted industrial expansion unless accompanied by appropriate pricing policies, tax policies, and the development of an infrastructure; and a plan for water development may merely gather dust on the planner's shelf if it is formulated without reference to the social, legal, and administrative factors on which it will depend for its implementation. Social guides, therefore, can be one of the most important elements determining the outcomes of decisions in water management.

Table 5 (*infra,* pp. 154-55) indicates some of the problems that relate to the various elements in decision-making in water management in Canada.

6. Combining the Classifications

Each of the approaches noted above has advantages and disadvantages, depending upon the purposes for which the classification is to be used. Used in combination, however, they serve to point up the most urgent questions that relate to a particular resource management problem, and the types of social science research that would be helpful in the search for a solution.

[23] For a discussion, see Harold E. Thomas, "Cultural Control of Water Development," *CIBA Journal,* Autumn 1964, pp. 25-32; and Gilbert F. White, "Formation and Role of Public Attitudes," in *Environmental Quality in a Growing Economy,* Henry Jarrett (Ed.) (Baltimore: Johns Hopkins Press, 1966) pp. 105-127.

Section 3

NEEDED SOCIAL SCIENCE RESEARCH RELATING TO WATER MANAGEMENT

It is evident from a review of the emerging problems of water management in Canada that knowledge is lacking in many important areas. It is also clear that a major expansion of the present research effort is required. Not all the needed studies can be done at once and so priorities must be assigned. Bearing these considerations in mind, five major types of research appear to be especially urgently required:

1. determination of the magnitude of the resource;
2. determination of the potential uses of water resources and the alternative solutions to water problems;
3. identification and measurement of the economic impacts of water development;
4. determination of impacts of various social guides on water management and development of improved frameworks of laws, policies, and administrative arrangements;
5. determination of the value of additional information and of expanded research efforts.

Detailed discussions of the types of research that might be undertaken in the fields of economics, geography, planning and political science appear in the reports of the individual members of the study group.[24] The following discussion notes the accomplishments to date in the various categories of research, and the gaps that need to be filled.

1. Estimating the Magnitude of the Resource

As noted earlier, knowledge of the nature and extent of the resource is a prerequisite to sound planning. Various types of study are needed in this connection. Many of them are physical in nature and might best be undertaken by physical scientists and engineers. Several reports prepared for the Study Group have specified the areas of research on the physical dimensions of water management that are most urgently needed. These reports and a

[24] One of the reports is concerned with problems relating to the weighing of economic considerations in water management decisions. See Richard W. Judy, *Economic Problems in Water Resources Management.* Another is focussed on the difficulties involved in attaining desirable social goals within the legal and institutional framework that conditions water management in Canada. See Lionel Ouellet, *Programme for Basic Legal and Institutional Research in Canada.* A third is focussed on past and potential contributions of geographical research to water management in Canada. See W. R. D. Sewell, *The Role of Geographical Research in Water Management in Canada.* All of the individual reports discuss the general problem of getting the research done. The fourth report, however, concentrates specifically on this matter, and outlines various strategies that might be pursued towards this end. See Michel Chevalier, *Planning the Development and Use of Social Science Research for the Problem of Canadian Water Resources Management.*

number of other studies[25] have drawn attention to the lack of data on the spatial and temporal distribution of water resources in Canada, and to gaps in the understanding of factors which influence the hydrologic cycle.[26] They note the need for research on streamflow characteristics: the inter-relationships between precipitation, temperature, evapotranspiration, soil moisture, groundwater recharge and other factors; the behaviour of sediment loads; and on the incidence of floods and droughts. Studies are also needed on means of increasing water resource availability, such as reduction of evapotranspiration,[27] and weather modification.[28] Research is also required for the assessment of potentials of other related resources, such as soils and minerals.

The problems of estimating resource availability have traditionally been principally the concern of the physical scientist, the natural scientist and the engineer. Social scientists, however, can make useful contributions to the needed research. Geographers in particular have long interested themselves in studies relating to resource estimates. In the water resources field they have undertaken particularly valuable work relating to water balances, hydrographic mapping, the identification of areas subject to floods and droughts, and factors affecting streamflows.[29] The effort of Canadian geographers in this connection has not been large but a number of useful contributions have been made, particularly during the past decade.[30] Several of them are now engaged in investigations of streamflow characteristics, factors affecting the hydrologic cycle, sedimentation and subsurface drainage. With increased availability of funds other geographers would participate in these and other investigations relating to water resource estimates.

Geographers have also undertaken studies in connection with the inventorying of other related resources such as agricultural land, forests, and mineral resources. Many of them are now engaged in the Canada Land Inventory. Gradually the methods used in collecting the data for such surveys have been improved. At the same time data storage and retrieval systems have been modernized through computerization, making information much more readily available. There remain a number of weaknesses in present land use surveys, however, and research is needed to overcome these

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[25] Various studies prepared for the Resources for Tomorrow Conference drew attention to this problem. See especially, D. Cass-Beggs, "Water as a Basic Resource," and R. H. Clark, A. K. Watt and J. P. Bruce, "Basic Data Requirements for Water Management", in *Resources for Tomorrow Conference Background Papers, op. cit.*, Vol. 1, pp. 173-189 and 191-201, respectively.

[26] For a discussion, see R. H. Clark and J. P. Bruce, *Introduction to Hydrometeorology,* Toronto, Pergamon Press, 1966.

[27] See A. E. Ackerman and G. O. G. Löf, *Technology in American Water Development,* Baltimore, Johns Hopkins Press, 1958.

[28] See National Academy of Sciences—National Research Council, *Weather and Climate Modification,* Washington, D.C., 1966; and National Science Foundation, Special Commission on Weather Modification, *Weather and Climate Modification,* Washington, D.C. 1966.

[29] See W. R. D. Sewell, *The Role of Geographical Research in Water Resource Development in Canada, op. cit.*

[30] *Ibid.*

deficiencies. The emphasis in such surveys continues to be on the mapping of what physically exists on a given plot of land. Only infrequently is information collected as to the economic, social, and institutional factors that are responsible for land use patterns. Obviously it is only with information on these latter considerations that predictions as to future land use are possible. Studies need to be undertaken to determine how land use surveys can be made to reveal not only physical possibilities, but also the changes that seem likely to take place, given various economic, social, and institutional considerations.

2. Determination of Water Uses and of Alternative Solutions to Water Problems

Of all the types of research that are needed in connection with the human dimensions of water management in Canada, perhaps the most urgent is that relating to the determination of water uses, and the identification of alternative solutions to water problems. Several studies have drawn attention to the lack of data on water use in Canada,[31] and the implications of this for water resources management.[32] It acts as a major inhibition, for example, to policy-making in connection with such matters as inter-basin diversion and water export. In addition, the narrow range of alternatives commonly considered in water resources decision-making is a major source of potential inefficiency in resource allocation.

Several types of research need to be undertaken to make possible precise estimates of future water needs. These include economic base studies which would provide information relating to population growth and expansion of various economic activities; water service-demand studies, including inventories of present use by households, industries, agriculture, recreation, and other non-consumptive activities; analytical studies to assess the influence of water availability on industrial location, agricultural development, and urban growth, to determine the influence of price increases on water consumption, and to evaluate the effects of the introduction of new technologies on water consumption; and studies to derive multi-variate demand functions based on data provided by the other investigations. Types of studies that should be undertaken are set out in Table 8 (*infra*, pp. 158-59).

It is essential that these studies be undertaken *before* any attempt is made to undertake an evaluation of the benefits and costs of a water resource development project, and that water use inventories be kept up to date. A series of water use studies should be undertaken in each of the provinces of Canada and an attempt then made to consolidate these into an overall review of water use in the nation as a whole.

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[31] See R. H. Clark, A. K. Watt and J. P. Bruce, *op. cit.*, and D. Cass-Beggs, *op. cit.*
[32] See T. Lloyd, *op. cit.* and E. Kuiper, *op. cit.*

Research on water use in Canada to date has been very meagre. Apart from some exploratory work on recreational water use,[33] Canadian social scientists have shown little interest in this matter. Government agencies have not examined it very much either. Some valuable work has been done in the United States and elsewhere in the past few years, however, in developing conceptual frameworks and techniques of measurement,[34] and these might be applied with some modification in Canada. Studies of these problems might be undertaken by universities, consulting firms and government agencies.

Research designed to expand the range of choice has also been fairly limited. There is as a consequence little innovation in the alternatives considered for dealing with water problems. Concentration on construction alternatives remains a dominant characteristic in water management in Canada. Even within that limited range, there have been only modest attempts to innovate, as is illustrated in the cases of adjustment to floods or to pollution. Studies need to be undertaken to identify what are the theoretical possibilities for solving various water problems, and to determine what are the factors which inhibit such factors being taken into account. This is an area of research that has been little explored to date, but could result in a major payoff in terms of improved efficiency in water management.

3. Identification and Measurement of Impacts of Water Development

Another major category of research that needs to be pursued relates to the identification and measurement of impacts of water development. Water management is generally undertaken with some economic or social goal in mind, even though such a goal may be rather vague and not well articulated in policy statements. It is important, nevertheless, to determine whether a proposed scheme is likely to attain the implied objective. In addition, because water development involves the alteration of natural flows of a stream, it inevitably results in differential effects on various water users and on the biological systems within the river basin. Some of these effects may be beneficial to certain users but adverse to others. Careful appraisal of relative gains and losses therefore is required.

A considerable amount of the social science research effort relating to water management in recent years has been devoted to the development of theoretical frameworks and techniques of measurement for assessing the impacts of water management. Most of this work, particularly in the field of

[33] See, for example, P. H. Pearse, "A New Approach to the Evaluation of Non-Priced Recreational Resources," Paper presented to the 1967 Annual Meeting of the Canadian Political Science Association, June 1967; and Canada, Department of Fisheries, *Economic Aspects of Sport Fishing*, Ottawa, Queen's Printer, May 1965.

[34] For reviews of progress in this connection, see Allen V. Kneese and Stephan S. Smith, *Water Research*, Baltimore, Johns Hopkins Press, 1967.

economics,[35] has been undertaken in the United States, but several Canadian economists have made useful contributions both to the development of theory and of techniques of measurement.[36] Research on sociological impacts and on political consequences of water resource development in Canada, however, has been very meagre.

There remain important conceptual problems relating to impact measurement, not the least of which is that of specifying the social welfare objective that is to be pursued.[37] Ideally, in welfare economics the objective is to pursue those courses of action which result in increasing income without making anyone worse off. Water resources development projects and measures, however, generally cause shifts in the distribution of income among members of society. Such redistributions may benefit one geographical area while harming another; or they may reward one class of citizens at the expense of another. Consequently, the social welfare function (or objective) must be specified in terms of a desired income redistribution. Research is needed into the theory and practice of specifying such income redistribution constraints.[38] Other conceptual problems requiring study relate to the treatment of time, uncertainty, opportunity costs, externalities, indivisibilities, and intangibles.[39]

Besides the conceptual problems, there are difficulties attached to the actual identification, measurement, and evaluation of impacts. As noted earlier, a good deal of attention has been focussed on these matters in recent years and considerable progress has been made. There still remain, however, problems of identifying and measuring the value of goods and services that do not normally enter the market mechanism, such as recreation, pollution abatement, and flood loss reduction. Research designed to determine what consumers would be willing to pay rather than do without such goods and services is now being pursued by a number of Canadian economists. This research should be encouraged and expanded. There are also problems of tracing the broad impacts of various alternative developments through the economic, social, and biological systems. Much progress has been made in this connection in recent years through the application of computer technology, and the building of mathematical models.[40] Most of the applications thus far have been in connection with economic impacts, but increasing use of these techniques is now being made by biologists and others concerned with effects of resource development. The design and use of digital simulation models is a very young art. The technique holds great promise for water

[35] *Ibid.;* see also Turvey and Prest, *op. cit.;* Maass *et al., op. cit.;* and Hufschmidt and Fiering, *op. cit.*

[36] For a review of these contributions, see R. W. Judy *op. cit.*

[37] See, for example, Otto A. Davies and Andrew B. Whinston, "Externalities, Welfare, and the Theory of Games," *Journal of Political Economy,* Vol. 70, 1962, pp. 241-262.

[38] See, for example, A. Myrick Freeman III, "Six Federal Reclamation Projects and the Distribution of Income," *Water Resources Research,* Vol. 3, No. 2, 1967.

[39] See R. W. Judy, *op. cit.*

[40] See, for example, Maass *et al, op. cit.,* and Hufschmidt and Fiering, *op. cit.*

resources management because it creates the analogue of the laboratory in which alternative system designs can be tested and evaluated. Research in this field should be enthusiastically supported, especially at the universities.

Another type of research connected with impact measurement that is urgently required relates to the valuation of the actual performance of water development projects. Generally evaluations are undertaken only *ex ante*, that is, prior to the decision whether or not to proceed with implementation of a proposed program. Studies are needed to determine whether in fact the perceived objectives have been attained. In this way planners would have a means of determining how good their estimates were, and in those cases where the goal was not attained, they would be motivated to search for the reasons why. Care would need to be exercised in undertaking such studies. Hindsight appraisal is, of course, much easier than prediction. Nevertheless, an objective appraisal, taking into account the various factors that appear to have influenced the outcome, would be invaluable for future decision-making. Hindsight studies should be undertaken of particular projects, such as the South Saskatchewan project or the Mactaquac project in New Brunswick, or of particular policies, such as those embodied in the PFRA Act, ARDA,[41] or the Canada Water Conservation Assistance Act.

4. The Role of Social Guides in Water Development

A fourth category of social science research that should be accorded high priority relates to the influence of various social guides in water management. As noted earlier, social guides comprise a wide variety of influences that encourage or discourage development taking place in particular ways. They include informal influences such as social mores, customs, and attitudes, and formal influences such as laws, policies and administrative arrangements. Kowledge of the effects of such factors is essential to sound water resources planning. Thus far, however, very little study has been given to such matters by Canadian lawyers, political scientists, sociologists, or psychologists.[42]

Among the types of research that are most urgently required in connection with social guides, five appear to be particularly important, namely: (a) a review of the effectiveness of the present legal and administrative framework in dealing with the emerging problems of water management; (b) the examination of the criteria that need to be applied in water between competing users and in selecting among competing projects; (c) the determination of the potential effectiveness of incentives to private action in dealing with

[41] A pioneering study of this type was undertaken recently under the auspices of the Economic Council of Canada. See Helen Buckley and Eva Tihanyi, *Canadian Policies for Rural Adjustment: a Study of the Economic Impact of ARDA, PFRA, and MMRA*, Ottawa, Queen's Printer, 1967.

[42] For a discussion see W. R. D. Sewell and Ian Burton, "Recent Innovations in Resource Development Policy in Canada," *Canadian Geographer*, December, 1967.

water problems; (d) studies of the role of perceptions and attitudes in decision-making; and (e) the determination of the appropriate areal units for water management.

Water resource development in Canada is profoundly affected by the jurisdictional division of powers imposed by the BNA Act, various laws that have been enacted for allocating water among competing users, the structure of administrative organizations that have been established to guide the management of water resources, and by government policies. Laws and administrative structures give expression to the views and circumstances of the time in which they were established. To be effective in dealing with water problems, however, they must be sufficiently flexible to accommodate new social and political ideas, new technologies, and problems that were not on the horizon when the laws were enacted or the administrative structures were established. Rapidly changing ideas, the emergence of new technologies and the intensification of competition for the use of certain water resources in Canada, have placed increasing demands on the legal and administrative framework.[43] Some changes have already been made and others are now underway. In general, modifications have been made on an '*ad hoc*' basis to accommodate particular problems as they have arisen. There is no way at present of determining how effective such modifications have been or, even more important, whether some other modification might have yielded better results.

One of the most valuable types of research that could be undertaken in the field of water management in Canada would be a thorough review of legal and administrative frameworks, examining present systems against an 'ideal' system of laws and agencies designed to achieve specified goals. Such a study might be undertaken in four parts or phases, which are methodological rather than chronological; in other words, they could be undertaken simultaneously, although at a given point of the research the conclusions of the preceding phases must be known before the planned research program could be continued. The four phases would consist of the development of a model of 'ideal' legal and administrative frameworks, based upon legal principles and principles of administrative organization designed to attain specified goals; the inventorying of present systems of water law and water management agencies; a comparison of the present system with the ideal system; and the consideration of institutional changes that might be made to improve water management, given various political and other constraints. Specific types of studies that might be undertaken in this connection are outlined in Table 9 (*infra,* p. 160).

A *second,* and related type of research, is concerned with criteria for choice. As the number and complexity of the claims for the use of given

[43] See Morris Miller, "The Developmental Framework for Resource Policy and its Jurisdictional-Administrative Implications," *Canadian Public Administration Journal,* Toronto, June 1962, pp. 133-155.

water resources continue to grow, the problem of selection among them will become increasingly more difficult. Traditional criteria of law and historical precedent will prove to be inadequate and will need to be supplemented by others, such as economic efficiency and social desirability. Similarly, as claims on the public purse continue to expand, and especially as the demand for collective goods continues to grow, more sophisticated economic criteria will need to be applied. In addition, as inter-jurisdictional projects grow in number and in size, the need for means of reconciling the goals of the various jurisdictions will become more urgent. Studies are needed to assess the influence of criteria that have been used in the past in water management in Canada. To what extent, for example, is the present pattern of water use a reflection of legal doctrines rather than economic considerations? Does the present system ensure that water resources will move into their economically most profitable and socially most desirable uses? What influence has the misapplication of techniques of economic analysis had on the development of water resources?

Studies are also needed to assess the outcomes of the application of various criteria to particular resource allocation cases or resource development projects. What would be the effect, for example, of applying economic criteria to all the water allocations that now exist? Would there be major changes in the relative allocations to various types of water use? What would be the effects of relaxing the requirements in the present Canada Fisheries Act relating to the protection of anadromous fish runs? Would such a relaxation be economically sensible and socially desirable? Is the insistence upon uniform standards for water quality, based on drinking water criteria or criteria for protection of particular fish species, likely to produce the kind of environment that society desires for working and recreating or are additional criteria required for this purpose? Many water management decisions in the past have been based on the use of single criteria. In the future, competing social goals will call for the application of several criteria. Research should be undertaken, therefore, to trace the outcomes of the application of various criteria and combinations of them.

A *third* type of needed research concerned with social guides relates to the provision of incentives to private action. Social goals can be pursued in the development of water resources in several ways, such as by the enactment of regulations, the provision of goods and services through the use of tax funds, or the provision of incentives to encourage private initiative. Each of these courses of action has advantages and disadvantages in resource allocation depending on the circumstances. Generally, it is believed, the most satisfactory allocations of water between users and the provision of the social or most desirable level of goods and services will occur when there is the greatest freedom of individual choice, and especially when this can be expressed through the mechanism of the market.[44] Some water-derived goods and services, however, are not generally provided through the operation of the market, notably collective goods, such as recreation facilities, de-pollution and flood control. Since the provision of such goods is thought to be socially desirable, the government often undertakes the responsibility for providing them. The problem arises, however, as to how much to provide.

One possible guideline for the provision of such water-related public goods and services as recreation facilities, flood protection, or de-pollution is the price people would be willing to pay for such services rather than go without them. Research is needed on this matter. Studies also need to be carried out to assess the effectiveness of other incentives to private action. In the case of adjustment of floods, for example, studies might be undertaken to determine the overall effects of an edict making it mandatory for flood-plain dwellers to purchase flood insurance, or the effects of building codes which only permit the construction of buildings that can withstand floods up to a certain specified level (such as the largest flood on record).

A *fourth* area of needed research relates to the role of perceptions and attitudes in decision-making. The way in which decision-makers perceive water problems and potential solutions to them conditions, to an important extent, the choices which they make. As noted earlier, problems are often perceived imperfectly and the range of solutions considered is typically narrow. Attitudes as to what the people want, and as to who should initiate action to deal with a given problem, also appear to play an important role in actual decisions.[45] Some pioneering work has been done in determining the role of perception in decision-making relating to floods[46] and droughts,[47] and in connection with the use of recreational areas.[48] Studies relating to the role of attitudes have also been carried out in connection with polution[49] and weather modification.[50] Such investigations, however, have been few in

[44] For a discussion of this view, see J. Hirschleifer *et al., Water Supply: Economics, Technology and Policy* (Chicago: University of Chicago Press, 1958), pp. 74-86.

[45] For a discussion see Gilbert F. White, "Formation and Role of Public Attitudes," *op. cit.*

[46] See, for example, Robert W. Kates, *Hazard and Choice Perception in Flood Plain Management,* Chicago: University of Chicago Department of Geography Research Papers, No. 78, 1962; Gilbert F. White, *Choice of Adjustment to Floods, op. cit.*; and Ian Burton and R. W. Kates, "The Flood Plain and the Seashore: a Comparative Analysis of Hazard Zone Occupance," *Geographical Review,* Vol. LIV, 1964, pp. 366-385.

[47] Thomas F. Saarinen, *Perception of the Drought Hazard on the Great Plains,* Chicago: University of Chicago Department of Geography Research Papers, No. 106, 1966.

[48] Robert C. Lucas, "Wilderness Perception and Use: the Example of the Boundary Water Canoe Area," *Natural Resources Journal,* 1964, pp. 394-411.

[49] See, for example, D. R. Lycan and W. R. Derrick Sewell, "Pollution as an Element of the Urban Environment of Victoria," *The B.C. Geographer,* Fall 1967.

[50] T. F. Saarinen, "Attitudes Towards Weather Modification: A Study of Great Plains Farmers," and W. R. Derrick Sewell and J. C. Day, "Perceptions of Possibilities of Weather Modification and Attitudes Toward Government Involvement," both in *Human Dimensions of Weather Modification,* W. R. Derrick Sewell (Ed.), pp. 323-328 and pp. 329-344, respectively.

number and much remains to be learned about the factors which condition perception and attitudes, and the extent to which the latter vary from one set of geographical circumstances to another. The relative importance of perception and attitudes in deicisions about different water problems is still unknown. Do attitudes towards responsibility for initiating action play a greater role, for example, in the case of pollution than they do in the case of domestic water supply? Greater understanding of perceptions and attitudes would make possible improvements in policy-making and implementation for it would permit the prediction of likely reactions to various alternative courses of action. Research in this connection, therefore, is likely to have a very high payoff, not only in terms of increasing understanding of human behaviour, but also in terms of improving decision-making.

Among the various types of studies that are needed in this connection, the following seem to be of particular urgency: in what ways do people perceive particular water problems (such as floods, droughts, or pollution) and what do they see as potential solutions (in the case of floods, do they see flood plain regulation, flood proofing, and flood insurance as well as flood-control works, evacuation, and compensation?); do the perceptions of the layman differ significantly from those of the specialist; how do attitudes about the nature of the problem and questions about who should initiate action, and what should be done, affect actual decisions; are there major differences in attitudes between the various groups that participate in the decision-making process (individuals, pressure groups, industrialists, administrators, and politicians); in what ways can attitudes be changed; and, most importantly, how do perceptions and attitudes vary from one place to another?

The determination of appropriate areal units for water management constitutes a *fifth* area of needed research. The river basin has often been suggested as the ideal unit,[51] and it has become increasingly popular in many parts of the world as the areal basis for planning.[52] Water management in the United Kingdom is now organized entirely on a river basin basis. It has been adopted so far to only a limited extent, however, in Canada.[53] Various explanations have been offered for this, including the problems of divided jurisdiction, the effects of historical precedent, and the large size of many of

[51] See United Nations, Department of Economic and Social Affairs, *Integrated River Basin Development,* New York, 1958. For a discussion of the underlying concepts of the river basin approach, see Gilbert F. White, "A Perspective of River Basin Development," *Law and Contemporary Problems,* Vol. XXII (Spring 1957), pp. 157-187.

[52] See Tennessee Valley Authority, *T.V.A.: Symbol of Valley Resource Development,* Knoxville, Tennessee: Tennessee Valley Authority, June 1961.

[53] See T. M. Patterson, *op. cit.* For discussions of actual applications see J. W. MacNeill, "Law and the Agencies," Transactions of the *Fourteenth B.C. Natural Resources Conference,* 1962, pp. 133-142; and E. G. Pleva, "Multiple Purpose Land and Water Districts in Ontario," *Comparisons in Resource Management,* H. Jarrett (Editor), Baltimore: Johns Hopkins Press, 1961.

Canada's river basins.[54] There has also been debate as to whether other areal units, such as urban-based regions might not be more appropriate as units for planning and development.[55]

Research needs to be undertaken on the various administrative forms that might be applied to the management of water resources, to determine which are the most appropriate for the various phases of such management. Should data collection, for example, be organized on a river basin basis? Should the river basin be used as a basis for outlining technical possibilities for development and then combined with other units, such as broader economic regions (which may encompass only part of the river basin or which may cover several river basins) for purposes of development? What factors inhibit the adoption of a river basin approach to water management in Canada? How can these be overcome? One of the most fruitful avenues of research in this connection would be an intensive study of a particular river basin, exploring the possibilities and difficulties of managing it on that basis.

5. The Value of Additional Information and Research

Viewed in terms of the seriousness of emerging problems, the inefficiencies that have occurred in water management, or what is spent in other advanced countries, investment in water resources research in Canada is extremely small. It is clear that a major expansion of this investment is required if optimum use is to be made of these resources. The need for much greater investment in social science research is especially urgent. The question arises, however, as to *how much* more money should be spent in this connection. Decisions must also be made as to the types of research that deserve priority, and as to which research agencies (government departments, universities, or private individuals or firms) should be supported. Such decisions are difficult to make, particularly because it is not easy to specify what the return on the investment will be. There is no simple relationship between research and payoff.

Nevertheless, criteria must be developed so that objective decisions can be made about the appropriate scale of investment in research and about the types of research that should be supported. A good deal of attention has been given to this matter in recent years[56] but there remain weaknesses in methodologies that are used for the economic evaluation of research. One of the most important is the assumption that there is a direct relationship

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[54] See J. W. MacNeill, "Water Resource Administration in Canada," in *Proceedings of the Resources for Tomorrow Conference* (Ottawa: Queen's Printer, 1961), pp. 331-336.

[55] See W. R. Derrick Sewell, "Multiple Purpose Development of Canada's Water Resources," *Water Power,* April 1962, pp. 146-151, and J. W. MacNeill, *loc. cit.*

[56] See, for instance, U.S. Committee on Science and Astronautics, *Basic Research and National Goals,* Washington, D.C.: U.S. Government Printing Office, 1965; Alvin Weinberg, "Criteria for Scientific Choice," *Physics Today,* Vol. 17 (March 1964), pp. 42-48; and F. M. Scherer, "Government Research and Development Programs," in *Measuring Benefits of Government Investments,* R. Dorfman (Ed.), Washington, D.C., 1965, pp. 12-70.

between the investment in research and the economic payoff.[57] Another is that there is seldom an attempt to weigh the payoff from a specified type of research with alternative types of research on which the money might be spent.[58]

Studies are needed to improve methodologies for evaluating the economic benefits of research. With the findings it would be possible to determine the appropriate magnitude of the research effort and the studies to which the investment might be profitably allocated.

Section 4

TOWARDS AN EXPANSION OF RESEARCH ON THE HUMAN DIMENSIONS OF WATER MANAGEMENT

The purpose of the foregoing section was to outline the types of social science research that are most urgently required in the water resources field in Canada. The list is highly selective, but judged on terms of the past record, in terms of the present availability of funds and personnel, or in terms of various institutional impediments to the expansion of research, it is a very formidable one. It is evident that changes must be made in policies relating to research funding, that liaison between those who do the research and those who use its results must be improved, and that better methods of disseminating information about research must be found.

1. Research Funding Policies

As noted earlier, investment in social science research in the water resources field in Canada has been very small. Less than $280,000 a year is presently allocated for this purpose, even when a very liberal definition of research is used.[59] Most of this money is provided by the Federal Government, principally through the action agencies (such as the Departments of Agriculture; Energy, Mines and Resources; and ARDA), the Canada Council, and the National Research Council. Provincial government agencies have supported social science research in this field to only a very minor extent.

[57] See Robert W. Kates and W. R. Derrick Sewell, "The Evaluation of Weather Modification Research," in *Human Dimensions of Weather Modification, op. cit.*, pp. 347-362.

[58] See James A. Crutchfield, R. W. Kates and W. R. Derrick Sewell, "Benefit-Cost Analysis and the National Oceanographic Program," *Natural Resources Journal*, Vol. 7, No. 3 (July 1967), pp. 361-375.

[59] The small amount of money allocated to social science research in the water resources field is symptomatic of the inadequacy of support for social science research in general and in Canada. At present less than $2 million is allocated to such research each year in this country. This represents less than 1 per cent of the total expenditures on scientific activity in Canada. For a discussion of the implications of this lack of support, see S. D. Clark, "The Support of Social Science Research in Canada," *The Canadian Journal of Economics and Political Science*, May 1958, pp. 141-150.

There is only a small amount of money provided by private foundations in Canada for such research. This contrasts with the situation in the United States and several other countries where an important part of the funding of social science research comes from private foundations. There is no Canadian equivalent of Resources for the Future, Inc., a Ford Foundation sponsored organization in the United States (although it should be noted that this organization has generously supported some resource studies in Canada). It has come to be highly respected in the United States because of the high calibre of the work it has produced and the independent viewpoint which it is able to take. It has worked closely with government agencies and with universities, and has contributed materially to training as well as research.

In the water management field as a whole the principal source of research support has been the Federal Government. In recent years, however, the physical sciences have also counted upon growing support from private industry, and through various international research programs, such as the International Hydrologic Decade (IHD) and the International Biological Programme (IBP). In contrast, the social sciences receive very little support from private industry or from those international research programs.

A result of the small allocation of funding in the Social Science field has been to restrict the training of new researchers at the universities, as well as to limit the potential contribution of government researchers and non-government researchers, both at the universities and elsewhere. The effect on resource management training programs at universities is clear. Not until very recently were there any such programs in Canada and anyone interested in obtaining training in this field had to go elsewhere, principally to the United States. Unfortunately, many of those who did so never returned to Canada.

It is clear, therefore, that there must be a major expansion in the funding of social science research in the water resources field in Canada to several times the present level. Given the list of topics urgently requiring attention, a target of $1 million a year appears realistic. But it is a target that should be pursued gradually. There are just not enough social scientists who are sufficiently capable and available at present to put that amount of money to work efficiently. Once the funds are made available, however, social scientists who are now working on other topics might turn their attention to the water resources field. At the same time training programs could be accelerated. A time period of three or four years, therefore, might be used for attaining the target of $1 million a year.

Guidelines will be required for the allocation of the expanded research funds. As noted earlier, greater emphasis needs to be placed on funding of research outside government agencies, particularly in the universities. In addition, attention must be given to training as well as research.[60] Another

[60] The basic elements of a university program for training and research have been described in Maynard M. Hufschmidt, "The Role of Universities in Water Resources Education," *Water Resources Research*, Vol. 3, No. 1, 1967, pp. 3-9.

problem is the relative emphasis that should be given to various types of research. Many of the problems requiring study are in the field of applied research, and doubtless there will be a motivation to allocate most of the funds to such studies. Care must be taken to ensure, however, that basic research in the social sciences is adequately supported. A proper balance must also be sought between research offering immediate results and that which will require several years before conclusions can be reached. The attainment of this balance will hinge in part on the adoption of a much broader view of funding in the social science field than has been the case to date. At present research grants are made available on an annual basis, generally without possibilities for renewal. This contrasts with the situation in the physical sciences where renewal is common. The annual basis of grants in the social sciences has doubtless limited the scope as well as the pace of research. The benefits from lengthening the time horizon, therefore, could be substantial.

Research funding policies also need to be broadened to take into account inter-disciplinary research. The nature of many water resources problems is such that there are important advantages to inter-disciplinary contacts in studying them. Problems relating to pollution are an obvious example. The matter of the provision of recreational facilities, or the preservation of wilderness areas are other illustrations. There are of course many others. At present most research funding is undertaken on a single disciplinary basis, and no convenient mechanisms exist for funding on a multidisciplinary basis.

2. Improvements in Liaison

Not only is it necessary to expand research on the human dimensions of water management, but it is also important to ensure that the results of such research are put to use. This will require improvements in liaison between such agencies, universities, and other organizations involved in research in the water resources field. Such liaison has been generally lacking in Canada thus far.[61] A consequence has been to limit severely the contribution of universities in the water management field, both in terms of the provision of personnel required by government agencies and industries, and in terms of research output. As a result, university professors have often remained merely critics of policy rather than as contributors to its improvement.

There are several ways in which liaison might be improved. One would be for government agencies and industries to discuss problems of resources management with university professors more frequently than has been the case in the past. This might be accomplished by the establishment of advisory committees on water policy at the Federal level and the provincial level, composed of government personnel, industry representatives and university

[61] This deficiency has been pointed out by several social scientists. See, for example, F. K. Hare, "A Policy for Geographical Research in Canada," *Canadian Geographer*, Vol. 8, No. 3, 1964, pp. 113-116.

professors. Liaison could also be improved by increasing the opportunities for university personnel to work on resource management problems in government agencies for a period of several months, and for representatives of government agencies to participate in resource management courses and seminars at universities.

Liaison also needs to be improved between the various disciplines interested in water problems. Typically, researchers in the water management field have worked in isolation from each other. It has become increasingly clear, however, that effective solutions to water problems may require inputs from several disciplines. Mechanisms are required to bring together researchers in the various fields involved. Several possibilities suggest themselves, including the establishment of inter-disciplinary Water Resources Institutes or Centers, and the development of inter-disciplinary training programs. A seemingly successful experiment has been undertaken in this connection at the University of Manitoba in which a water resources center co-ordinates a broad program of water resources research, provides a means of bringing together researchers working in a wide variety of disciplines, and maintains effective liaison between the university and various provincial government and Federal Government agencies and with industry. Proposals have been made for the establishment of Water Resources Centers and Institutes at universities elsewhere in Canada. How many centers or institutes should be set up, however, is an open question. The case for their establishment is most forceful where it is possible to show that they would lead to an improvement in the calibre of research and where the nature of the studies to be undertaken is such that it can benefit substantially from inter-disciplinary contact. There must be close co-ordination of the efforts of the various centers so as to avoid costly duplication of effort and so as to ensure that the most urgent questions are investigated. Such considerations should be borne in mind in the formulation of Federal and provincial policies for funding such centers.

The matter of improving liaison was the subject of a special study undertaken by one member of the social science advisory group. His report discusses in detail various strategies for achieving the needed co-operation and co-ordination.[62]

3. Improvements in Dissemination of Results

It is obviously not sufficient that the research effort be increased. It is even more important to ensure that the results be put to use. Of all the impediments to an expansion of research mentioned in the survey undertaken by the Study Group, the most frequently cited were the lack of funds and problems of disseminating results of research. It was noted that research results are frequently not published, and even when they are, they do not always appear in a form in which they can be of greatest value to policy makers.

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[62] See Michel Chevalier, *op. cit.*

Several suggestions were made as to ways in which the effectiveness of research programs could be improved by modifications in the methods of communication of results. One was for the establishment of a central data bank, using modern methods of storage and retrieval. Regional centers might also be established along similar lines. Another suggestion was for the publication of a catalogue of ongoing research, similar to the Water Resources Research Catalog published by the U.S. Office of Water Resources Research. A series of bibliographies on socio-economic aspects of water management and a Water Resources Thesaurus would also be invaluable in stimulating research as well as in improving communication.

Another possibility for encouraging an expansion of the research effort and for increasing its effectiveness would be the publication of a Canadian journal dealing with water problems. In the absence of such a journal the researcher is forced to depend upon journals published in the United States, which understandably are less interested in Canadian problems than American ones. Moreover, researchers have no convenient means of keeping abreast of studies that are being undertaken in various disciplines concerned with water management in Canada. The cost of such a journal would not be high but the returns in terms of improvement of research efficiency would doubtless be considerable.

Section 5

RECOMMENDATIONS

Based on the foregoing reviews of emerging problems of water management in Canada, the related social science research needs, and the various impediments to research in this field, the following recommendations are made for expanding the research effort.

1. *It is recommended that the level of funding for social science research in the field of water management in Canada be expanded from its present total of $280,000 a year to at least $1,000,000 a year.* Bearing in mind the present shortage of researchers, and the desire to ensure high calibre research, the funding should be increased gradually, to reach the recommended level by 1970. This would require a 50 per cent per annum increase in such funds over the next three years. It is believed that this represents a realistic target, taking into account the problems to be solved and the research capacity likely to be available to do the needed studies. The returns on the expanded effort are likely to be very high, and are likely to remain so with additional increments of investment in research. Diminishing returns are likely to set in only after investment has reached several times its present level.

2. *It is recommended that the proportion of funds allocated to the university community for research on the human dimensions of water problems be increased from its present level of about $100,000 to about $300,000 per year over the next two or three years.* The payoff from such an increase would be twofold: expanding the research effort on the one hand and increasing the number of future researchers on the other.

3. *It is recommended that funding continue to be provided by a variety of mechanisms, including mission-oriented agencies, special research funding agencies (such as the Canada Council and the National Research Council), and private foundations, but that a national advisory committee be established to co-ordinate the funding programs of the various agencies.* Such a committee should be composed of representatives from these agencies, the academic community, private foundations, and from private industry. Representation would be by appointment and for specified terms (say three years) subject to renewal. It is understood that plans are underway for establishing a committee along lines similar to those outlined above, to advise the Minister of Energy, Mines and Resources on the allocation of grants-in-aid for research in the water resources field.

4. *It is recommended that encouragement be given by the Federal Government to the establishment of private research foundations, such as through the provision of tax reduction incentives.* Canada could benefit considerably from an organization established along the lines of Resources for the Future, Inc. Such an organization would make it possible to fund independent appraisals of resource management problems, and to pursue basic as well as applied research. It would provide a useful link between government and the academic community.

5. *It is recommended that strong efforts be made to improve liaison between the academic community and government agencies, between government agencies and industry and between industry and the university community.* Several methods should be used in this connection, including the establishment of advisory committees at Federal and provincial levels of government, and the provision of opportunities for university personnel to work temporarily in government agencies, and for government employees to participate in university resource management programs.

6. *It is recommended that a number of Water Resources Centers be established in various parts of Canada to co-ordinate, encourage and raise the calibre of research.* Such Centers might be established to facilitate studies on a single area of research, such as pollution, or several areas of research. They might be organized within the physical sciences, or the social sciences, or they might be multi-disciplinary in nature. Care must be taken, however, not to proliferate such Centers. They should only be established

where they will facilitate an increase in research effort and an improvement in its calibre. Their function should not be regarded as that of a vehicle for obtaining research funds. Nor should membership of such a Center be regarded as a prerequisite for obtaining such funds. There are many researchers who can undertake productive research independently.

Where governments agree to provide support for the establishment of a Water Resources Center, a commitment should be obtained from the university involved to provide an equivalent amount of funds. It must be borne in mind that it may take several years before the returns on the investment in a Center begin to appear. Before establishing a Center, therefore, there must be assurance of support for several years.

The activities of the various Water Resources Centers across Canada might be co-ordinated through the establishment of a Water Resources Research Council for that purpose.

7. *It is recommended that strong efforts be made to improve the dissemination of results of research, such as through the establishment of data banks, and the publication of journals, catalogues of research, and bibliographies.* These efforts should be pursued at all levels of government, but the Federal Government should provide leadership in this connection. The Canadian Council of Resource Ministers could provide an especially useful vehicle for stimulating much of the needed effort.

Tables

Table 1.—Emerging Problems and Issues

1. *Minor Problems*
   - Day to day problems of operating water supply facilities.
   - Provision of water supplies for expanding urban areas.
   - Provision of storm drainage sewers for urban areas.
   - Preventing health hazards from roadside ditches and septic tanks.

2. *Major Problems*
   - Water shortages developing in arid regions (e.g. in the Prairies).
   - Major flood problems in several regions (British Columbia, Manitoba, Ontario, Quebec).
   - Declining water quality in some regions (e.g. in Ontario, Quebec, the Maritimes).
   - Lack of data on groundwater supplies.
   - Lack of information on water use.
   - Conflicts between different water uses (e.g. fish vs. power on the Fraser River, log driving vs. fish in British Columbia and the Maritimes).
   - Declining water levels on the Great Lakes.
   - Lack of trained staff.
   - Lack of research on water problems.

3. *Emerging Issues*
   - The definition of respective responsibilities of various levels of government in water management, emphasized by Columbia River Treaty experience.
   - Determination of basis upon which the Federal authority should provide funds for water development, illustrated by demands for Federal participation in non-traditional areas.
   - Determination of areas of co-operation for the development of interprovincial and international rivers.
   - Determination of whether, and under what circumstances, Canada should export water to the United States.
   - Determination of who is responsible for reducing levels of pollution in Canada: industries, municipalilties, provincial governments or the Federal Government.

Table 2.—Water Management Problems Classified According to Geographical Incidence

1. *Local*

    Drainage.
    Minor floods.
    Minor pollution.
    Minor conflicts in water use.

2. *Provincial*

    British Columbia
    - Floods on the Fraser River.
    - Possible over-allocation of available supplies in some regions.
    - Conflicts between fish and power, fish and log driving, pollution and other uses.
    - Erosion in Lower Fraser Valley.

    Alberta
    - Recreation needs in the Rocky Mountain foothills.
    - Water storage requirements for various purposes.

    Saskatchewan
    - Water shortages in several areas not adjacent to major rivers.
    - Sedimentation problems in small reservoirs.
    - Possibility of pollution from upstream areas.

    Manitoba
    - Flood problems on the Red River, Assiniboine River, and Lake Winnipeg.
    - Drainage of marshlands.
    - Long distance transmission of power from northern rivers.

    Ontario
    - Pollution problems on the Great Lakes and certain rivers.
    - Flood problems in Southern Ontario.
    - Erosion and sedimentation in Southern Ontario.
    - Increasing demands for recreation space.
    - Conflicts in water use, including irrigation vs other uses in Southern Ontario.
    - Water supplies for Southern Ontario cities.

    Quebec
    - Fluctuating levels on the St. Lawrence River.
    - Navigation problems due to winter ice.
    - Flood problems in various areas.

    Maritimes
    - Pollution of some major rivers,
        e.g. St. John River and tidal waters near mouth of that river.
    - Conflicts in water use,
        e.g. log driving vs fish power development.
    - Planning the development of major rivers on a comprehensive basis.
    - Lack of knowledge about groundwater supplies.

3. *Inter-provincial*

    Lack of co-ordinating mechanisms for planning and development of inter-provincial streams,
        e.g. Peace River, Ottawa River, Saskatchewan-Nelson River.

    Lack of devices for solving inter-provincial disputes over water use, such as use of Saskatchewan River for waste disposal.

Table 2 (cont'd)

4. *National*

Confusion as to the respective responsibilities of the various levels of government in water management, as in the problems of floods and recreation.

Difficulties of co-ordinating national goals with provincial goals in water development planning.

Conflicts between uses involving Federal jurisdiction and uses over which provincial authorities have complete control,
e.g. fish or navigation vs other uses.

Determination of the basis upon which the Federal authorities ought to contribute funds to development.

5. *International*

Increasing pollution on the Great Lakes.

Lack of ongoing mechanisms to co-ordinate planning of international rivers.

Lack of principles for determining and allocating gains from co-operative international river development schemes.

Table 3.—Water Management Problems Classified According to Professional Interests

1. *Engineering Aspects*

Lack of knowledge as to the magnitude and quality of the resource,
e.g. how much water is there and what affects its availability and its quality?

Problems of construction techniques,
e.g. construction in permafrost regions.

Problems of transferring power over long distances.

Problems of increasing the efficiency of water use,
e.g. what are the possibilities of developing techniques for re-cycling or techniques for evapotranspiration reduction, and what are the chances they will be adopted?

Problems of increasing water availability,
e.g. what are the costs of desalination, de-pollution, and weather modification, and are these techniques likely to be adopted?

2. *Economic Aspects*

Economic gains and losses from water resource development schemes,
e.g. what are the overall gains and losses from the development of an irrigation project in the Prairies or a hydro-power project in British Columbia?

Value of water in alternative uses,
e.g. is it better to use the Fraser River for migration and spawning of fish rather than for other potential uses?

Evaluation of alternative means of supplying water-derived goods and services,
e.g. what are the overall gains and losses from providing recreation on a given lake or river compared with providing recreation in an urban area?

Evaluation of alternative operations of river development systems,
e.g. what are the relative gains and losses in the various parts of a river system when the system is operated for flood control instead of power production?

Determination of factors underlying water demands,
e.g. what is the impact of pricing on water consumption?

Estimation of future water demands in various regions and in the nation as a whole,
e.g. what is the demand for water for various purposes in the different regions of Canada?

Determination of economic benefits of providing public goods such as flood protection and recreation,
e.g. what would people be prepared to pay for such services if they were given the choice of paying or going without them?

Determination of economic benefits of investment in research,
e.g. which types of research can be evaluated in economic terms and what factors need to be taken into account in determining payoffs from such investment?

3. *Sociological Aspects*

Impacts of water management projects on social systems within and beyond the project area,
e.g. in what ways does the introduction of irrigation into a community affect the relationships between those who adopt it and those who do not?

Table 3 (cont'd)

3. *Sociological Aspects* (cont'd)

Impacts of various social considerations, such as education, attitudes and perceptions, on decision-making in water management,

e.g. to what extent does the attitude of the city water manager as to what the people will tolerate affect his decision whether to bring in new supplies or to re-cycle water from a polluted stream?

Influence of various factors on the acceptance of new techniques,

e.g. what accounts for the differential response to weather modification in various regions?

4. *Institutional Problems*

Influence of jurisdictional constrains on decision-making,

e.g. to what extent does the division of jurisdiction set out in the BNA Act inhibit water development in Canada?

Influence of legal constraints on decision-making,

e.g. to what extent do existing laws inhibit the allocation of water into its most profitable uses?

Adequacy of the present administrative framework to cope with emerging problems of water management.

Appropriateness of various types of administrative agencies for dealing with planning, development, and management of water resources, such as the consolidation of all functions in one agency compared with the establishment of an agency for co-ordinating the functions of several agencies.

Determination of appropriate areal units for planning, development and management of water resources, such as river basins or urban regions.

Determination of appropriate responsibilities of various levels of government in planning, development, and water management,

e.g. in what ways can the Federal Government most usefully assist in the undertaking of research, data collection and planning?

Determination of the relationship of water development projects to those who benefit and to those who pay,

e.g. what should be the areal basis for charging for the support of a flood protection project—the flood plain or the province as a whole?

Determination of means of reconciling Federal, provincial, and local objectives in water development.

Table 4.—Water Management Problems Classified According to Phases in the Planning and Development Process

1. *Research*
   - Scarcity of funds available for research.
   - Lack of personnel and facilities.
   - Lack of mechanisms to ensure research results will be used.
   - Problems of determining priorities for research and the value of research.
   - Determination of the role of water resources research institutes,
     - e.g. which types of research are more efficiently pursued through such an institute than in its absence?
   - Determination of the allocation of support among universities, industry, and government agencies,
     - e.g. what are the relative advantages of reducing government "in-house" research and increasing university research support?

2. *Data Collection*
   - Determination of appropriate areal units for data collection,
     - e.g. Census Divisions versus watersheds.
   - Determination of appropriate time intervals for data collection,
     - e.g. Census years or more frequently.
   - Development of means of making information in private files available for research purposes,
     - e.g. in insurance companies.
   - Increasing the sophistication of land use surveys to include data relating to economic, social, and political considerations.
   - Determination of value of additional information.
   - Increasing the usefulness of data already collected by expanding data analysis.

3. *Planning*
   - Determination of goals and objectives of water management, and selection of time horizons for planning.
   - Co-ordination of planning efforts of various levels of administration,
     - e.g. what types of administrative devices are required?
   - Determination of appropriate boundaries of the planning region,
     - e.g. is the river basin the most appropriate region or are other units more suitable for certain purposes?
   - Problem of determining how closely the various phases of water management should be linked together,
     - e.g. should planning and implementation be the responsibility of the same agency?
   - Problem of linking water resources planning to planning in other connections,
     - e.g. planning for economic development.
   - Determination of appropriate criteria for selecting among alternative water uses and alternative plans.

4. *Implementation*
   - Problem of translating goals and objectives into plans that are politically acceptable,
     - e.g. determination of why some plans are implemented and others are shelved.
   - Confusion as to the respective responsibilities of various levels of administration,
     - e.g. determination of which level of government should initiate action in cases where jurisdiction is in doubt.
   - Determination of the most effective mechanisms for financing water resource development,
     - e.g. loans versus grants.

Table 5.—Water Management Problems Classified According to Elements in Decision-Making

1. *Range of Choice*

Problem that range of alternative uses or alternative means of dealing with water problems is usually very narrow, thus increasing the possibility that an inefficient choice will be made,

e.g. the concentration of bringing in water from afar instead of considering making better use of existing supplies.

Problem that emphasis is generally placed on technical alternatives rather than alternatives involving changes in patterns of human behaviour,

e.g. the concentration on dams and dykes to solve flood problems compared with emphasis on flood plain zoning or flood insurance.

2. *Estimate of the Resource*

Lack of knowledge as to the magnitude and quality of water resources in various parts of the country,

e.g. which types of data are most urgently required and who should collect this information?

Lack of knowledge as to actual and potential uses of available water supplies,

e.g. which types of data are most urgently needed and who should collect this information?

Lack of knowledge as to factors which condition water demands,

e.g. what is the potential effect of pricing policies, or technological innovations on water demands?

3. *Technology*

Lack of knowledge as to the extent to which various technologies are known and applied in water management in Canada, such as in agriculture or industry, or in adjustment to floods,

e.g. to what extent could water-use efficiency be improved by more widespread adoption of new techniques?

Lack of knowledge as to factors which encourage or inhibit the adoption of innovations in water management.

4. *Economic Considerations*

Determination of the gains and losses from water development projects,

e.g. how can various gains and losses be identified and measured?; what needs to be done to improve present techniques of measurement, particularly in the case of non-marketed goods and services, such as recreation or flood protection?

Problems of taking into account time, risk, uncertainty, externalities and intangibles in the analysis,

e.g. what is the appropriate discount rate?; how can the downstream effects of pollution be identified and measured?

Determination of the importance of water as a factor in the location of various activities,

e.g. what is the propensity of water supplies to attract income-generating activities to a region?

Determination of the costs of various constraints in the development of water resources,

e.g. what is the cost of divided jurisdiction or the cost of the lack of co-ordination in water management?

Determination of the costs and benefits of increasing the fund of information,

e.g. what is the economic value of various types of data in planning and operating water systems?; when does the incremental value of additional information begin to decline?

Table 5 (cont'd)

5. *Spatial Linkages*

Determination of the impacts of water development beyond point at which the development takes place,
e.g. what is the impact of waste disposal on downstream water users?; what are the effects of dam construction on stream flow and ecology of a region and in what ways are these effects manifested in gains and losses?

Determination of the effects of development elsewhere on the project or water use in question,
e.g. to what extent does development of one river preclude development of other rivers in a province, for instance, through the pre-empting of power markets?

6. *Social Guides*

Determination of the influence of perceptions and attitudes on decision-making in water management,
e.g. to what extent do imperfections in the perception of flood hazards or pollution, and attitudes as to who is responsible for initiating action, account for the typical crisis-sponsored approach to these problems?; to what extent do perceptions and attitudes of specialists and professionals differ from those of the layman?

Determination of the extent to which the specified goals and objectives of water development are in fact achieved,
e.g. has the PFRA achieved the goals it set out to achieve?; how effective has the Canada Water Conservation Assistance Act been?

Determination of the ability of the existing administrative framework to cope with the emerging problems of water management,
e.g. to what extent are improvements in co-ordination within and between levels of administration required to improve the efficiency of water management?

Determination of the roles that the various levels of administration can most effectively play in the management of water resources,
e.g. in what ways might the Federal Government provide leadership in dealing with water problems, and especially those where there is confusion as to who is responsible for initiating action?; what kind of institutional framework would be desirable for comprehensive planning and development in an inter-jurisdictional river basin?

Determination of the roles that can be played most effectively by the public sector and the private sector in water management.

Determination of criteria that can be used in allocating water among competing users and that can be employed in selecting among competing projects,
e.g. what considerations should be taken into account in decisions relating to the preservation of anadromous fish runs?; what should be the relative importance of such factors as historical precedent, existing laws, economics, social considerations, and aesthetic considerations?

Determination of ways in which incentives may be provided to stimulate private action as an alternative to public action,
e.g. what incentives might be provided for industrialists to reduce water pollution as well as enacting de-pollution regulations?

Table 6.—Expenditures in 1966 on Categories of Water Resources Research Identified by the Science Secretariat Questionnaire

Code	Category	$'000	Percentage of Total
100	Nature of Water	42.5	.5
200	Water Cycle	3,909.9	46.6
300	Water Supply Augmentation and Conservation	428.2	5.1
400	Water Quantity Management and Control	300.5	3.6
500	Water Quality Management and Control	2,518.2	30.0
600	Economic, Social and Institutional Aspects	279.4	3.3
700	Resources Data	427.0	5.1
800	Engineering Works	484.0	5.8

Table 7.—Expenditures on Social Science Research[a] in Water Management in Canada by Various Types of Agency in 1966
$'000

Code	Sub-categories	Fed. Govt.	Prov. Govt.	Ind.	Univ.	Non-Profit Orgs.	Total
601	Planning	16.0	14.0	—	20.8	—	50.8
602	Evaluation Process	33.0	5.0	—	21.1	—	59.1
603	Cost allocation, cost sharing, pricing/repayment	—	2.0	—	—	—	2.0
604	Water requirements	—	25.0	—	30.0	—	55.0
605	Water law	—	—	—	2.8	—	2.8
606	Institutional aspects	—	2.0	70.0	9.1	—	81.1
607	Sociological and psychological aspects	—	—	—	28.6	—	28.6
608	Ecological aspects	—	—	—	—	—	—
	Total	49.0	48.0	70.0	112.4	—	279.4
	Percent of Total Expenditures on Water Research						3.3

[a] Assumed to relate principally to the Category 600 (Economic, Social, and Institutional Aspects) defined in the Science Secretariat Questionnaire.

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Table 8.—Type of Economic Studies Needed in the Field of Water Management in Canada

1. *Theoretical Research*
   - A. Welfare Economics
     - e.g. (1) Specification of objective functions;
       - (2) Problems of measuring utility;
       - (3) Problems of optimizing under various constraints, such as income redistribution;
       - (4) Problems of taking indivisibilities and externalities into account;
       - (5) Problems of measuring opportunity costs;
       - (6) Problems of decision-making under uncertainty;
       - (7) Problems of selecting appropriate social discount rates.
   - B. Econometrics
     - e.g. (1) Problems of deriving demand functions;
       - (2) Problems of estimating costs;
       - (3) Models of the regional economy;
       - (4) Models of land use and transportation.
   - C. Economic Structures and Organizations
     - e.g. (1) Studies of centralized versus decentralized decisions;
       - (2) Problems of estimating costs;
       - (3) Models of the regional economy;
       - (4) Models of land use and transportation.
   - D. Mathematics, Operations Research, and Computer Science
     - e.g. (1) Development and application of mathematical programming, and optimizing techniques;
       - (2) Simulation modelling.

2. *Base Studies*
   - A. Regional Planning and Projection
     - e.g. (1) Demographic studies;
       - (2) Analyses of economic growth in various regions;
       - (3) Studies of impacts of technological change;
       - (4) Studies of changing patterns of land use.
   - B. Public and Private Investment in Various Sections of the Economy
     - e.g. (1) Estimates of payoffs in various economic activities;
       - (2) Estimates of payoff in infrastructure development.
   - C. Targets and Constraints for Various Levels of Administration
     - e.g. (1) Identification of goals of regional development;
       - (2) Analyses of impacts of income redistribution constraints;
       - (3) Analyses of impacts of taxation constraints;
       - (4) Analyses of impacts of water law and various institutions.

3. *Water Service-Demand Studies*
   - A. Descriptive inventories of water use in each category of water use, such as industrial water use, domestic water supply, agriculture, and various non-consumptive uses.
   - B. Analytical studies relating to each use, taking into account the effects of pricing, technical substitution possibilities, and impacts of water availability and price on industrial location decision.

4. *Histories, Case Studies, and Postmortems*

A. Histories of Decisions and Subsequent Impacts

e.g. (1) Impacts on various economic activities;

(2) Impacts on other activities or phenomena, such as on plant and animal ecology.

B. Hindsight Evaluations

e.g. (1) Assessment of the extent to which announced goals have in fact achieved a particular goal, and the extent to which unpredicted consequences occurred;

(2) Examination of the influence of various constraints on the outcomes.

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Table 9.—Summary of Types of Needed Research Relating to Legal and Institutional Aspects of Water Management in Canada

Phase 1: THE IDEAL (theory)	Phase 2: THE SITUATION (inventory)	Phase 3: THE DESIRABLE (critique)	Phase 4: THE POSSIBLE (action)
1st level: Law	*1st level: System of ownership*	*1st level: Law*	*1st level: with BNA Act*
0. Statement of the problem: —requirements and limitations Legal requirements: —ownership	8. System (water+base) government action	14. Analysis of existing law (0+10)	23. Description of provincial responsibilities
1. Characteristics	9. Inventory of regulations	15. New legal norms (2+5+4)	24. Description of Federal responsibilities
2. Choice of system (0+1) —government action	10. Analysis of water law (8+9)	16. Resultant amendments to existing law (14+15)	25. Theories of interpretation
3. Operative intervention	*2nd level: Institutions*	*2nd level: Institutions*	26. Analysis of the present constitutional distribution of powers (15+19+23+24+25)
4. Regulation (0+2)	11. Inventory of responsible public bodies	17. Examination of water institutions (7+13)	27. Responsible authorities to be reformed (23+24+25+15+16+19+20+22)
5. Choice of management techniques (3+4)	12. Inventory of supplementary private bodies	18. New Institutions (7+17)	28. Joint legislation and delegated bodies (26+27)
2nd level: Institutions	13. Synthesis of the administrative complex (11+12)	19. Constitutional texts (17+18)	29. Parallel legislation and methods of co-ordination (26+27)
6. Administrative models		20. Resultant amendments to existing laws (11+12+19)	*2nd level: other than BNA Act*
7. Institutional choices (5+6)		21. System of procedures (15+19)	30. One single authority (7+23+24)
		22. Laws of procedure (19+21)	

Table 10.—Science Secretariat Meeting on Social, Economic and Institutional Aspects of Water Resources Research

Toronto—June 5-6, 1967

LIST OF PARTICIPANTS

Consultants to Science Secretariat

Professor W. R. Derrick Sewell (Prime Consultant), Departments of Economics and Geography, University of Victoria

Mr. Michel Chevalier, Institute for Environmental Studies, University of Pennsylvania

Professor Richard Judy, Department of Political Economy, University of Toronto

Professor Lionel Ouellet, Department of Economics, Laval University, Quebec.

Invited Specialists

Mr. Alan Albury, Consulting Engineer, Toronto, Ontario

Professor Ian Burton, Department of Geography, University of Toronto

Dr. H. F. Fletcher, Department of Energy, Mines and Resources, Ottawa

Mr. J. P. Gourdeau, Consulting Engineer, Montreal, Quebec

Dr. Joseph Kates, Consultant, Toronto, Ontario

Professor Ed. Kuiper, Department of Civil Engineering, University of Manitoba

Mr. W. Packman, Consultant, Ottawa, Ontario

Professor E. G. Pleva, Department of Geography, University of Western Ontario

Professor Gunter Schramm, School of Natural Resources, University of Michigan

Mr. Gilbert Tardif, Consulting Engineer, Quebec.

Steering Committee

Mr. James P. Bruce, Science Secretariat

Mr. Christian H. de Laet, Canadian Council of Resource Ministers, Montreal

Mr. James W. MacNeill, Department of Energy, Mines and Resources, Ottawa

Mr. Michel Slivitsky, Department of Natural Resources, Quebec.

Science Secretariat

Dr. Dirk E. L. Maasland, Science Secretariat, Ottawa

Mr. G. T. McColm, Science Secretariat, Ottawa.

Appendix

The Science Secretariat engaged four consultants to study the social, economic and institutional aspects of water resources research. The consultants were:

M. Michel Chevalier—Institut d'Urbanisme, Université de Montreal

Dr. Richard Judy—Department of Political Economy, University of Toronto

M. Lionel Ouellet—Department of Political Economy, Laval University

Dr. Derrick Sewell (*Chairman*)—Departments of Economics and Geography, University of Victoria

Each consultant submitted a report, which served as a background document for the present report written by the Chairman of the group. The individual reports are expected to be published in appropriate journals. At the time of publication of this report it was not possible to state the appropriate references, because the four documents had not all been submitted for publication. Interested readers may at a later date inquire at the Science Secretariat for this information.

Brief abstracts of the four background studies follow below.

I. PLANNING FOR THE DEVELOPMENT AND USE OF SOCIAL SCIENCE RESEARCH FOR THE PROBLEM OF CANADIAN WATER RESOURCES MANAGEMENT

By Michel Chevalier

This paper defines a general planning strategy for relating social science research to water resources management. An underlying approach is offered, designed to act as a basis for more specific strategies.

Difficulties of reviewing social science research accomplishments and needs in water management stem from the field's close but unclear relationship with other functional areas and from the multiplicity of organizations involved in it. It is not enough simply to make a review. As the initial inventory can at best be no more than a preliminary and disjointed one, a straightforward and rational planning response in operational terms cannot readily be made. To make operational use of the inventory, then, a way progressively to revise and extend it is needed.

A strategy for this purpose is proposed. It defines two related systems, one made up of organizations primarily engaged in water resources management (e.g. public agencies), the other of organizations primarily engaged in social science research (e.g. universities). The main consideration is the nature of the interaction between these two systems as represented by the activities of organizations across system boundaries.

The task force mechanism is proposed as an illustration that organizational change in the water resources management system is a prerequisite to the development of the strategy. A specific example of a task force role in national water policy formation is given.

A main directional goal is defined for the strategy—an intensification of the relationships between the two systems considered in the context of both product and process values. The goal has two aspects—a strengthening of the capability of the social science research system to provide knowledge to the water management system, coupled with a strengthening of the capability of the water management system to make use of it.

Three kinds or stages of organizational interpenetration between the systems are described. *One* is that of water management organizations to the social science research system as represented by the support or commissioning of research activity. *Two* is the reverse interpenetration, that is, the carrying out of social science research relevant to water management. *Three* is joint interpenetrations and represents the application of social science research in water management settings.

The goal aspects together with the kinds of interpenetration are designed to provide a common denominator for water managers to assess the kinds of social science research programs they should support, from both the substantive and organizational standpoint.

II. ECONOMIC PROBLEMS IN WATER RESOURCES MANAGEMENT

By Richard W. Judy

The report indicates areas of economics and water resources management where research seems likely to produce important payoffs. It is difficult to specify the priorities which should be attached to research on the various topics. Major progress in any one of them would make an important contribution to more efficient resource allocation in water systems management. Nevertheless, three topics are singled out as deserving special emphasis and support. These are: (1) Demographic and economic base studies, (2) Industrial, residential, and agricultural water-service demand studies, and (3) Digital simulation models for complex systems analysis.

In science there should be strong interaction between empirical analysis and practical problem-solving on the one hand and the development of theory on the other. Necessity is often the mother of invention in science just as it is elsewhere. The strategy of research support should take account of this. The theorist working in isolation from empirical reality is likely to produce errored or irrelevant theory. The practitioner who is uninterested in conceptualization and theory can make little progress in perfecting the methodology of his work. For these reasons, it is desirable to seek extensions of theory and the solution of practical problems in one and the same study. Although topics of theoretical research have been separated from those of more applied nature, there is every reason to expect that the two should progress simultaneously.

Investment in theoretical research will reap its greatest dividends if it supports the work of scientists strongly interested in improving the theory and methodology of decision-making and who accept the field of water resources management as a testing ground for the development of their ideas.

Canada has many competent economists, operations researchers, mathematicians, and computer scientists who would be capable of making important contributions to the topics mentioned in the report. But it is necessary to turn their interests and attention to those topics and to support their research.

At both the provincial and Federal levels of government there are economists working in government agencies who could assume much of the burden for producing the economic base studies. Such base studies are perhaps less "research" than they are "development" because they are based on existing economics methodology. The important point to be stressed is that these studies are vitally necessary to the development of the water-services demand functions recommended in the report.

The methodology of water-services demand function estimation is much less developed. Much basic research and experimentation remains to be done and it is desirable to attract to this research the talents of imaginative economists working in the government service and universities. Many Canadian universities have staff members who, if their talents were so directed, could contribute measurably to progress in this field. Graduate students working on theses and dissertations could benefit themselves and the field of water resources management if they were to select topics from this area for their research.

The design and use of digital simultation models is a very young art. The technique holds great promise for water resources management because it creates the analogue of a laboratory in which alternative system designs may be tested and evaluated. Research work, especially in the universities, should be energetically supported.

In selecting research projects for financial support, it seems unwise to confine the view only to members of water resource research centres. Economists and other scientists capable of making major contributions can be found in every province of Canada; those with a theoretical bent will often not have affiliated themselves with a centre or institute oriented towards research in any specific empirical field. If one seeks real breakthroughs, some of these people must be attracted to research in the water resource management field. To make financial support for their research contingent upon membership in a water resources research institute would therefore be unwise.

The major constraint hindering the needed increase of research efforts in the water resources management field is financial. Many economists and other scientists of high calibre are available in Canada, and a substantial number would be prepared to devote their talents and energies to research in this field, given adequate financial support. Considering the kinds of problems that presently occupy the attention of many economists, it is felt that the real opportunity cost of diverting those attentions into research in water resources management would not be excessively high.

III. BIBLIOGRAPHIE SUR LES EAUX CANADIENNES

(doctrine—articles de revues—jurisprudence)

By Lionel Ouellet

This document will be published by the Secretariat of the Canadian Council of Resource Ministers.

IV. THE ROLE OF GEOGRAPHICAL RESEARCH IN WATER RESOURCE DEVELOPMENT IN CANADA

By W. R. Derrick Sewell

1. The Focus of Research to Date

The development and use of natural resources have provided a major focus for geographical enquiry in several parts of the world. Some valuable contributions have been made both to the fund of knowledge and to theory in this connection, particularly in the field of water resources. In Canada, geographical research relating to water resources has tended to concentrate on three main lines of enquiry: factors affecting the distribution of these resources, the development of water resources in particular regions, and the influence of various institutional factors in decision-making.

The distribution of water resources is affected by a wide variety of physical factors, including climate, terrain, and geology. Such factors have received considerable attention by Canadian geographers, and some important contributions have been made to the literature in this connection, as is noted in recent reviews. Although only a few of the studies have been undertaken with water resource development in mind, many of them have provided material that has potential value in this regard. Thus far the principal concentration has been on the Canadian North, the St. Lawrence and the Great Lakes, but interest in other regions is now growing. At the same time Canadian geographers are making some important contributions to research on hydrology and to techniques of identification and measurement of physical phenomena, such as subsurface water flows.

A second focus of geographical research has been on the development of water resources in particular regions. Here again the principal emphasis has been upon the St. Lawrence-Great Lakes drainage system and the Mackenzie River. This concentration reflects a recognition of the focal point of Canadian economic activity on the one hand, and the Canadian geographer's interest in the North on the other. Particular attention has been given to the St. Lawrence Seaway and its contribution to the economic growth of the Great Lakes region and to the nation as a whole. Other studies have dealt with the development of hydro-electric power, and with floods in various parts of the country. Most of the earlier studies were descriptive accounts and used relatively simple tools of analysis. Few of them added to theory. More recent contributions have reached higher levels of sophistication, particularly through the use of quantitative methods of statistical analysis and economic analysis. A number of Canadian geographers have assisted in the improvement and adaptation of methods for use in the appraisal of water resource development projects.

The third type of study relates to the influence of various institutional factors in decision-making relating to water management. Important among such factors are problems resulting from divided jurisdiction, administrative arrangements, and legal constraints. Geographers have examined the influence of these factors on river basin planning in various parts of Canada, notably in Ontario, the Prairie Provinces, in British Columbia and in the Territories. Most of these studies have been undertaken in the past five years, reflecting a growing interest among Canadian geographers in policy questions.

The foregoing review indicates that Canadian geographers have made some important contributions to water resources planning and development. It also shows that there have been some significant shifts in the focus of geographical research in the water resources field in recent years. There has been a change in emphasis from physical aspects of water management to economic, social and political aspects, accompanied by increasing use of more sophisticated tools of analysis and by a growing interest in public policy questions in the resources field.

2. New Horizons for Geographical Research

Given the increasing interest and capability of geographers in the field of water resources, what are the types of research that they might usefully undertake in the search for solutions to the emerging problems of water management in Canada? Taking account of the kinds of studies that have been undertaken by geographers in Canada and elsewhere in the water field directly and in cognate fields, four major types of study suggest themselves. These are concerned with estimating the magnitude and possible uses of Canadian water resources; the analysis of spatial impacts of development; the influence of institutional constraints in the formulation and implementation of resource development plans; and the role of perception and attitudes in decision-making. The various types of research are described in detail in the report on geographical studies prepared for the Science Secretariat.

Undertaking the needed research will require some important changes in funding mechanisms and in training programs at universities. At present less than $60,000 a year is spent on Canadian water resources research in the field of geography. Several possible explanations may be offered for this. One is that very few Canadian geographers have been interested in water resources problems and particularly in the public policy aspects of such problems. Of the 150 or so professional geographers in Canada, probably no more than a half dozen have made continuing contributions to water resources research. A second explanation is that there have been very few agencies making funds available for geographical research. The Geographical Branch of the former Department of Mines and Technical Surveys and the Canada Council were about the only possible sources and neither of them were especially interested in water resource studies. A third possible explanation is that programs of graduate training in Canadian universities have only recently begun to offer courses in water resources management. The lack of such courses in the past has inevitably meant that the supply of resource geographers in Canada has been small. Most students who have been interested in this field have had to go to the United States for graduate training and many of them have not returned to Canada, partly because of the greater availability of research funds there but also because of the lack of job opportunities here. Water management agencies have tended to be staffed almost entirely by engineers.

During the past five years, however, some important developments have occurred which have improved the prospects for employment of geographers and for the expansion of geographical research. The Federal Government and several provincial government agencies have broadened their view of the potential contribution of geographers to policy formulation and implementation. At the same time, there has been a gradual increase in the amount of money available for research in the water resources field, not only for the investigation of physical aspects but also for the study of human dimensions. A third change is the development of resource geography programs at more than a dozen universities across Canada, some of which extend to the graduate level.

3. Guidelines for the Future

Important as these changes have been, they are clearly only a beginning. Further modifications of existing policies and programs will be required if the needed geographical research is to be undertaken. A much larger allocation of funds for such research is urgently required. Part of the additional funds should be spent on developing training programs, for it is only in this way that increasing numbers of researchers will be made available. In addition, a much broader view of funding must be taken in the social science field than has been the case to date, providing long-term grants as well as annual grants. Funds should also be provided for inter-disciplinary research programs. At present no convenient mechanism exists for the funding of such programs. The Canada Council and the National Research Council should consider the establishment of a special joint committee to screen applications for inter-disciplinary research support. Another urgently needed improvement is the establishment of more effective liaison between government agencies and the universities and between industries and universities. Such liaison has been generally lacking in Canada thus far. It could be improved by such means as the appointment of university professors on advisory committees, the establishment of retraining programs at universities in which government servants would participate either as students or as lecturers, and by engaging university personnel to work on topics of high importance in government agencies, either during summer recesses or on a longer term basis.