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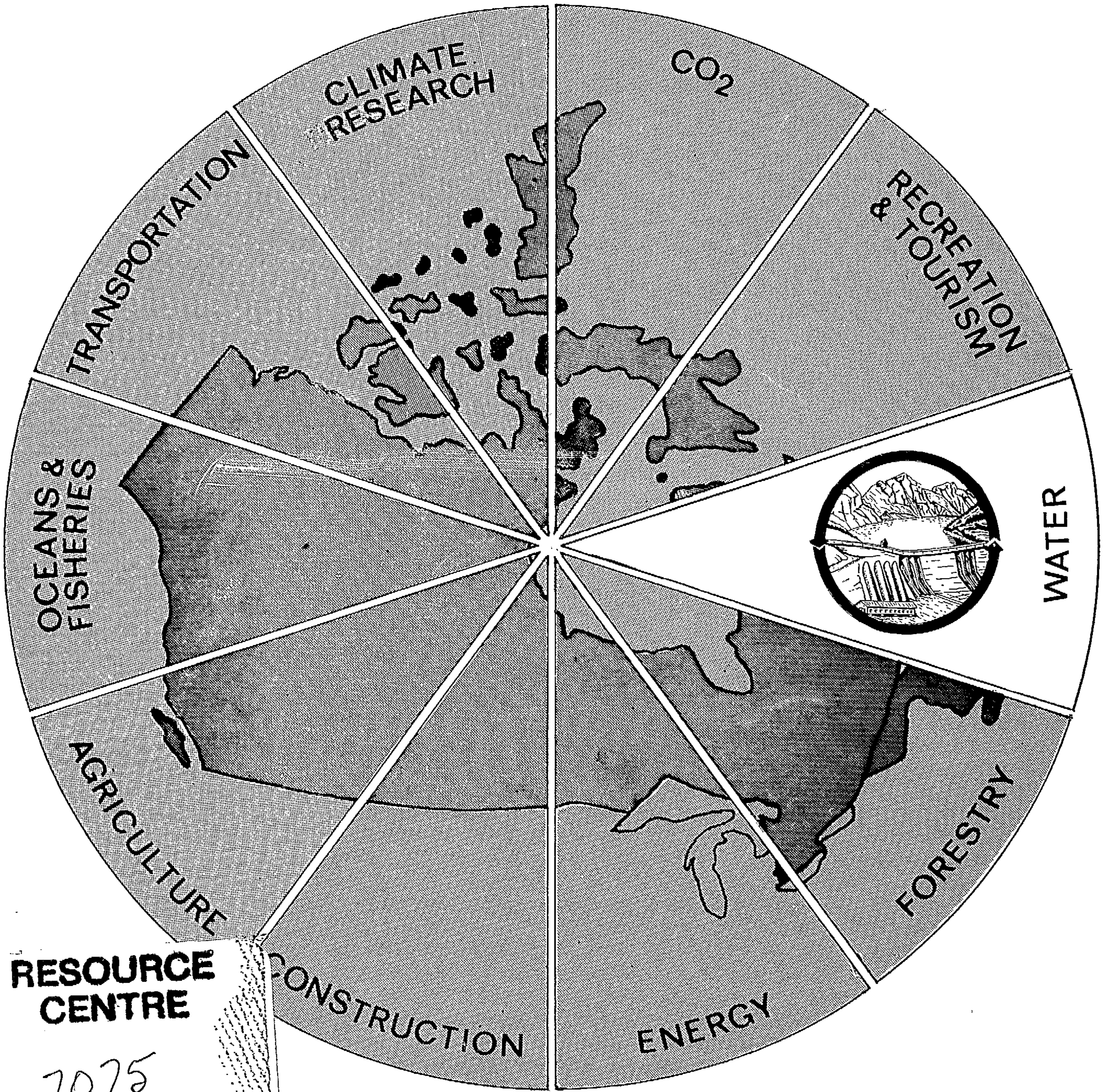
PROCEEDINGS OF THE CCP WATER RESOURCES-CLIMATE WORKSHOP



BRUARY 28–29, 1980

EDMONTON

CANADIAN CLIMATE PROGRAM

PROCEEDINGS OF THE WATER RESOURCES WORKSHOP

EDMONTON, FEBRUARY 28 AND 29, 1980

Sponsored by: Environmental Management Service
Alberta Climatological Association
Atmospheric Environment Service

Water Resources Workshop

Sector Summary and Recommendations

Water is a universally important resource. It plays a crucial role in the management and development of agriculture, energy, transportation, forestry, wildlife, inland fisheries, mining, recreation and tourism, water supply for industrial, municipal and rural uses, pollution abatement, etc. Both water and air are so basic to Canada's economic and social activities that their importance is all too often overlooked.

Atmospheric processes are reflected, though modified, in the hydrologic process. Water resource planners and managers are intimately concerned with weather information, climate definition and associated anomalies and impacts. Ninety per cent of the water which is withdrawn for water supply in Canada comes from surface water resources, while the remainder is from ground water. Both these sources are dependent on precipitation for renewal. The availability of Canada's water resource thus depends basically on precipitation, evapotranspiration rates and terrain and soil conditions in each region.

Water is central to most climate change problems, be they associated with man's activities or natural variability. Climatic warming, for example, has major significance for Canada: alteration of the break-up and freeze-up regimes of northern rivers; increased aridity in southern regions requiring adjustment of water systems, allocations and regional land-use and development; and, change in extent of snow cover and ice fields and the resultant effect on timing and amount of snowmelt runoff and subsequent effects on flood flows, hydro production or water supply. Man's activities in diverting northern rivers into more southern regions have large potential impacts on Arctic sea ice conditions and ultimately on our hemispheric climate. Such major impacts must be assessed. Climatic risks have been a traditional design problem and the potential consequences of extremes and persistence as well as natural variability must be known if hydrometeorological data are to be transformed into planning and policy information. In addition to this fundamental question of the impact of climate on large water resource developments, there is the equally important problem of the impact of these developments, such as dams and irrigation, on climate both, regional and national scale.

Deficiencies in hydrometeorological information currently exist and adversely affect all aspects of the water resources sector. There is a need for more climatic data in remote, and currently data sparse, but economically important, regions of Canada. Additional specialized analyses would be of benefit. Runoff is an areally integrated parameter; there is a demand for similar areal estimates of hydrometeorological parameters, particularly precipitation. Proxy data are required to extend the historical hydrometeorological record, and appropriate means are needed for their acquisition, interpretation and use in the evaluation of streamflow, floods and lake levels. Continued research into hydrological processes characteristic of cold regions is necessary. Improved access to data in the computer archive, faster publication of climatic information, and incorporation on non-standard short-term hydrometeorological data into existing data banks would improve service. Finally, there is a need for better coordination and communication among agencies, particularly in relation to joint network planning.

The Canadian Climate Program (CCP) must address the needs of the water resource sector to provide climatic information not only for planning and design purposes, but also for the construction, operation and management of water resource projects and for the investigation of climate-water interrelationships in wildlife and inland fisheries. This includes: assessment of the impact of climate change and climate variability on the water resource sector; assessment and priorization of the needs for climate data, services and predictions; and identification of the input that research workers in the water resource sector can make to the understanding of climate and climatic change.

Recommendations

The final recommendations of the Workshop are summarized below according to the general categories of service, research and development and institutional. They reflect the needs of the water sector in general across Canada. The specific recommendations of each working group are provided in the working group reports later in this report.

Service

1. Enhance the climatological data base by matching networks to user needs, such as:

   a) expanding and upgrading the existing hydrometeorological network in data sparse regions where future economic development presents current design and planning problems, especially northern and alpine regions.

   b) augmenting the real time observing network, especially in remote regions and on large Canadian lakes, with automatic stations and providing appropriate standardization of real-time sensing, transmission and archiving of hydrometeorological parameters.

   c) expanding climatic networks in water sensitive regions, e.g. for drought mitigation.

   d) establishing specialized short-term high density climate networks to assess fine scale climatic variability impacting on other economic sectors, e.g. agriculture, forestry, inland fisheries recreation and tourism.

2. Improve data access and dissemination through:

   a) improved availability of recent climate data

   b) computer to computer linkages to access climate data banks

   c) catalogues of available climate data

   d) provision of expertise to help convert data into a more usable form.

3. Co-ordinate the collection and/or cataloguing of all climate data for Canada in one archive in a standard, readily usable form, including:

a) data collected by other agencies

b) "non-standard" observations obtained from special short-term networks and by remote sensing techniques

c) all relevant data on major hydrometeorological events

4. Develop and implement climate data analysis techniques useful to the water resources sector, such as:

a) monitoring and analysis of water availability (e.g. for drought monitoring), snow accumulation/ablation, soil moisture, lake evaporation

b) development of up to a six month climatic outlook, including seasonal prediction of climatic parameters, for use in water resources management, wildlife and fisheries management

Research and Development

1. Studies should be conducted to improve the physical basis for climatic models, and their effective use in the water resource field such as for streamflow forecasting, on both a national and regional scale.

2. Special projects should be conducted to assess the sensitivity of resource projects and ecosystems to climatic fluctuations, including:

a) the impact of climate and the spatial variability of climatic extremes on water resource activities

b) the production of fish, survival of marine mammals and the impact on wildlife and recreation and tourism directly or indirectly through changes in water quality

c) the development of operational models for the monitoring of such climatic trends and anomalous climatic events

d) development of methods for predicting the onset and ending of extreme water supply conditions, e.g. droughts

3. Research should be directed at the improved measurement and estimation of hydrometeorological parameters especially:

a) point and areal measurements of snowfall, snow cover and snowmelt basin evaporation and evapotranspiration; areal soil moisture

b) development and evaluation of improved automated measurement systems for remote applications for the measurement of (in order of priority): precipitation, snowpack, temperature (max and min), soil moisture, dew point, wind and radiation

4. Effective techniques should be developed to integrate radar, satellite, airborne remote sensing and ground based measurements for determining the areal distribution of climatic variables, particularly precipitation, snow water equivalent, soil moisture, lake temperature/evaporation.

5. The collection of all types of proxy data should be encouraged and research should be conducted with the ultimate aim of extending historical non-instrumental records, by:

a) linking proxy data with present climatic and hydrologic conditions

b) calibrating and integrating various methods of obtaining proxy data against the instrumented record

c) planning, developing and implementing methods for identifying regions in which proxy data are most needed.

<u>Institutional</u>

It is recommended that:

1. There be better co-ordination among agencies in the design and operation of hydrometeorological networks.

2. A federal lead agency be designated to co-ordinate operational remote sensing activities, especially the use of data collection platforms.

3. Research grants be extended to be compatible with the longer time period required to assess climatic variability in water resource projects, for example, in forest management and water supply.

4. The CCP should take an active role in assisting in the establishment of regional/provincial climate centres of committees.

5. The CCP should play a lead role in assisting other agencies in standardizing their networks with regard to recommending sensors, maintenance programs, calibration standards and the formating and publishing of data.

6. The CCP should increase its efforts to improve the transfer of knowledge gained from research to planners and designers.

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Introduction

Water is a universally important resource. It plays a crucial role in the management and development of agriculture, energy, transportation, forestry, wildlife, inland fisheries, mining, recreation and tourism, water supply for industrial, municipal and rural uses, pollution abatement, etc. Both water and air are so basic to Canada's economic and social activities that their importance is all too often overlooked.

Canada's economic development is vitally dependent on the effective utilization of our water resources. It is projected that over two billion dollars will be spent in 1980 for the design and construction of hydraulic structures (such as bridges, culverts, dams and irrigation projects and water control structures for hydroelectric power). Flood damage and relief assistance have amounted to some 200 million dollars annually. This amount has been escalating steadily and can only continue to increase as our standard of living rises and people continue to build in areas with a known history of flooding. In contrast are the problems associated with the lack of water. In relation to agriculture, the Manitoba Crop Insurance Corporation has estimated that if a full scale drought developed in Manitoba and crops failed throughout the province, claims amounting to more than 150 million dollars could be made. However, the effects of severe water shortages could have even greater implications for other economic sectors: power generation suffers decreased production because of low water levels and reduced water availability for cooling at thermal stations; industries, such as pulp and paper, which are heavily water dependent, suffer through production cutbacks due to the lack of process cooling water and curtailed water-borne transportation; low water levels lead to lower water quality, thus increasing industrial and municipal water treatment costs; and, deteriorating water quality economically damages the tourism and recreation industry. Unlike the 1930's, droughts will have great impact on economic sectors other than just agriculture.

The contribution of water resources to the Canadian economy can be demonstrated by citing a few examples of the value of water based on the cost of the next best alternative for providing similar services and goods. To illustrate, 68 per cent of Canada's electricity was supplied from hydroelectric power in 1977. For 1980, the replacement value of hydroelectric generation in Canada using thermal plants would be 5.4 billion dollars using the current domestic price for oil or 11.7 billion dollars using the world price. Similarly, the five largest withdrawal uses of water in Canada, consisting of thermal power, manufacturing, municipal services, agriculture and mining, have an estimated economic value of 926 million dollars for 1980 on the basis of the next best alternative cost.

The water resource sector makes extensive use of forecasting and monitoring services to support water resource operations. Climate data are used for hydrologic modelling, flood forecasting, river flow regulation, design of hydrologic structures, etc. Research into the associated hydrologic processes is carried out by many agencies, both federal and provincial, as well as by personnel in the university and private sectors. A large number of federal agencies are involved in or make use of water-climate interrelationships in their activities in Canada, including the Departments of: Environment; Agriculture; Indian Affairs and Northern Development; Fisheries and Oceans; Energy, Mines and Resources; Regional and Economic Expansion; Transport; and Public Works. At the provincial level all water resource agencies and departments associated with the federal responsibilities outlined above make extensive use of climate and water information.

Hydrology has a prime role within any climate program. Water is central to most climate change problems, be they associated with man's activities or just natural variability. Climatic warming, for example, can be of major significance for Canada. Man's activities in diverting northern rivers into more southern regions have large potential impacts on Arctic sea ice conditions and ultimately on our hemispheric climate. Such major impacts must be assessed. Climatic risks have been a traditional design problem and the potential consequences of extremes and persistence as well as natural variability must be known if hydrometeorological data are to be transformed into planning and policy information. In addition to this fundamental question of the impact of climate on large water resource developments, there is the equally important problem of the impact of such developments, dams and irrigation works, on climate, both on a regional and national scale.

Suitable application of climate information is an important part of water resource management and operational procedures. The Canadian Climate Program (CCP) is being designed to facilitate greater use of climate information in economic planning and environmental management. The Climate Program must address the needs of the water resource sector to provide climatic information not only for planning and design purposes, but also for the construction, operation and management of water resource projects and for the investigation of climate-water interrelationships in wildlife and inland fisheries. Through this Water Resources Workshop, the water community from across Canada has an opportunity to provide input into the design of the Canadian Climate Program. A list of workshop participants is given in Annex 1.

The goals of the Workshop were as follows:

a) to identify major water sector programs using climate data

b) to assess the impact of climate change and climate variability on the water resource sector, including wildlife and inland fisheries components

c) to assess and priorize the needs for climate data, services and predictions for water sector programs

d) to identify the input that research workers in these sectors can make to the understanding of climate and climatic change

e) to formulate recommendations for the design of the Canadian Climate Program which will meet the needs of the water resources sector

This report summarizes the proceedings of the Workshop. The Workshop opened with overviews on Canadian and international perspectives on climate and water resources, followed by a series of invited papers. These papers focussed on climate-water interrelationships in the planning and design of water resource projects and in the operation and management of such projects, on climate and its impact on water related wildlife activities, and on the availability of climatological data and analyses in support of water resource activities. All of these papers are included in this volume.

Attendees then participated in one of nine concurrent working groups and sub-groups based on their particular interests. There were four general areas of concern, with two topics requiring discussion in sub-groups. The discussion groups were as follows:

W.G. #1 Planning and Design of Water Resource Projects

- 1.1 Climate and its impact on large river developments
- 1.2 Climate and its impact on small stream developments
- 1.3 Proxy climatic data and their implications for planning and design

W.G. #2 Operation and Management of Water Reosurce Projects

- 2.1 Climate and its impact on large river developments
- 2.2 Climate and its impact on small stream developments
- 2.3 Climate and its impact on forest watershed management
- 2.4 Climate and its impact on water quality for inland fisheries

W.G. #3 Climate Information for the Use of Water in Dry Regions, Including Drought Assessment Strategies and Water Allocation Between Competing Demands

W.G. #4 Climate and Its Impact on Water Related Wildlife Activities

Prior to the working group discussions, an attempt was made to identify some of the existing climate-related problems and information needs with respect to the water resource sector in Canada. These problems and needs would be grouped as either service, research, or institutional. The basic questions to be kept in mind during the discussion and when writing and presenting the recommendations were:

a) What information is wanted? Why is it wanted?

b) Can the present climatological services provide that information?

c) What additional climatological services or research are needed (i.e. analyses, technical developments)? Justification or reasons for the need are to be included.

Suggested topics for discussion were prepared. These included general questions to be considered by all working groups relating to potential service, research and institutional requirements. There were also topics related to climatic problems and information needs more specific to each working group. This list of suggested topics for discussion is given in Annex 2.

The working groups prepared their recommendations, which were then tabulated and copied for every attendee to review. Over one hundred recommendations were made. Working group chairmen then met to consolidate these recommendations for presentation in general session. After presentation and discussion of the summarized list of recommendations, regional working group sessions were held to review and priorize the recommendations on a regional basis. There were four such working groups: British Columbia (alpine and uplands); Alberta (alpine and uplands); Central and Arctic Canada (Prairies); and, Eastern Canada. The working group reports were then presented in general session for review and discussion. The consolidated set of recommendations from all of these groups are included into the sector summary statement given at the beginning of this report.

Prior to the Workshop, participants were provided with reference material which would aid them in focussing their thoughts on water-climate relationships and climate-related problems and information needs. Reference material, other than those papers printed in this proceedings which were distributed to participants included:

a) "Climate and Water Resources: A Selected List of Recent Publications", Canadian Climate Centre Documentation Sheet #12-80 (Annex 3)

b) "A Catalogue of Climatic Data Sources of the Atmospheric Environment Service, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario, January 1980, 40 pp.

c) "Climatic Perspectives", Vol. 2, No. 7, February 22, 1980, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario, 8 pp.

d) "Designing the Canadian Climate Program", Canadian Climate Centre Report No. 80-3, Atmospheric Environment Service, 4 pp (unpublished manuscript)

e) Schaake, John C. Jr., 1979: "Climate Variability and the Design and Operation of Water Resource Systems", Proceedings of the World Climate Conference. A Conference of Experts on Climate and Mankind. Geneva, 12-23 February 1979, WMO-No. 537. World Meteorological Organization, Geneva, Switzerland, p. 290-312.

f) McKay, G.A., 1979: "Climatic Changes", Proceedings, Canadian Hydrology Symposium: 79. Vancouver, 10-11 May, 1979. National Research Council of Canada, Associate Committee on Hydrology, NRCC No. 17834, Ottawa, Ontario, p. 461-472.

A parallel effort to the Workshop was the assembly of an inventory of climate related programs in the federal and provincial governments, universities and private industry. The questionnaire was given wide circulation prior to the workshop. Over ninety replies were received. The questionnaire and a list of respondents are given in Annex 4. Preliminary analysis of the inventory replies was completed and distributed to workshop participants. This analysis focused on the types of water programs using climate data, the climate information used, and suggested improvements in climate service from federal or other agencies. The results are summarized in Annex 4.

Acknowledgements

This workshop was made possible through the joint efforts of the Environmental Management Service (W.Q. Chin, G. Cooch, B. Ayles), Atmospheric Environment Service (B.E. Goodison) and the Alberta Climatological Association (K. Leggat, J. Kotylak, W. Kuhnke, R. Whinstance -Smith). Thanks are extended to the Alberta Climatological Association who served as local hosts and to the University of Alberta for provision of their facilities for the meeting.

INVITED DISCUSSION PAPERS

ORAL PRESENTATIONS

A Canadian Perspective on Climate and Water Resources

J.P. Bruce
Assistant Deputy Minister, Environmental Management Service,
Environment Canada, Ottawa, Ontario

In 1960 Ray K. Linsley, one of the world's leading hydrologists, wrote an article in which he identified the single most serious technical problem facing water resource managers as that of determining the appropriate response to climatic change. I think that the same thing might still be said today, 20 years later. The question remains of what to do about possible climatic change or trends when designing and operating water projects intended to last for 50 to 100 years. This problem is a pressing one for Canada, where we invest up to $4 billion per year on water structures. The only difference between 1960 and today is that now, both in Canada and internationally, some realistic programs are being launched to find some solutions.

This workshop is one of a series sponsored by the Canadian Climate Planning Board. We are delighted to have the Alberta Climatological Association as hosts for this meeting. The purpose of this, and other workshops, on agriculture, forestry, solar energy, transportation, tourism, oceans and salt-water fisheries, is to determine our priorities and needs for climatic information. This information will aid us in designing the Canadian Climate Program. In these two days you are being asked to help provide input on climate-related issues concerning the water sector. These issues should be considered to include climatic variability and its potential impacts on water resources and other closely related resources such as inland fisheries and water dependent aspects of wildlife.

As water specialists, we are here to determine what we would like to gain from the Canadian Climate Program; but we should be also looking at the research and data programs in the water sector to determine the ways in which workers in our field can contribute to climatic knowledge.

What has been started here in Canada as part of the Canadian Climate Program? Well, first of all we should pay tribute to AES for the lead role they have taken and the imagination they have shown in developing the Canadian Climate Program. As a first step, they are putting their own house in order by bringing together under one manager climatological research and climate data management in the newly formed Canadian Climate Centre. This Centre also provides the Secretariat for the Climate Planning Board, which is chaired by Professor Ken Hare. That Board is charged with developing a program plan which will extend and apply the work of the Canadian Climate Program throughout the various sectors of the Canadian economy. The plan will involve not only those active in climatology, but also those who make use of climatic knowledge for managing their own programs and activities.

How important to water resource management might climatic change really be? A few examples of a "what if" nature might be helpful. If we had a 2% reduction in the solar energy reaching the earth, it is estimated that snow cover would extend to the equator. If we had a rise in average global temperature of 2%, this could melt the Polar ice caps and raise ocean levels to drown our present coastal cities - while much of the northern hemisphere would take on a sub-tropical climate. If we had a drop in global temperature of 1°C, we would have conditions similar to the "Little Ice Age" of 1450 to 1850, and this would mean crop failures in the Prairies and a generally stormier and less stable climate.

Are man's activities likely to influence climate? Let me give some examples. First of all, waste heat from a projected world population of 20 billion people with a per capita energy consumption rate of 20 kilowatts could increase average global temperatures by several tenths of a degree Centigrade. Even now, "heat islands" or urban centres produce temperature differences as great as 2°C between urban and surrounding rural areas. Some researchers contend that particles released to the atmosphere from cars and industry become nuclei for rain droplets and increase precipitation by as much as 15% up to 50 miles downwind from urban centres. Carbon dioxide emitted into the atmosphere from burning of fossil fuels is causing a slow but steady increase of CO_2 concentrations. This tends to reduce amounts of infrared radiation emitted from the earth escaping to space, creating a "greenhouse" effect. Some scientists maintain that an increase of CO_2 by 25% (which conceivably could occur) would cause a global warming of 1°C. Such a global warming would be uneven with the polar ice caps experiencing seven times as much warming as the global average and thus could cause melting of the Polar Ice Caps.

It is then abundantly clear that man's activities can be very significant in bringing about climatic change and that the kind of climate change possible would have enormous effects on water projects. But what about large water projects? Can they in turn affect climate? The verdict is not in yet, but evidence is pretty strong that some types of projects may have profound effects. Although small and medium-sized reservoirs may affect only the micro-climate in their immediate vicinity, major diversions and changes in flow regime can be much more significant. Among the most significant potential effects in Canada are those in the Mackenzie River Basin. Two major schemes are of concern.

First, the province of Alberta appears to have a revived interest in diverting waters in the Mackenzie drainage - particularly from the Peace and Athabasca Rivers southward into the Saskatchewan system to assist in meeting water supply needs in the dry southeastern part of the province. Planning hasn't proceeded far enough to decide exactly how this might be done and how the total flow of the Mackenzie River system and the flow regime might be altered, but significant changes would certainly occur. Of perhaps even greater potential significance to the flow regime of the lower Mackenzie River is the possibility of large hydro dams on the Liard River, under study by B.C. Hydro. Such dams would have profound effects on the spring floods in the lower Mackenzie system. The relatively early spring flood in the Mackenzie delta (due to break-up and silt from the Liard) permits a microclimate in the valley which affects the whole way of life of the indigenous people and others. It permits a longer growing season for trees, plants, wildlife and fish which are a source of food and livelihood for the local people. In addition, the break-up and movement of ice in the lower Mackenzie system has a major effect on shipping, oil drilling and other economic activity. With reduced spring flows on the Mackenzie River, the delicate balance of salt and fresh water in the Beaufort Sea might well be affected. This in turn could influence the ice regime in important oil and gas drilling areas.

In short, projects such as these can have far-reaching hydrological, climatic, oceanic and social effects. We must urge the British Columbia and Alberta governments to consider carefully the likely downstream effects of any such projects before proceeding.

Our main themes today will be:

(a) Climate and Inland Fisheries

Here we are concerned with climatic variations and their influence on water quality, water quantity and the aquatic environment, and in turn the impact on the numbers and species composition of the various inland fisheries.

(b) Climate and Wildlife

Recent loss of wetland habitat has resulted from encroachment by man, through agriculture, urbanization and resource exploration and exploitation. But drought and climatic variability can also greatly reduce the available habitat. Changes of this type, especially on the Prairies, have effects on the most important breeding and staging grounds for waterfowl in North America.

Another climatic effect on wildlife is illustrated by the case of the Peary Caribou. The herd, whose range is the Arctic Islands, has been reduced by 40% over the last few years. This has been due to several seasons which freezing rains and unusual weather in the area destroyed flood supplies for grazing. Both the quantity and quality of the water habitat determine the numbers of many important wildlife species.

(c) Climate: Planning and Design of Water Projects and Floodplain Mapping

Water resource projects are, of course, designed on the basis of analysis of historical streamflow and meteorological records. The longer the available record, the more reliable are the estimates of design floods, storage capacity, flood lines, and so on. There are two techniques for "extending" the records backwards in times before instrumental records, and both involve use of proxy data from glacier cores, sediment cores, tree rings, etc. In one approach, a correlation is obtained between the proxy data and the instrumental records. This relationship is used simply to extrapolate backward in time before the instrumental data period. In the long run, however, it would be much more reliable if the proxy data could be used to verify mathematical models which are being developed for simulating long-term climate. Such models are necessary to provide various scenarios from which actual experience based on short-term records can be better understood. These models would have the great advantage of being able to distinguish natural from man-made changes.

This brings me to data. We should no longer think of climatic data as being only those obtained from instrumental records of the past century or so. Paleoclimatic research to obtain information from tree rings, ice cores and sediment cores offers a promising approach to better estimates of climatic variability and drought and flood probabilities. We must ensure that greater effort is being put into the collection, storage, retrieval and interpretation of such data.

Another important concern in Canada is the deficiency in our climatological network in the alpine regions. Snow is a manageable resource and glaciers provide a substantial source of runoff from mountainous regions during late summer low flow periods. There is a need for a better alpine climatological network to provide the necessary information for managing this resource.

Let me now address the "theme speakers" and working group participants. There are a few questions which I hope will be addressed by our theme speakers and participants in the working groups.

(a) To what extent will a better knowledge of long-term variations in climate and streamflow help the water managers to make better decisions?

(b) How much does a better data base or increase of climate and water information improve engineering decisions and solutions?

(c) Are we putting enough effort into proxy data collection to extend records back in time?

(d) How big (or small) a climatic change would be significant for the water sector?

(e) Climatic change occurs on all scales of time from a portion of a year to the age of the earth. There is a lack of comprehensive theory to explain these changes. How important to us is this lack and thus what level of effort should be directed to research in this field?

As we meet in the working group sessions we should keep in mind three broad activities to be addressed in our recommendations:

(a) <u>Service Requirements</u>

(i) Data collection and data storage and retrieval systems; their present deficiencies and the kind of improvements required.

(ii) Interpretation and analysis of hydrometeorological data for ease of use by the water sector; present deficiencies and improvements required.

(b) Research Requirements

(i) Assessments of the effects on micro-climate from large reservoir developments;

(ii) Development of numerical models of atmospheric circulation to further our understanding of changes in climate and their causes;

(iii) Statistical research on the impacts of climatological and hydrological variability on fish and wildlife.

(iv) Development of proxy data and improvement of their use for trend studies.

(c) Institutional Requirements

(i) Development of informal and formal arrangements between the Canadian Climate Centre and the water sector agencies;

(ii) Co-ordination between agencies in the design and operation of hydrometeorological networks.

I am convinced that the topic we are tackling over the next few days is one of the most important ones facing water, wildlife and fisheries managers. Your work in this meeting will greatly influence the design of the Canadian Climate Program. We are counting on you for advice of the highest quality.

An International Perspective on Climate

A.E. Collin
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Environment Canada, Ottawa, Ontario

I would like to spend a few moments to outline for you the background and framework within which many of the nations of the world are contributing toward an international climate program. This initiative is taken through the World Meteorological Organization and other UN agencies which are responsible for climatological matters and related environmental concerns. As a result, the nations of these organizations are now moving ahead to formulate a major new World Climate Program to provide the understanding and the services that may reduce the vulnerability of nations to climate variability and change. This exceptional effort is in response to a series of internationally recognized events which have served to focus the attention of nations on the impact of climate variability. As a result, it is now clear that within the present economic order, even modest fluctuations, in world food production for example, can be caused by small changes in climate and can result in malnutrition and starvation on a continental scale.

Throughout the sixties and into the seventies climatic events have attracted serious economic and political attention.

In the late 1960's the southern regions of the Sahara were subject to a disastrous five year drought which brought about death and starvation on a continental scale.

In the early 1970's severe winter temperatures followed by summer droughts reduced the Russian grain production by 12%, leading the Soviet government to make massive purchases in the world food grain market with serious implications in the international price structure. The same year, the anchovy harvest off Peru collapsed with a major impact on the world supplies of animal protein and on the world demand for alternate sources. In 1974 a weak monsoon season in India led to a major reduction in food production in that part of the world. In 1975 severe frost in Brazil destroyed half the coffee trees in the country and coffee prices went out of sight. In the winter of 1977 abnormally cold weather in eastern and mid-western parts of the United States resulted in a shortage of natural gas supplies which forced the closing of schools and industries and caused widespread unemployment.

We have also begun to realize that our industrial, agricultural and land use practices can affect key atmospheric processes and as a result, our climate. We now know that the photochemical balance of the stratosphere can be changed by small amounts of the oxides of nitrogen and fluorocarbons, and of even greater concern is the projected increase in carbon dioxide which is now taking place due to the increased use of fossil fuels.

Discussions on the focus and organization of the World Climate Program have taken place over the last few years within the World

Meteorological Organization and other UN agencies such as the United Nations Environmental Program and the International Council of Scientific Unions. The World Meteorological Organization has recognized that this program must encompass a wide breadth of activities if it is going to be accepted internationally. In particular, it has been recognized that the WMO must give very serious attention to the application of climatological information and the impact of climate on the economic structure of our society.

For this reason, the outline of the program has been divided into three major components. The Climate Data and Application Program, the Program for the Study of the Impact of Climate on Society, and thirdly , the Research Program on Climate Change and Variability. The World Meteorological Organization has recognized that there is a broad overlap between these three components of the program. Nonetheless, it is acknowledged that we are at a different stage of work in each of these studies and that the program must be responsive to the fact that nations have different needs for climatological information and that in many nations there is a fundamental requirement for the most basic kinds of climate information. In other nations, climate services have been developed to a high degree and in these countries we will try to identify the influence of the knowledge of climate in those policy considerations which are seen to be most responsive.

This approach was examined in great detail by the World Climate Conference which was convened in Geneva during the period 12-23 February, 1979.

The World Climate Conference was unique in a way in that it brought together scientists who could comment authoritatively on the impact of climate variation in various parts of the world. For example, the Conference focussed on the influence of climate change on agricultural productivity and energy requirements and attempted to evaluate this impact on evolving national policy. The Conference was concerned about the impact of natural variations in climate upon world food production, water resources, land use and of course on the energy supply and demand problems. More importantly, perhaps, it spent considerable time examining a response to the ominous indications that man, through his own industrialization, may cause significant changes in climate. There are now sufficient indications that some of these potential changes, such as those which might result from increased atmospheric carbon dioxide, could have a pervasive impact upon the climate of the world and may require unprecedented international action to deal with it effectively.

The World Climate Conference is now seen as the first stage in an international effort to address a wide range of growing concerns related to climatic change and variability. A large part of this effort will revolve around the World Climate program which has now been put in place by the World Meteorological Organization and will be undertaken in collaboration with other international, intergovernmental and non-governmental organizations. It is planned that, through the World Climate

Program, individual nations will set out programs to take greater advantage of climate information and to identify ways in which they may mitigate the adverse impacts of climate. The Conference was not convened as a specialized meteorological meeting, but was organized to bring together a number of experts from around the world to examine the relationship of climate to human activity and to the human environment.

The Conference stressed the need to take steps to improve significantly our knowledge of climate and made the point that the climates of the countries of the world are, in fact, interdependent, and for this reason and in view of the increasing demand for resources by a growing world population, there is now an urgent need for the development of a common global strategy for a greater understanding and a rational use of climate.

There was also serious concern that the continued expansion of man's industrialization on earth may cause significant extended regional and even global changes of climate. This possibility was seen to add a further urgency to the need for global cooperation to explore the possible future course of climate and to take this new understanding into account in the planning for the future development of society.

The overall purpose of the proposed programs is thus to provide the means to foresee possible future changes of climate and to draw the attention of nations to the application of climatic data and knowledge in the planning and management of a nation's business. This obviously will require an interdisciplinary effort of an unprecedented scope at the national and international levels and will likely lead to the presentation of these interests at the international ministerial level within the next few years.

These concerns are, of course, of great interest to Canada.

The relationship between climate and the management of energy sources may have some aspects that are uniquely Canadian. The Canadian climate and geography dictate that in comparison with other parts of the world, we use a large proportion of our total energy for space heating and for transporation. We also use a comparatively large amount of energy to exploit our biologically marginal zones, for example, our northern Prairies and boreal forests, for economic gain. In these areas, Canada's use of energy is very climate sensitive. However, this sensitivity is not a simple relationship. For example, much of our agriculture is more moisture sensitive than degree day sensitive and if carbon dioxide induced fluctuation of middle latitude climate carried a shift of precipitation patterns, the detrimental impact of a drying of the Prairies could more than offset the benefits of a slight lengthening of the growing season. As another example, most Canadian cities would welcome a slightly warmer winter climate, but if that climate change brought greater snowfall, the increased winter urban energy budgets could easily offset the savings in carbon dioxide emission connected with heating.

The energy options open to Canadians, therefore, are to varying degrees climate dependent. For this reason, it seems most important that we know whether and to what degree carbon dioxide induced perturbations in climate could reasonably be expected to alter the economics of the country. For example, a persistent reduction of 10% in winter sea ice cover could conceivably open the entire Arctic Archipelago to marine traffic and at the same time, such an increase in temperature would obviously shift our growing patterns in the Prairies.

It goes without saying that there would be other compensating and important factors to keep in mind in looking at these sorts of scenarios.

Our other main concern deals with Canadian food production. As a country on the northern margin of grain production, our sensitivity to fluctuations in the growing season is extremely critical since a significant proportion of the total Canadian producing area would be affected by any slight change in the growing season. This change in turn would inevitably have a bearing on the Canadian production policy and our ability to maintain a position in the world markets.

In looking at the interrelationship between these geophysical events and the social reaction, the sequence of events seems to go like this: temperature change, other environmental effects such as change in agricultural potential and change in sea level, economic impact, social response, and finally, political decision. This being the case, in order to focus enough attention to bring the required action as well as discussion on the international implications of such events, it seems clear that information must be brought to the attention of the public in a systematic and responsible manner.

In order to take some steps in this direction, the Atmospheric Environment Service has moved towards the creation of a Canadian Climate Centre and the development of a Canadian Climate Program as the Canadian contribution to the international World Climate Program.

A large bank of climatic data and information exists in Canada which is not being utilized to the extent possible and desirable in the planning of the nation's affairs. The country is blessed with considerable climatic expertise but there has previously been no mechanism to direct and integrate climate-related activities on a national scale.

The Canadian Climate Centre (CCC) provides a central focus for Canadian Climate Program activities. In addition to functioning as the lead agency for the program, the Centre undertakes basic climate functions relating to data management, research, information services, applications, impacts, monitoring and prediction.

A very important function of the Program is to bring together users and participating agencies. Included in this approach are federal departments, provincial agencies, universities, private companies, industrial associations, professional societies and the general public.

The Canadian Climate Centre has set in motion an innovative sectoral approach to design a Program that will effectively provide climate information and services that best serve Canadian interests and promote their effective use.

The first step in this approach has been to identify existing climate and climate-related programs across the country from the viewpoint of resource commitments, goals and objectives. Secondly, the need for climate data services and research by both the public and private sectors across Canada and the mechanisms to meet current and potential demands is being defined by convening workshops or small working groups. The workshops address the following questions:

- How does climate impact on each specific sector?
- To what extent are climate services utilized?
- What are the deficiencies in climate services or information?
- How should the Canadian Climate Program be designed to serve the sector's requirements?

Formal workshops such as this one have taken place on the CO_2 issue, solar energy, and in the agriculture and forestry sectors. Following this workshop will be one on the Fisheries and Ocean sectors at the Bedford Institute of Oceanography next week in Halifax. Other sectors such as Transportation, Energy, Climate Research, Recreation and Tourism, and Building Construction are being addressed through smaller informal meetings with selected experts.

This workshop is important not only because of the profound implication of climate on this sector, but also because water is an abundant and valuable resource in this country that impacts strongly on all other sectors being considered in the Canadian Climate Program.

Climate, Water and Wildlife - Changing Information Needs for Resource Management

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Introduction

In the late 60's a colleague of mine was addressing a group of Inuit fishermen at the remote community of Holman Island on Victoria Island, N.W.T. The purpose of the meeting was to explain the imminent decline of the local char fishery given over-exploitation of the population by gill-nets. During the discussion of the reproductive cycle of the anadromous char my colleague noted an elderly gentlemen in the audience laughing quietly to himself. The quiet laugh continued throughout the remainder of the discussion period much to the amusement of others in the group. However, at the end of the presentation my colleague who knew the elderly gentlemen asked him what was the source of humour in the presentation. The response was in effect - "you talk of char coming up the river in the fall to lay eggs and small char hatching from those eggs. That is funny because char (fry) come from the sky when it rains!"

The elderly gentleman had one of many perceptions as to the impacts and values of water to our living resources and to the users of those resources.

Interests in Climate Information

What then is the Canadian Wildlife Service particular interest for climate information? Perhaps I can best explain the interest with some background facts. The productivity of 2.3 million lesser snow geese, 200 thousand greater snow geese, 200 thousand brant, 500 thousand white-fronted geese, 1.5 million king eiders, 1 million common eiders, 1 million oldsquaws, 1 million scoters of 3 species, 5 million murres, 3 million guillemots, perhaps 15 million larids (gulls, terns and kittiwakes), and 10 to 15 million shorebirds breeding north of the treeline, is directly dependent on the capriciousness of climate. Unlike the prairies where drought is probably the single most important factor governing reproductive success, the tundra breeding populations are regulated by the length of season available for breeding. For most species, failure of the snow to melt until after June 15 means reduced reproductive success. Good years on the tundra mean seasons when significant amounts of habitat is exposed by June 1, in poor years habitat is exposed by June 15 and it is diaster when habitat is not exposed until June 22. In 1972 for example, summer never came for the birds, or for that matter anyone else. A similar situation occurred in 1975.

Although the date of break-up and the date at which ground level temperatures do not fall below 30^{o}F (-1^{o}C) are critical, severe storms, days of wind driven sleet or rain in mid-July, or the onset of heavy snowfall in late August are also important factors.

The climate of the prairie parkland region of Canada is highly variable. It is characterized by wet and dry periods, or cycles, which influence the amount of surface water in the approximately six million natural runoff basins. These wetlands provide breeding habitat for up to 50% of the total North American duck population and up to 60% of the continental mallard and pintail populations. Waterfowl population data from southern Saskatchewan for the period 1955-1979, illustrate the effect of climate caused variability in wetland habitat on waterfowl populations. Surveys indicate that pond numbers varied from a high of 4.5 million to a low of 0.5 million. Breeding populations of mallard, the most numerous duck species in this areas, varied from a high of over 5 million to a low of approximately 1 million.

The value of prairie wetlands as breeding waterfowl habitat is due to the climatic instability of the region. Periodic drying out of basins rejuvenates the wetland ecosystems and ensures their long-term high biological productivity. Without the periodic drying out and oxidation of the sediments, basins would accumulate organic matter and through successional processes no longer provide breeding habitat. In the long-term climatic instability is extremely beneficial to prairie waterfowl. Populations have evolved reproductive strategies to maintain equilibrium with the changing habitat.

Environmental Impacts Related to Climate

In the Arctic the direct effects of climate on wildlife are important. These effects are primarily in the form of factors controlling reproduction and survival. In the boreal forest, climate effects are not as direct but contribute to local and regional contamination problems. In the prairie parkland area the effects of change of climate migratory bird populations are striking. Our major concern, however, is related to the alterations to the natural variation in water caused by human activities.

Northern Canada is once again on the verge of tumbling into the turmoil of large scale resource development initiatives. While site-specific impacts may well be minimized there is increasing and justified concern over marine transportation networks. The use of the Davis Strait-Lancaster Sound region poses some interesting questions with regard to ice, oceanographic features and transport corridor alternatives. Literally hundreds of thousands of seabirds lay claim to cliffs and crags adjacent to the proposed Liquid Natural Gas (LNG) tanker route. Timely and reliable climatic information will be essential for ships plying the northern waters - such information will be invaluable in minimizing hazards to navigation which in turn reduces the risk of environmental disaster. The scale of such potential disaster from an oil spill is almost unimaginable given an entire new generation of cargo vessels for carrying petroleum products.

Polynyas are found throughout Arctic marine zones occurring as open water areas surrounded by ice. The Canadian Wildlife Service is currently investigating the value of polynyas to wildlife with an ongoing research program in the eastern Arctic Islands. Characteristically polynyas are very productive as a result of sunlight falling upon nutrient-enriched open water. Plankton blooms attract fish which attract seals, whales and birds which in turn attract polar bears. All of these contribute nutrients back into the system. Perhaps more importantly polynyas appear to be a kind of oasis which allows a small survival advantage to the denizens. The difference is between life or late-winter death by starvation. However, it is also a simple fact of life that polynyas are potential shipping corridors and harbours. Clearly there is a need to determine the relationship between climate, polynyas and related marine zones prone to lead formation.

Somewhat closer to home for many of us is the impact of acid rain. I believe it an understatement to say that we have seen nothing yet - the impacts are insidious and are guaranteed to catch us off-guard and ill prepared to respond with timely action. It is one thing to document affected areas and track down sources. Such action is necessary for a problem that already exists. How do we respond to new projects that propose emitting SO_2 and NO_2 as process by-products? It is important to note that use of low grade fossil fuels (high sulphur content) is becoming economically attractive. The same economics apply to influence the recovery of non-conventional oil sources such as heavy oil in the McMurray formation. Process technology will influence production of by-products such as SO_2 given that legislation to control such emissions is in many cases after process engineering has been completed. Nevertheless, climate and atmospheric characteristics will determine emission outfall pathways and assimilative capacities for emissions. Is the capability available to predict these pathways and capabilities?

Needs for Climate Information

The Canadian Wildlife Service is interested in two types of climatic data. The first is long term trends for well defined regions. For example, is Foxe Basin likely to cool off in the next decade, or to warm up? Canada has made commitments with the Inuit and Cree of Nouveau Quebec for guaranteed levels of harvesting of geese that breed largely in Ungava and on the Great Plains of the Koukdjuak, Baffin Island. Since production is climate controlled, it would be helpful to know the prognosis for the climate by 1990-2000 and henceforth in order to assess long-term production of geese.

The second need has two parts which are: (a) better spatial coverage; and (b) better ecological type data. At present we extrapolate to the west coast of Baffin Island from hall Beach 300 miles away. Coral Harbour is 70 miles from Boas River and 50 miles from East Bay. Karrak Lake is 300 miles southeast of Cambridge Bay, 400 miles east of Bathurst Inlet and so it goes. The closing of the weather station at Isachsen with its run of data was a disaster for us.

As for the need for better ecological type data, what we currently get often results from Stevenson Screen readings - at convenient eye-level. What we need are ground level temperatures, at least in the spring to summer interval (May - June - July - August). Data are provided on the amount of snow on the ground at the end of a month and how much has fallen during the month, but we don't know what kind of snow is on the ground or if there have been melts early in the season which has resulted in an ice-snow, ice-snow layering with ice at the snow-land interface and so forth. Also we do not know what percentage of the land (on the flat areas away from the settlement) is snow free.

Interestingly enough the Danes went to automated weather data collection for Greenland. The use of automated remote stations has not been followed in Canada to date, however, automated stations at Bowman Bay, Cape Dominion, Boas River, Karrak Lake, Egg River, Bylot Island - put out in May and picked up in September and hooked to a satellite or the nearest Atmospheric Environment Service (AES) weather station would enhance our ability to predict the weather more accurately. The existing series of resource satellite information is simply not complete enough for predictive purposes with regard to weather impacts on wildlife populations. We use the output when our target areas are not obscured by fog or cloud but, readings every 9 to 18 days do not give us our required precision. The data from existing stations is of high quality however, there just are not enough stations. What wildlife managers are requesting is more complete coverage plus ground-level climatological data.

Our major concern with respect to climate and water in the prairies relates to the cumulative effect, on a regional scale, of site-specific alterations to the distribution of water. Human alteration of the distribution of water, in the form of wetland drainage, destruction of associated upland vegetation, etc., have direct negative impacts on waterfowl populations. In our opinion, the water requirements for wildlife, in particular waterfowl, would be met by economic and environmentally sound water resource use planning. The majority of water impacts related to the six million natural wetlands in the prairies occur on private land. Decisions to drain or otherwise alter these wetlands are made on the basis of incomplete cost benefit analyses that are restricted to the site in question. In simple terms, the cost benefit analyses compares potential agricultural production in that basin with the value of wildlife that may be produced on it. At this level of comparison, it is obvious what the landowners land use decision will be. There are many publicly funded and promoted schemes to bring private wetlands into agricultural production, based on a similar type of economic evaluation. Such schemes typically assume that product yields (or prices) are high, that climatic conditions are predictable and that land is universally productive; all of which signify agriculture stability for the producer - in the short term!

What the region really needs is long term water use planning for each watershed basin in the prairies and the aspen parkland zones of western Canada. Moreover, we are long overdue for new and innovative approaches to cost benefit analyses where both agriculture and wildlife are the variables under evaluation. I refer to recent works by Sawatzky (pers. comm.) and Zittlau (1979) both at the University of Manitoba.

Summary

The cumulative effects of these site-specific actions have the potential to represent a significant economic cost to society. The costs associated with flood prevention or flood damage compensation related to increased channelization of water or conversely costs to society as a result of drought conditions that are compounded by drainage, should be brought into initial cost benefit analyses. The same applies to quality climatic information for Arctic Marine navigation; the costs associated with environmental disasters are significantly higher than the costs of providing essential and better information for navigation purposes.

It is our contention that sound evaluation of water management programs which include long-term regional and downstream implications will result in decisions that are beneficial to both the Canadian economy and to wildlife and with some changes in the kinds of climatic information collected, we can improve our effectiveness in wildlife management.

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Aspirations and Realities

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Introduction

The purpose of most water resource projects has always been to change the temporal and spatial distribution of water imposed by the local climate so as to make it more compatible with the perceived needs of social and economic development. Setting aside the fundamental problem of value judgement, i.e. the question of the legitimacy of these needs in view of what is or is not in the best interest of society (see, for instance, the recent devastating criticisms of cost-benefit analysis by Oelschlaeger, 1979, and Junger, 1979), we are left with an engineering task to control the water regime so as to achieve a specific objective: the provision of a certain amount of water in a given time and location, reduction of flooding by a specified degree, optimization of some economic indicator for a specific water resource, etc. In our struggle to achieve these objectives we are always faced with the (in our view regrettable) fact that our ability to control the world is not absolute, that we cannot make things happen by fiat. This is the main and perhaps the only reason why we need knowledge of the outside world, especially of those aspects of it which, being independent of us, make our decisions dependent on them. The less powerful our means for control of a given phenomenon, the more knowledge is needed to employ these means effectively.

Knowledge needed for water resources design

There is a substantial difference in the kind of knowledge needed, on one hand, for successful operation of a water resource project and, on the other, for its successful planning and design. In principal, operation requires knowledge of the water regime and of the desirability of its specific changes over a relatively short future period ranging from several hours to a few years. Planning and design, on the other hand, requires knowledge of the same two aspects of the outside world but for periods several decades long and, moreover, starting 20 to 30 (or more) years after the analyses and evaluations have begun. The present extent of this knowledge is very limited and, ironically, seems to be decreasing rather than increasing because of the gains made by science may be more than offset by the accelerating rate of social and ultimately environmental changes.

My discussion will be limited to problems concerning only one side of the planning-and-design coin - the knowledge of the water regime. The other, and in my view vastly more important side - the problems concerning the knowledge of our quarter-or-half-a-century distant scale of values and the resulting perceptions of utility of water resource projects such as dams, irrigation systems, etc. - is fortunately outside the terms of reference of my talk.

The following statement of J.R. Wallis, Chairman of the U.S. NRC Panel on Water and Climate (1977; p. 3), can serve as a motto for this paper:

> "The uncertainty of hydrology in water-resource design arises because hydrologists are unable to forecast the future sequence of flows that any proposed water-resource structure will encounter during its design life."

It is important to realize that this laconic statement summarizes the net result of many decades of countless efforts to overcome this inability; that on a number of occasions during this long time hopes were running high and the goal seemed to be within reach, at least in principle. We have come a long way from the early years of the century when an analysis based on 7 years of streamflow records inspired Johnston (1915) to say with confidence:

> "To sum up, it may be said that the general run-off conditions in the power reach of the (Winnipeg) river would warrant the assumption that a fairly complete regulation of the river can be attained"

to the present when it is generally acknowledged that even 100 years of flow records may not be enough to "attach reliability to any results" (Wallis and O'Connell, 1973) as far as storage for complete regulation of flow over a given period is concerned (see also Fig. 1).

Finding himself in such a precarious situation vis-a-vis the planner and the designer, it is only natural for the hydrologist to look for help. After all, streamflow is the final link in a long cause-and-effect chain which probably makes runoff much more complex a process than are its causative factors. Thus, when concerned with short-term flow forecasts the hydrologist turns to the meteorologist whose precipitation records are often more than 100 years long; when concerned with long-term forecasts he turns to the climatologist whose climate records are often more than 1000 years long. However, the disappointing fact is that, at the present time, the expected help is practically nil: "Unfortunately, it must be conceded that the available data make it impossible to draw on climatic patterns of the past for any assessment of climatic patterns of the future" (Budyko et al., 1979).

The options

The above quotations summarize the results of massive research efforts in both climatology (over a period of more than a century) and hydrology (over almost three quarters of a century) directed towards an option that at the outset appeared to be the most promising one: to discover regular patterns in the historical records and extrapolate them into the future, in other words towards deterministic extrapolation of historical records. The monumentally dominant theme of this area has been to correlate the temporal patterns of the processes of interest with those of the fascinating more-or-less regular astronomical process of sunspot number fluctuations. Although the resources devoured by

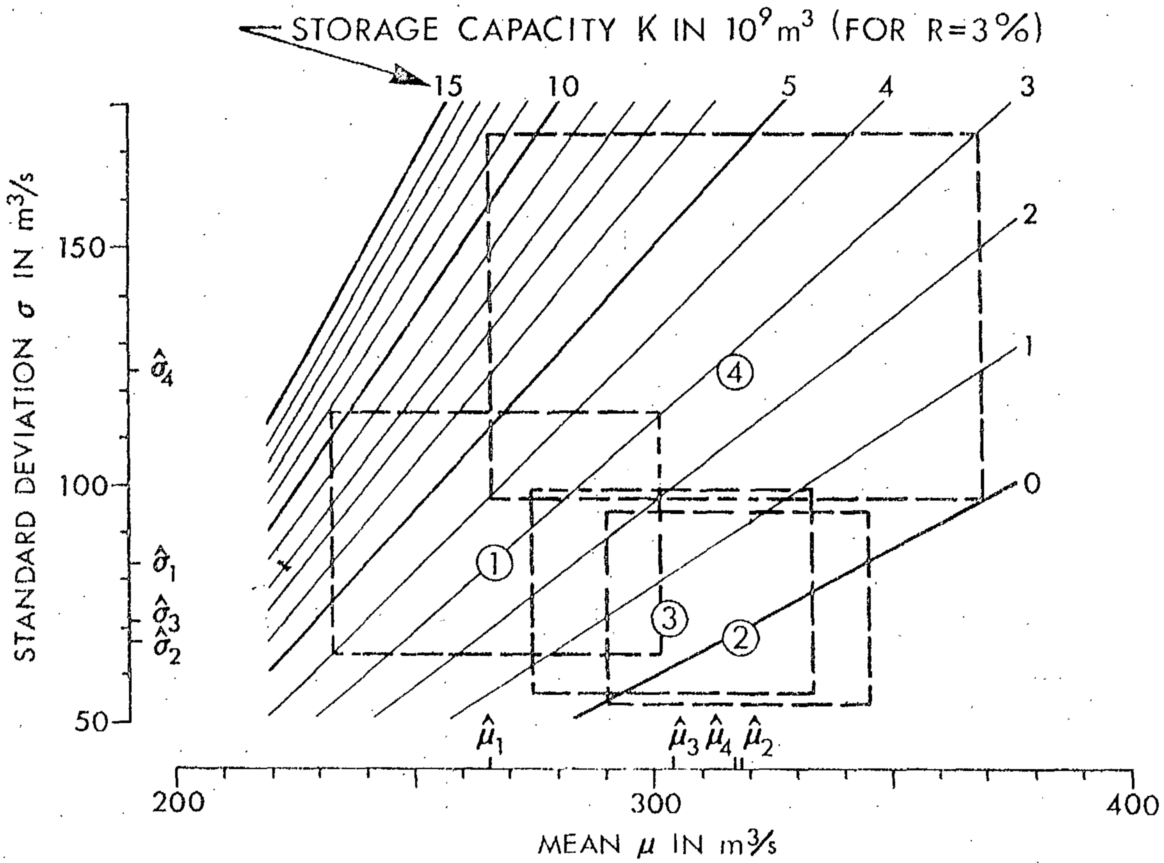


Fig. 1 Variability of the value of storage capacity K (for annual risk of failure Ra = 3% and draft D = 200 m3/s) as compared with the 95% confidence limits for the mean and the standard deviation of annual reservoir inflow computed from four different 25-year samples from a 100-year historic streamflow record of the Elbe River at Děčín, Czechoslovakia (Klemeš, 1979d).

this research has been truly astronomical, its results have been manifestly negative; however, the subject still attracts wide interest which is bound to persist (see Appendix) at least until the long-term forecast problem is solved in some other way. We shall return to this topic later but first let us consider what the other options are.

Another option, which has become extremely popular in hydrology in the past 20 years, can be labelled statistical extrapolation of historical records. The aim here is more modest than in the previous case in that the objective of real-time prediction of the future states of the process is replaced by an objective to predict only the frequency of the occurrences of these states without attempting to specify the times of these occurrences.

Naturally, the scaling down of the objective reduces the value of the result to the planner and the designer. Knowing only that a certain event may occur during the design life of the project prevents him from achieving the same effectiveness of the resources to be expended as would be possible if he knew when the occurrence will take place. For example, in situation depicted in Fig. 1 it would be possible to assign most of the storage capacity to flood reduction during the middle 50 years (and thereby postpone implementation of special flood protection measures) if the actual sequence of future flows could be predicted.

However, the designer would be grateful even for this statistical prediction if he only could be sure that it is reasonably accurate. As in the previous case, the confidence in statistical prediction was much higher at the outset than it is now after 20 years of intensive research. In the hydrologic context it has been realized during this period that historic streamflow records are in general much too short to make possible reasonably accurate estimates of future frequencies even under the most favourable hypothesis that the overall conditions during the period of interest (about 50 to 100 years) will be the same as those reflected in the historical record (again, Fig. 1. can serve as an example). Originally, it seemed that the difficulty could be substantially reduced if the length of the hydrologic series could be extended. The interest thus focused on long climate records which, it was believed, could serve at least in the statistical sense as proxy data for the water resource planner. This belief has weakened for several reasons: 1) The amount of information that can be transferred from one time series to another is relatively small even if the two series are relatively highly correlated. 2) The further a proxy series extends into the past, the more likely it is to be nonstationary. Moreover, it has been suggested (Sagan et al., 1979) that the past climate could have been affected by man more than we think; hence long climatic records may be much less representative of the future than originally believed. This is in conflict with the very reason for using the series because it implies that the further into the past we go, the less relevant the past data will be to the immediately following few decades in which the planner is interested. Thus the introduction of the faraway past combined with the inaccuracies in proxy series can bring about transfer of negative information (Panel on Water and Climate, 1977).

3) Climatologists are now quite unanimous in believing that man's activity will cause significant changes in climate in the near future (Budyko et al., 1979) so that even statistical predictions based on homogeneous historic records may be of little value to planning and design.

This brings us to the third option which is prediction based on physics-based modelling. While the two previous options are based on a hope of discovering empirical relationships among the various processes and their past and future states, the latter option derives from an explicit hope of discovering causal relationships among events. However, in addition to that, there remains an implicit hope that, if we then follow the causal chain far enough, we come to a link whose behaviour is so regular that it can be reliably extrapolated into the future without the necessity of its causal modelling. Thus, ironic as it is, the legitimacy of causal modelling for the purpose of long-term forecasting hinges on the feasibility of an empirical deterministic model for a link of an over-riding importance somewhere in the causal chain (this does not necessarily apply to short-term forecasting, where the forcast can be derived from the current states of the input variables). This, for practical applications, is a very crucial condition which is seldom appreciated. If it is not satisfied then causal modelling can lead only to conditional answers to problems or, to use the modish jargon, to various scenarios whose plausibility remains shrouded in uncertainty. For example, Budyko's predictions of changes in climatic conditions over the next 50 years rest "on the assumption that the CO_2 content in the atmosphere will rise as a result of growing consumption of fossil fuels of present rates of growth" (Budyko et al., 1979), with the implied assumption that other conditions will remain more-or-less the same as they are today.

In this context the first option, i.e. the search for correlations between regular processes such as sun spot numbers or planetary motions (Milankovich theory), and various climatic and other irregular processes appears in a more favorable light: if plausible causal mechanisms are discovered that can consistently explain all the apparent fits as well as misfits, these regular processes would become the very backbone of climatic and hence long-term hydrologic forecasting.

Merits and Demerits of Empirical and Causal Modelling

Sciences enter into the world of applications - whether it is planning, design, or operation - through the use of scientific models. As a result the merits of a given science (or a scientific program) are often viewed by the practitioner through the prism of utility of the models that the science can offer. It is important to realize that this criterion is very different from that by which the merits are judged by the scientific community - the contribution to knowledge and understanding of the object of study. Therefore on forums similar to ours the question will inevitably arise as to where the thrust of the Canadian Climate Program should be: whether it should be directed to empirical or to causal models.

Recently, I have discussed this problem in some detail in the context of hydrology and its relation to water resource management (Klemeš, 1979c). Since the problem is highly relevant to our workshop I will try to summarize the main points here.

First of all, it must be realized that there is no conflict between empirical and causal models; as long as an empirical relationship cannot negate it. It is also necessary to appreciate that every causal relationship must be anchored in empirical facts and relationships at the boundaries where the "free-body cut" of the causal chain is made. And third, empirical relations often are useful and, indeed, necessary as reductions of complex causal chains.

The main merits of empirical models are as follows:

1) The possibility of their development without much understanding of the modelled phenomenon ("Any idiot can draw a graph." Nelson Norgood, Sociological Sociometrics, The Inverse Press, Chicago, 1969; cited from Berlinski, 1976).

2) Their ability of short-circuiting complex causal chains makes them simple and easily applicable.

3) As a result of the two preceding points, empirical models have the potential for making the collected data useable without much delay thus offering a promise of high cost-effectiveness of the modelling excercise.

Their main drawbacks are these:

1) The danger of overfitting. Without an increase of physical insight into a problem, the only way open to model improvement is to achieve a better fit to observed data. The lack of knowledge of causal relationships makes the notion of "good fit" fuzzy and invites overfitting, i.e. mistaking noise for information.

2) The danger of being sidetracked into polishing theoretical points of the modelling methodology which are far below the noise level of the data. Many examples can be found in stochastic hydrologic modelling with arguments about consistent, sufficient, unbiased, etc., estimators where the differences among them are by an order of magnitude lower than, say, the differences resulting from measurement errors in case of flood peaks, etc.

3) Empirical models must be regarded essentially as interpolation formulae. They have no justification outside the range of the underlying data and their use for extrapolation involves risk of large errors. Unfortunately, it is exactly the use for extrapolation to which developers (and users) of empirical models aspire.

4) Uncertainty about the adopted model structure. In the absence of theoretical (causal) reasons for a specific structure, subjective auxiliary criteria are employed such as mathematical convenience,

current fashion, success of a technique in some other discipline, etc. This entails a risk of adopting basically wrong modelling approaches and wasting resources on a frightening scale. This seems to be the case with much of the applications of classical statistics in geophysical sciences. These statistical methods have been developed for the analysis of large masses of data from repeatable and controlled experiments. In empirical geophysical modelling they are often applied to small samples generated by "unique and uncontrolled" experiments as geophysical processes can broadly be characterized.

5) Empirical models encourage the "let-the-data-speak-for-themselves" philosophy presently formalized in black-box modelling and elevated to a status of an ideology: the physics is not being let to interfere by deliberate decision of the modeller. This "ostrich" philosophy is a tremendous disservice to science and, in the last analysis, to its users, because it is directed away from the discoveries of causal relations which form the very basis of the acquisition of new knowledge.

As for the causal models, their main attraction is their inherent capacity for extrapolation beyond the empirical experience, a capacity that is becoming increasingly important with the increased rate of man-induced environmental changes. This is especially important in the design context where errors often cannot be readily corrected after the design has become a reality. The credibility of design rests on the credibility of the models on which it is based. Since the results obtained from these models are generally untestable, the only source of their credibility is a sound theory behind them.

The major problem is that it is extremely difficult to materialize this inherent capacity of causal models. It depends on the increase of knowledge and this increase cannot be effectively planned and controlled. Discoveries cannot be brought about by filling appropriate positions and allocating funds. These things are necessary but not sufficient. They provide a basis from which the discoveries may, but need not, arise. The triggering element is the presence of talent and "serendipity". A very instructive example is one of the discovery that dry ice is an effective agent for cloud seeding (Blanchard, 1979). This unpredictability of discoveries combined with the necessity of long-term commitment of resources has always made basic research - which is the basis of successful causal models - rather unpopular with those who are interested in the end products and also, in general, with research managers who operate in the realm of planning, effective use of resources, systematic progress towards set objectives, pressures of changing attitudes, priorities, limited budgets, etc.

As a result, the direction towards empirical models usually prevails because, in the last analysis, even if the promise of a good result is smaller than with a causal model, the commitment of resources is smaller and is short-term and the cancellation of a program, if necessary less painful. Unfortunately, so far nobody has made a cost-benefit analysis that would take into account the overall effectiveness, over the past 50 or 100 years, of empirical models. And even if somebody made it, few managers would see it relevant to their terms of reference.

Problems of interest to design

With a regard to hydrology, and in the broader sense to climatology, the water resource planner and designer is interested in the prediction of two aspects of hydrologic processes, 1) the extremes, i.e. floods and droughts, and 2) the averages, or trends. The extremes tend to be the more important of the two since the related errors often lead to catastrophic events whose suddeness precludes effective remedial action to be taken in time. Because the prediction of both these aspects is subject to uncertainties, another problem of interest, which is within the terms of reference of the planner/designer himself, is the analysis of project robustness and resiliency, i.e. its ability to cope with a variety of possible climates and its potential for being adapted for climatic conditions different from those originally assumed (Panel on Water and Climate, 1977).

Given below are specific examples of problems of the three categories, which may help to identify thrusts in the Canadian Climate Program that would, if successful, benefit the planning and design process.

1) Extremes

Of great value would be a clarification of the notion of flood frequency and an improvement of the existing methodology for its computation. The present "flood frequency analysis" practiced by hydrologists is largely irrelevant to the problem the name of which it carries. The help that hydrologists were hoping to get from classical statistics is grossly inadequate because it arbitrarily relies on tools developed for different purposes and because it is rooted in inadequate hydrological understanding of the phenomenon of interest. It is not to the hydrologists' credit that they have devoted so much time and effort to endless variations of frequency distribution fitting without paying much attention to the nature of floods themselves. For this failure there is no excuse. Statisticians know very well that "...unless the statistician has a well-defined and realistic model of the actual process he is studying, his analysis is likely to be abortive" (Bartlett, 1962). This is exactly what has happened in flood frequency analysis: we know everything about the intricacies of plotting positions; efficient, unbiased, consistent, etc. estimation of parameters; treatment of outliers; goodness-of-fit testing; asymptotic convergence of estimators; Bayesian estimators; and so on, ad nauseam. That is, we know almost everything about the art of blind fitting of distributions to samples of sterile exact numbers drawn be well-tested random mechanisms from infinite homogeneous populations - but we know next to nothing about the likely frequencies of flood flows, volumes and durations.

The knowledge that is necessary here cannot come from hydrology alone. It must also come from climatology and meteorology since a flood is the end-result of climatic, meteorologic and hydrologic processes. However, the input from climatology and meteorology has so far been minimal. We know, for instance, that in the northeast quarter of this continent floods can be caused by snowmelt, local convective disturbances, frontal systems and hurricanes. But the short historic streamflow records are ridiculously short for any attempt to study the frequencies of these four kinds of floods separately, not to speak of floods where more than one of these causes is involved. How, for instance, can one make an interpretation of "frequency" from one occurrence, as is often the case with floods caused by hurricanes (see Fig. 2a), or what inference can one make from a seemingly clear trend resulting from accidental combination of several heterogeneous events (Fig. 2b)?

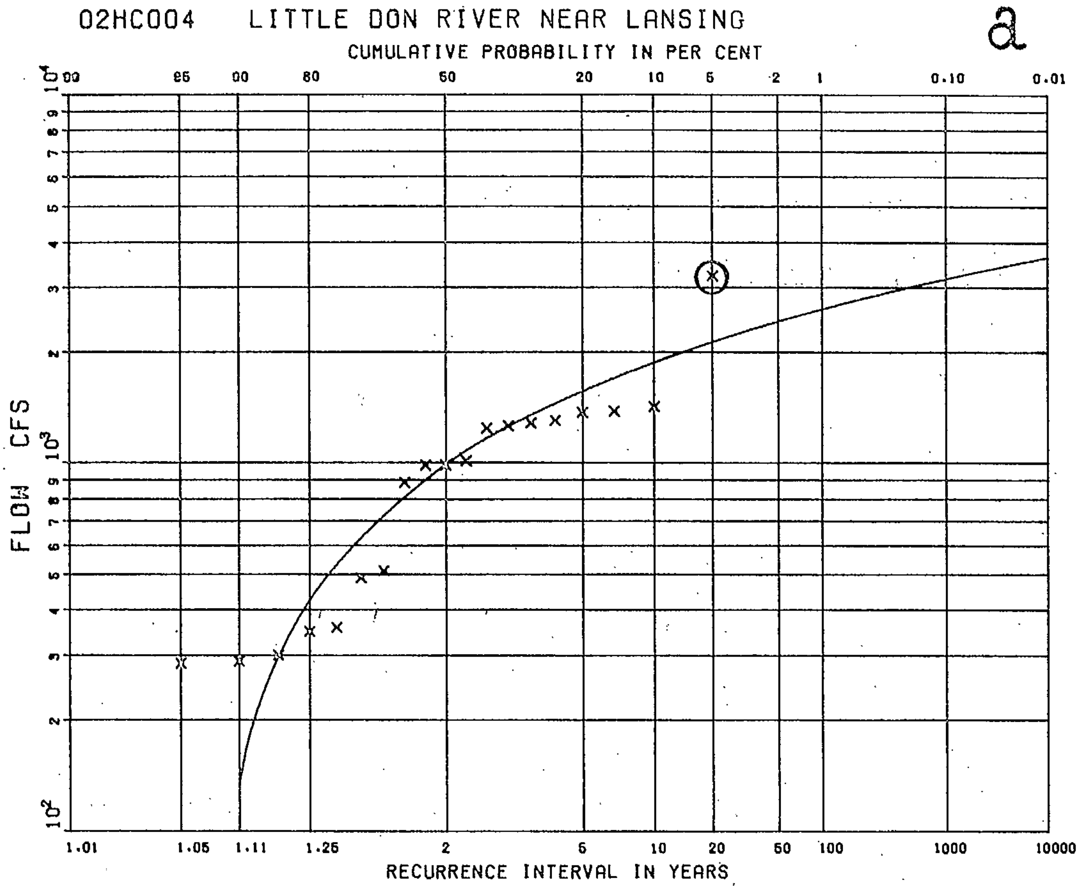
On top of these uncertainties come those related to the possible future changes in climate. Here climatology can be of great help to the planner but, and this has to be emphasized, only if the climatic findings go hand in hand with improved understanding (and hence modelling) of meteorological and hydrological processes which are needed for a quantitative projection of a climatic situation into a flood event.

In this context it also has to be emphasized that a potential benefit to design cannot be isolated from benefit to operation. For example, an error in the estimate of the design flood rooted in climatic (long-term) prediction can be compensated by a good meteorologic (short-term) forecast which can make it possible to pre-empt a part of a storage in a reservoir, thus increasing its flood-protection effectiveness.

2) Averages

Optimality of water supply, irrigation and water power projects depends (as far as hydrology is concerned) primarily on the average available flow and its average variability. They affect not only the quantity of the end product to be supplied by the project (water, energy, crops) but also the size of storage reservoirs necessary for seasonal and over-year redistribution of the water. The knowledge of the future averages increases in importance with the size of the project with regard to the total yield of a water resource, i.e. with the degree of water utilization. It is also of importance that with the increasing size the project becomes more robust and less dependent on short-term forecasts. Both these aspects can be demonstrated using a storage reservoir as an example. Fig. 3 (Klemeš, 1979a) shows optimal operation of reservoirs of three different sizes over a period of 25 years; the lines bounding the irregular corridors are residual mass curves of streamflow (reservoir inflow) and the lines of the shortest path through each corridor represent the residual mass curve of the optimal outflow. The straightline segments of these shortest paths represent constant rates of the outflow. With an increase in reservoir size they become progressively longer (on the average). Between their corner points, only the knowledge of the average inflow is needed, its instantaneous fluctuations having no influence on the outflow rate.

This illustrates the potential of long-term forecast of only such aspects of hydrologic processes as averages over longer periods, and the relationship between project size and usefulness of such long-term forecasts. Generally speaking, the smaller the project, the less useful the long-term forecast.



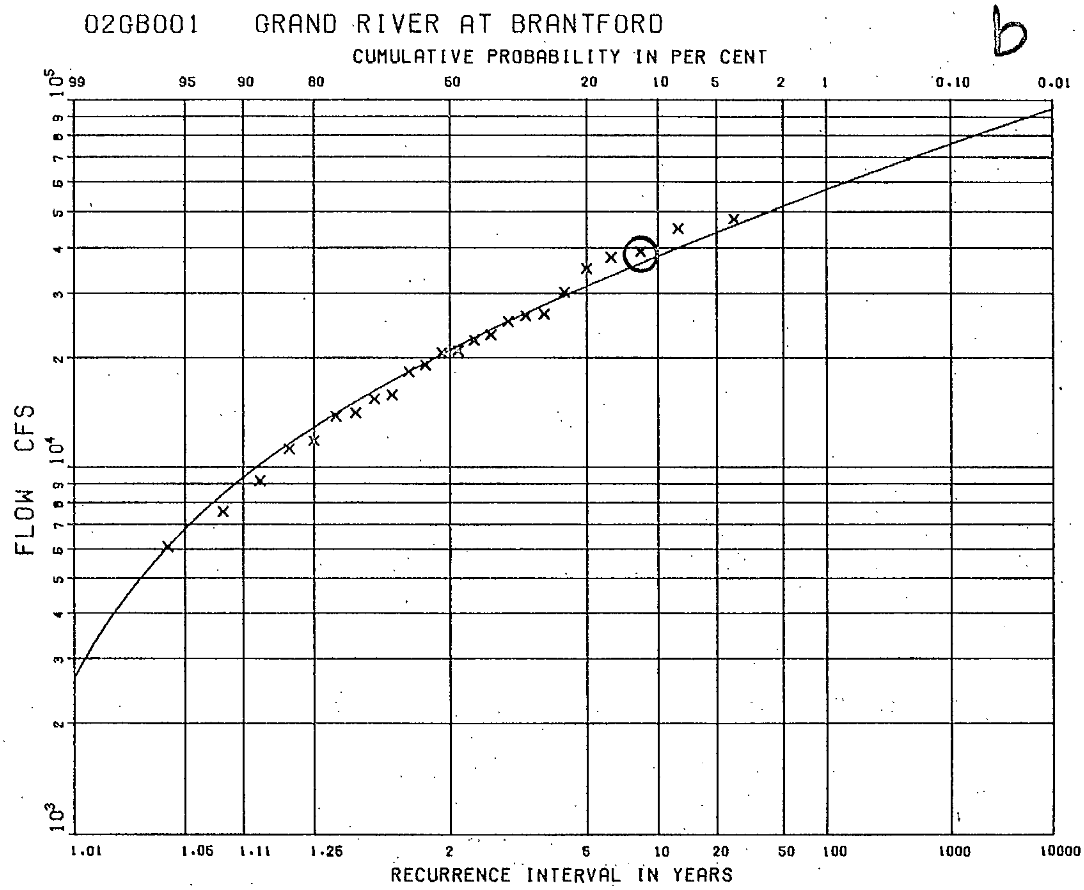


Fig. 2 Flood frequencies of two rivers in Southern Ontario. Flood caused by Hurricane Hazel (1954) has been circled (Sangal and Kalio, 1977)

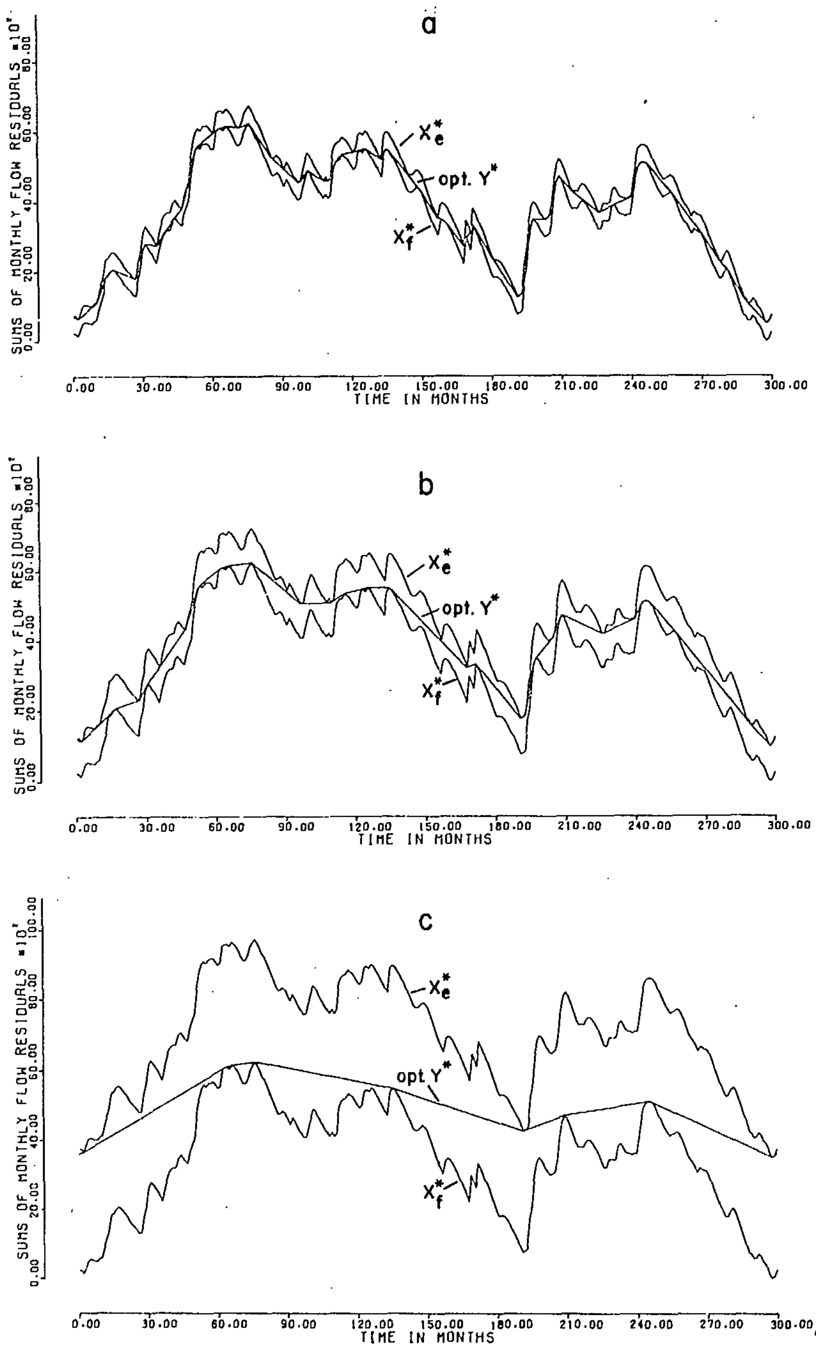


Fig. 3. Residual mass curves of mean monthly reservoir inflows over 25 years (1851-1880) for the Elbe River at Děčín, Czechoslovakia, and residual mass curves of optimum releases for three different storage capacities K (K is the vertical distance between each pair of inflow mass curves); from Klemeš, 1979a.

3. Project robustness and resiliency

Before the planner and the designer approaches the climatologist or the hydrologist with a request for better forecasts, models, more data and information, etc., he should know what effect the incremental information will have, how much the difference will matter vis-a-vis all the other uncertainties and how easily the project (or its operation) can be modified to mitigate the effect of inevitable errors. This was not being done systematically in the past, and perhaps it was not needed when the possibility of large differences between future and past conditions was not even contemplated. Now that the situation has dramatically changed in this regard, the first thing needed is a systems-analytic research that would identify the relations between the hydrologic information and its socio-economic benefit, the relations between design, and operation parameters, the tradeoffs between structural and nonstructural measures, "permanent" solutions and contingency measures, which all are different aspects of robustness and resiliency of water resource projects. I stressed the need for such research four years ago (Klemeš, 1976) with little success. Now that this need has reappeared in the context of climatic change and is being stressed south of the border (Matalas and Fiering, in Panel on Water and Climate, 1977), it may be more appreciated. Two examples of its importance for the assessment of the value of climatic information will be given.

The first pertains to the value of information to reservoir optimization (Klemeš, 1977). While concerned with performance optimization, which is an aspect of operation rather than one of design, the relevance to design is straightforward since optimal design is a function of optimal operation. Results of this research showed the following interesting things (among others):

1) The distribution model of annual flows was not too important.

2) By far the most important parameter was the mean flow over the design period or the planning horizon.

3) The value of the length of a historic flow record decreased with an increasing discount rate.

The value of such findings for hydrologic and climatic research is self-evident in that they show what is and what is not important. For example, the last finding indicates that the value of paleoclimatic record and of its hydrologic projections depends on the economic environment in which the project is set. In an unpredictable, volatile, chaotic world where the interest rates are soaring, the value of historic information is drastically reduced and any optimization is an exercise in futility. This finding has recently been echoed by Junger (1979): "Thus in an uncertain world, cost-benefit analyses are inherently deceptive... The concept that cost-benefit analysis can lead to a correct result in a world as complex as ours is simple madness."

The other example relates directly to design, in particular to the effect of various climatic scenarios on storage reservoir size. As some of you are aware, there has been a long-standing controversy whether the consideration of the so called Hurst phenomenon is important in reservoir design. This phenomenon is related to climatic variability in the sense that the Hurst coefficient is higher in streamflow series which exhibit high long-term persistence and the clustering of anomalies than it is for series which are statistically more regular. In general a higher Hurst coefficient indicates that a larger storage capacity is needed for the same reservoir draft. Thus, it has been argued, neglect of the Hurst phenomenon would result in significant underdesign of storage reservoirs. As a result, models for time series which can accommodate the Hurst phenomenon have been developed and large volume of scientific literature of high calibre exists on all aspects of modelling of the Hurst phenomenon. However, what has not been explored is how much its neglect is really likely to matter in view of the expected performance of a reservoir.

Results now have been obtained (Klemeš, 1979b; Sricanthan and Klemeš, in preparation) which indicate that in most practical situations the differences of performance reliability are lower than the noise level in reliability computations. An example is shown in Fig. 4. This is so because the relationship between performance reliability and storage capacity is highly nonlinear. Thus, as shown in Fig. 5, it may happen, for example, that while a reservoir with a storage capacity K is capable of ensuring the release of outflow equal to mean inflow with a 100% reliability over a period of 30 years, (Fig. 5a) a reservoir with storage capacity equal to only 50% of K does not reduce the reliability to anything close to 50% but, in terms of failure years to 90%, in terms of the time to 93.7% and in terms of the volume of water supplied to 99% (Fig. 5b). In other words, the reliability of reservoir performance is rather robust with respect to reservoir size. Seen from this perspective, Fig. 1 looks much less alarming than one would be tempted to think.

Conclusions

Increased understanding of climatic variability would be helpful for design of water resource projects if it resulted in models capable of predicting the features of the climate in the (roughly speaking) first 50 years of the 21st century (the degree of usefullness of such predictive capability is, of course, a function of economic stability and adequate predictability of future social priorities). Such a capability seems to be rather far away. Its achievement requires a much deeper understanding of the mechanisms governing climatic processes which in turn would require a broad program of basic research not only in climatology proper but in areas such as solar-planetary relations; upper, middle and lower atmosphere coupling; ocean-atmosphere coupling; feedback mechanisms among various climatic and geophysical processes on the one hand and between climate and biosphere on the other (Lovelock, 1979). This involves a very ambitious program on a global scale, long-term commitment of resources and talent, and no guarantee of early returns on the investment.

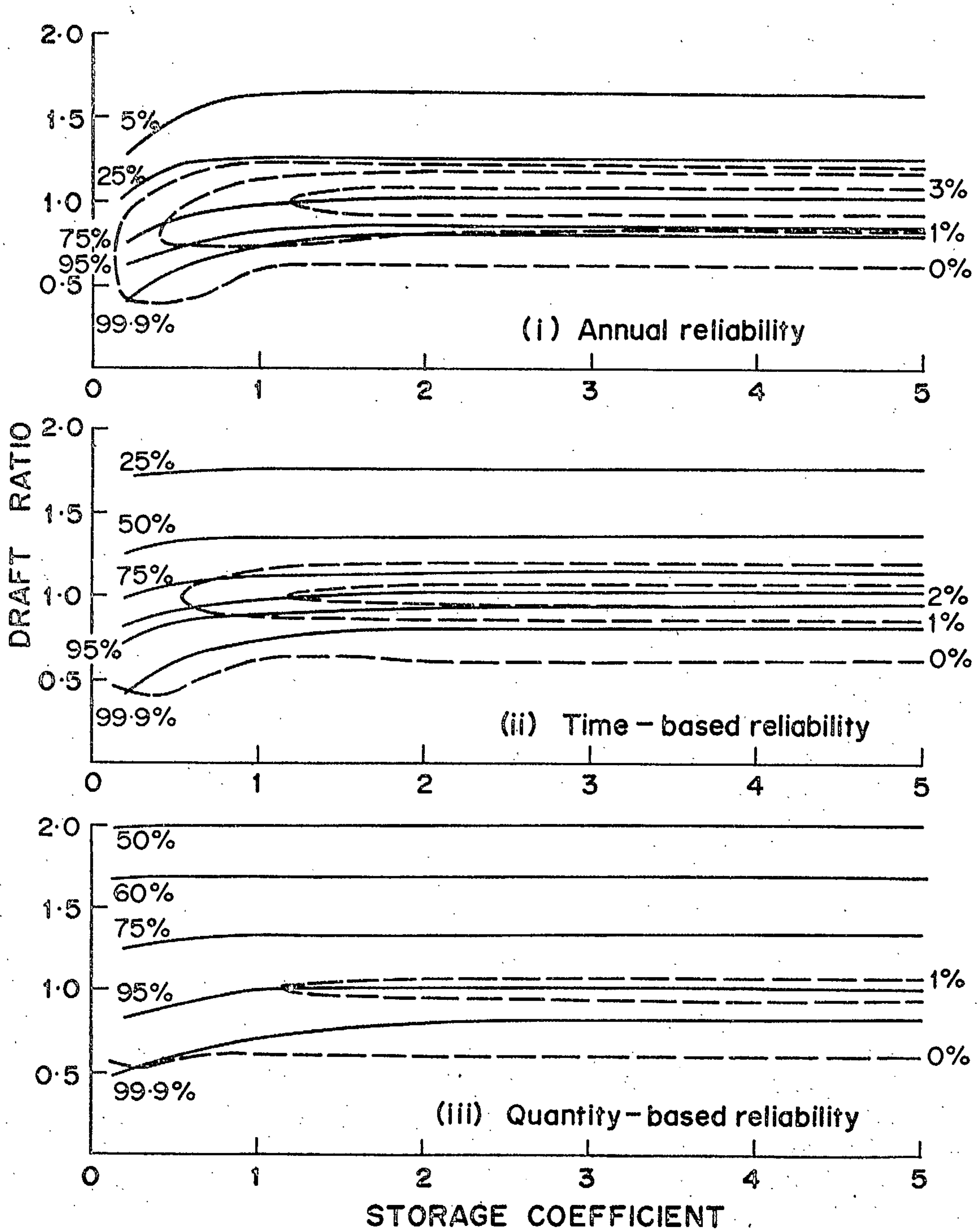


Fig. 4 Solid lines show the storage-yield relationship for a constant reliability for monthly inflows based on Markov annual model with Cv = 0.3 and r1 = 0.3. Dashed lines show reductions in reliability resulting from inclusion of the Hurst phenomenon (Sricanthan and Klemeš, in prep.)

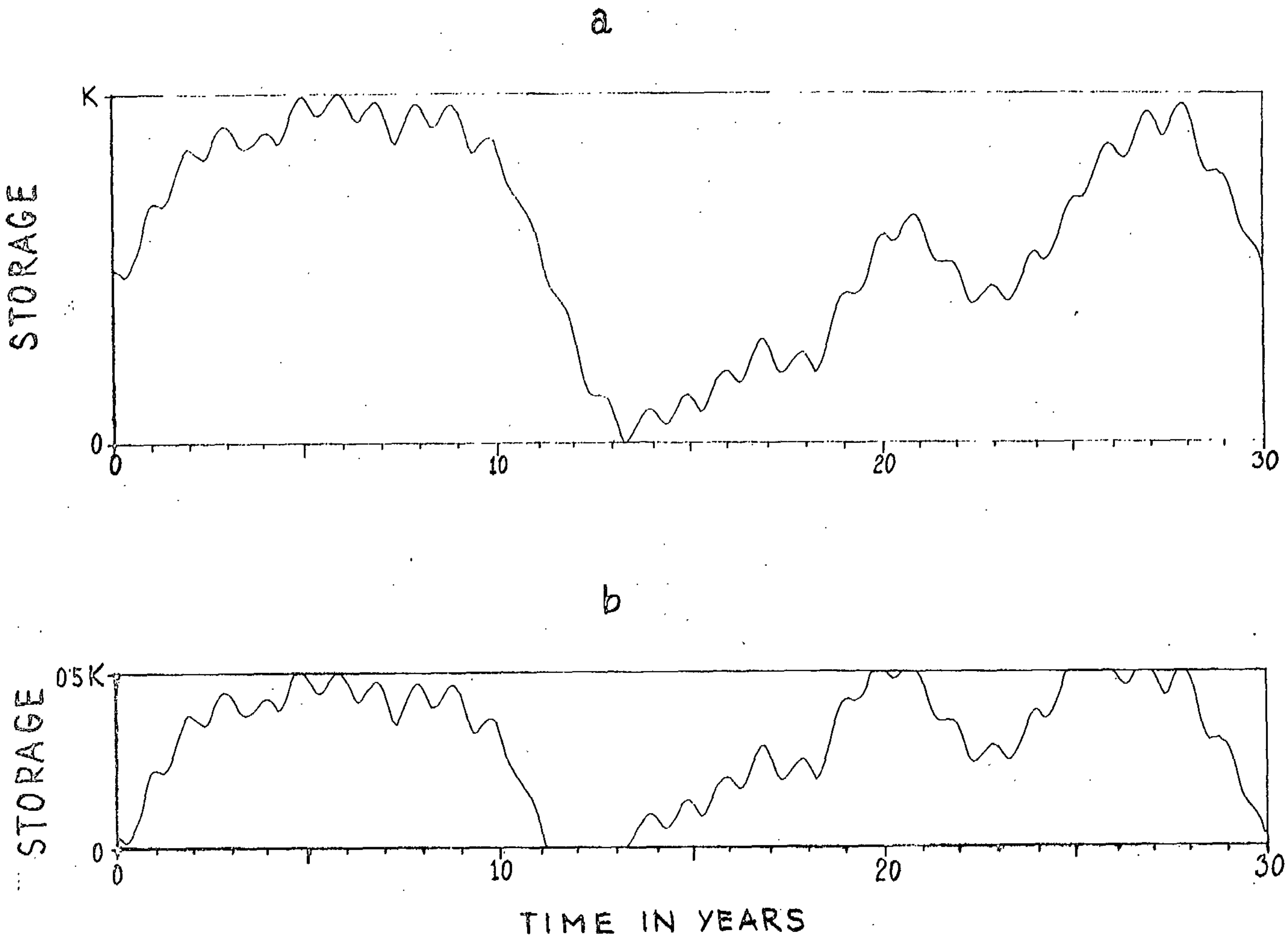


Fig. 5 Storage fluctuations in hypothetical reservoirs (on St. Mary's River at Sault Ste. Marie, Ontario) of capacities K and 0.5 K supplying draft equal to mean flow in the period 1881–1910.

a) Storage capacity K is needed to supply the draft with a 100% reliability.

b) Storage capacity 0.5 K supplies the same draft with annual reliability Ra = 90%, time-based reliability Rt = 93.7% and quantity-based reliability Rv = 99.0%.

From a shorter perspective, it seems realistic to expect that the presently existing climatic knowledge could help improve flood and drought frequency estimation for stationary conditions modelled on the fairly recent past, and suggest plausible scenarios for climate changes resulting from specific types of man's environmental interference such as various rates of fossil fuels consumption, reduction of the areal extent of tropical forests (e.g. in the Amazon basin), effect of continental water transfers (e.g., the effect on arctic climate of the diversion of Siberian rivers - see Gribbin, 1979; north-south water transfers on this continent). However the utility of these results is likely to be only marginal for several reasons, mostly because of the as yet low overall capability (and credibility) of climatic models as well as physics-based hydrologic models necessary to supply the design-relevant parameters. Thus, in the foreseeable future the impact on water resource design of the Canadian Climate Program is likely to be a minor one, notwithstanding the direction in which it may evolve.

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APPENDIX

Correlations and Processes

Solar-Terrestrial Influences on Weather and Climate. Proceedings of a symposium, Columbus, Ohio, Aug. 1978. BILLY M. McCORMAC and THOMAS A. SELIGA, Eds. Reidel, Boston, 1979 (distributor, Kluwer Boston, Hingham, Mass.). xiv, 346 pp., illus. $24.

Sun, Weather, and Climate. JOHN R. HERMAN and RICHARD A. GOLDBERG. National Aeronautics and Space Administration, Washington, D.C., 1978 (available from the Superintendent of Documents, Washington, D.C.). xii, 360 pp., illus. Paper, $4.50. NASA SP-426.

Like it or not, the study of possible effects of solar variations on terrestrial weather and climate is going to be with us for many years. Those professing to have found such effects have come to exceed the critical number necessary to maintain activity in the field, and books such as those under review here will be appearing with increasing frequency. The two books are of quite distinct types.

The volume edited by McCormac and Seliga evolved from a symposium. In many respects it is typical of the genre, containing review papers, results of recent research, and projections of individual programs into the future. Those active in the field should consider as "must" reading the paper by A. B. Pittock, "Solar cycles and the weather: Successful experiments in autosuggestion?," at least if they have not read the same author's longer critique (*Rev. Geophys. Space Phys.* **16**, 400 [1978]), and they owe it to any researchers they inveigle into the field to make them too read one or the other of these papers.

The book includes no record of debate or discussion following individual papers (though some changes have been made in the text in consequence of debate and discussion). However, an important chapter of "workshop conclusions" has been provided. In it are to be found a set of broad summaries that do not espouse any particular set of data or any particular claim and yet are sufficiently incisive to provide a firm base for those who wish to proceed with further studies. A report on correlation studies by J. Murray Mitchell, Jr., is a particularly valuable part of this chapter for future practitioners. Had its advice been taken in the past, the literature of the subject would be far less littered with garbage than it now is. The chapter also contains two resolutions adopted at the meeting for promulgation to the appropriate international scientific bodies. The participants in the meeting have thus come to act as a pressure group for the furtherance of the type of work they pursue and the continued gathering of certain types of data they hope to use.

The book by Herman and Goldberg is of a kind new in this field and must be welcomed if for that reason alone. It includes, as one might expect, a wide-ranging review of the claims and counterclaims of correlation that constitute the bulk of the relevant literature, and it attempts to come to grips with the physical processes that must be operative if the correlations are physically meaningful. But, more than that, it starts with a compendium of relevant information drawn from solar physics, aeronomy, and meteorology and presents the whole in a cohesive fashion. It serves, then, as a basic textbook for the composite field, valuable both to those whose background lies in one of the subfields and to those who will be entering the field in one jump.

Having no precedent to follow, the authors have had to face the difficult job of selection and emphasis, of finding the appropriate scope and depth. While I and others might disagree with some of the choices made, we would no doubt disagree in different ways. (There is, of course, the typical array of first-printing errors: for example, a mass density is given in units of kg^{-3} on p. 41, and the value cited for "the magnetic permeability of empty space" on p. 42 omits a necessary factor of π.)

The one serious shortcoming I find in the book is what I view as a relatively uncritical approach to claims of correlation. The authors may justify this by their own stated position (explained in the preface) as agnostics, and by their frequent (invariable?) use of the term "correlation" in a purely mathematical sense without the implication of physical meaning. Yet they use the same term when the physical significance of a correlation is beyond doubt, become apologists ("A critical period of 1930–1950 is thus indicated" [p. 133]) when the sign of a mathematical correlation becomes reversed, and on other occasions treat as serious business correlations whose relevance is questionable at the very least. This is dangerous stuff to place in the hands of newcomers to the field, who will be unaware of the travesties of the past, and a chapter delineating the traps that lie around and the means for avoiding them should have been included. In the absence of such a chapter, the papers singled out above (plus, perhaps, a recent article by R. Shapiro, *J. Atmos. Sci.* **36**, 1105 [1979]) should be considered to be a vital adjunct to this book.

All that having been said, I must repeat that the book by Herman and Goldberg is valuable and welcome. All who wish to pursue work in the field will wish to have it readily available, at least until some other authors face up to the rather formidable task of improving upon it.

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(from Science, Vol. 206, 1979, p. 1396)

Opportunities for Improved Planning and Design of Water Resource Projects with Better Climatic Information

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Introduction

Historically, water resources planners and designers have used simplistic ideas about climatic events in preparing their development plans and project designs. The end result of the climatic cycle (as reflected in recorded rainfall, streamflow and temperature values) is normally used as a starting point by planners and designers. Typically, little effort is devoted to either understanding the basic climatic mechanisms or to establishing improved perceptions about changing climatic events. It is assumed that recorded events (hydrologic, temperature, etc) are a reasonable basis for planning and design purposes, and for assessing development benefits.

In recent years, however, planners have been increasingly sensitive to the potential for climatic change and to assessing possible effects of such changes on water resources projects. It has been evident that there are continuing shifts in regional temperatures (gradual cooling), and that the incidence, duration and severity of extreme events (floods, droughts, extreme cold periods, etc) are increasing. This leads naturally to questions about whether structures have been adequately designed to cope with these more extreme events and whether expected benefits will occur.

It has long been established that a future sequence of hydrologic events cannot be forecast with any reasonable degree of accuracy. Hydrologic events respond to climatic inputs. As a consequence, the general approach has been to develop a statistical analogue of past events (in terms of mean, standard deviation, skew and lag representations of transformed historic data). These values are then expected to apply to future sequences along with a random component. It is possible to generate many synthetic sequences and to test the proposed plan or design against these various sequences.

This general approach suffers, however, from an inadequate knowledge of cause-effect relationships. Dracup, for example, has shown that this approach led to a major overestimation of project benefits in the Colorado River system.[1] The long-term mean annual flow in the early part of this century was 17.0 million acre-feet (maf), but has subsequently reduced to 13.3 maf. Furthermore, the pattern of events in the latter part of this century relative to a statistical analogue based on earlier events is so extreme as to suggest that the statistical analogue is, at best very suspect.

It has become clear, therefore, that future projects must be designed with better understanding of climatic processes. Obviously, it is preferable to understand the climatic system and all its various feedback mechanisms so that it becomes possible to develop a physically based reproduction of the essential features of local and regional climates. With this approach, it should then be possible to predict future events and their frequency with better understanding and accuracy. Such approaches, however, do not yet exist.

The purpose of this paper is to present a perspective on the use of better climatological information and knowledge for the improved planning and design of water resources systems. In presenting this paper, an initial overview is given of basic climatic processes in North America. A discussion of current planning and design methods which rely on climatic information is then presented. Opportunities for utilizing improved climatic information are also discussed.

General Atmospheric Structure

The atmosphere, that gaseous covering of the earth, is highly complex and made up of many layers. The lowest layer is the troposphere, and above this are the stratosphere, mesosphere and thermosphere, the latter including the several layers of the ionosphere and, finally, at a height of some 500 to 1,000 km, the exosphere where atmospheric gases escape to space.

There is evident, but as yet undefined, connection between the temperatures, chemical compositions, and motions of the gases and ions of the outer layers and the more recognizable weather behavior of the troposphere. Scientists have struggled to correlate sunspot cycles with weather phenomena such as droughts and floods, and are now concerned over the effects of the increasing leakage of man-made oxides of nitrogen into the ozone layer. This is the layer of the outer atmosphere roughly between elevations of 10 and 50 km where ozone is concentrated as a result of the filtering of man's survival. Although important, such relationships are longer term and of greater scale than the events which determine day-by-day weather conditions that immediately affect our lives and patterns of living.

Figure 1 shows a generalized temperature structure of the atmosphere to a height of 120 km, showing the troposphere as a relatively thin layer in the bottom 10 km. This figure is for illustration only; actual temperature soundings at a particular time show a discrete tropopause for each pressure zone and air mass. The various tropopauses are found at successively lower levels from the subtropics toward the pole. These levels also are variable in time.

It is informative in considering the makeup of the troposphere to examine the prevailing distribution of surface-level atmospheric pressures and, hence, air movements that govern the other parameters of weather that directly concern us. Figure 2 shows the gross configuration of barometric pressures on the earth's surface in the northern hemisphere. The pressure differences shown result from differences in the weight of

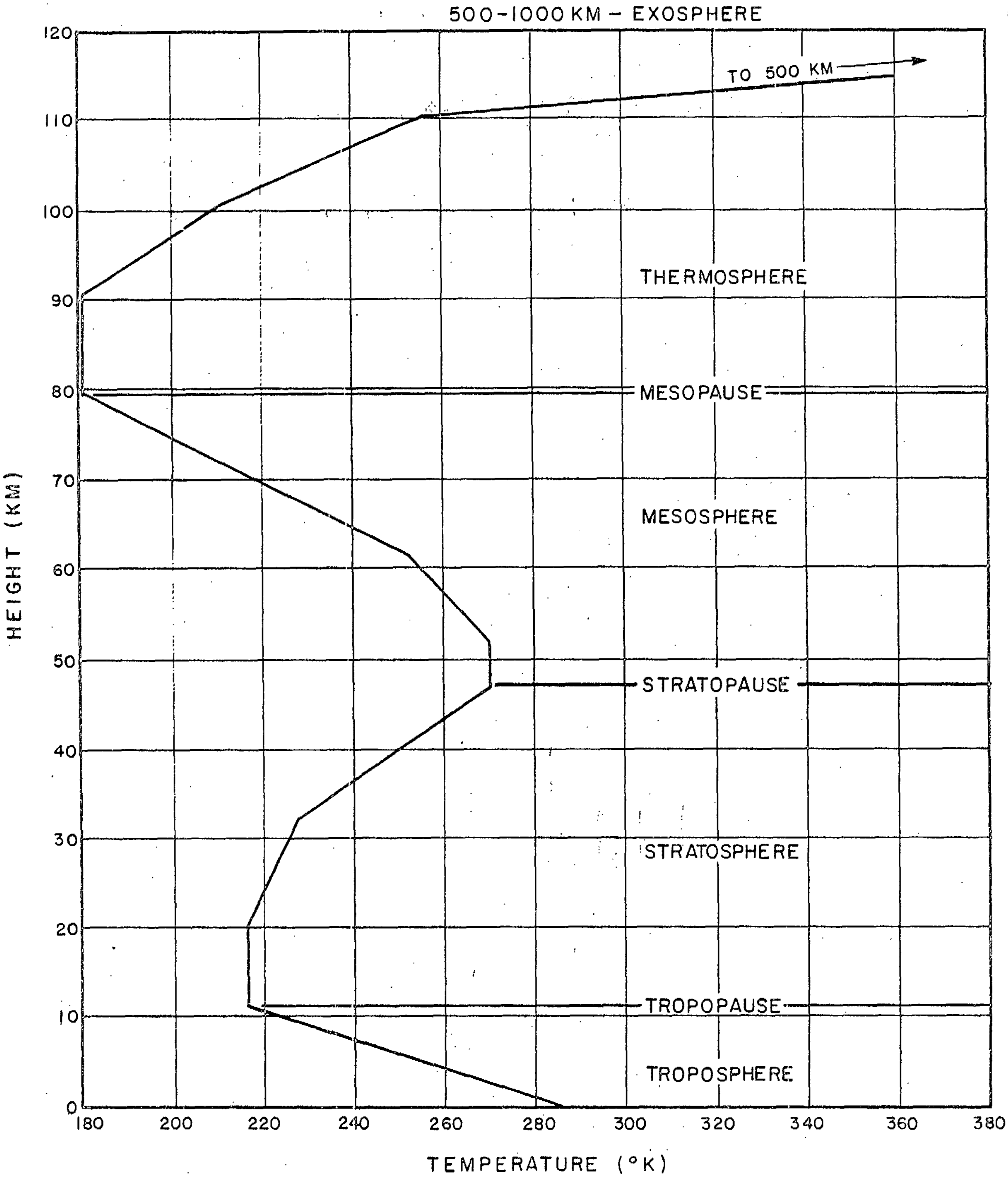


FIGURE I

THERMAL STRUCTURE OF THE ATMOSPHERE

tropospheric air on the ground as governed by the thickness and density (or temperature) of the troposphere which varies with latitude as well as time. Although straightforward, discussion of why these different pressure zones exist is not relevant to the points being brought out in this section.

Moving from the equatorial zone toward the northern polar region, four major pressure zones are identified.

Due to high solar radiation, pressure near the equator is low, relative to that at higher adjacent latitudes in both the northern and southern hemispheres. This results in convergence of air flowing into the equatorial "trough of low pressure" by the northeast trade winds of the northern hemisphere and the southeast trade winds of the southern hemisphere. The converging air streams near the equator cause uplifting motion, producing extensive cloud and rain.

As shown in Figure 2, the trade winds form the equator side of a closed clockwise circulation cells around subtropical areas of high pressure prevailing at about 30 degrees north latitude. Strung out at this latitude in the northern hemisphere are dry, light wind conditions that characterize the great deserts of the continents and the becalmed weather over the oceans, known for centuries to sailors as the doldrums. The zone of the northeast trade winds, forming the southern branch of the airflow around the high pressure centers, normally has a stable temperature layer at a few thousand feet above ground, the trade wind inversion, which breaks down during tropical storms or in rising convective air currents induced by strong solar heating over land having rugged terrain.

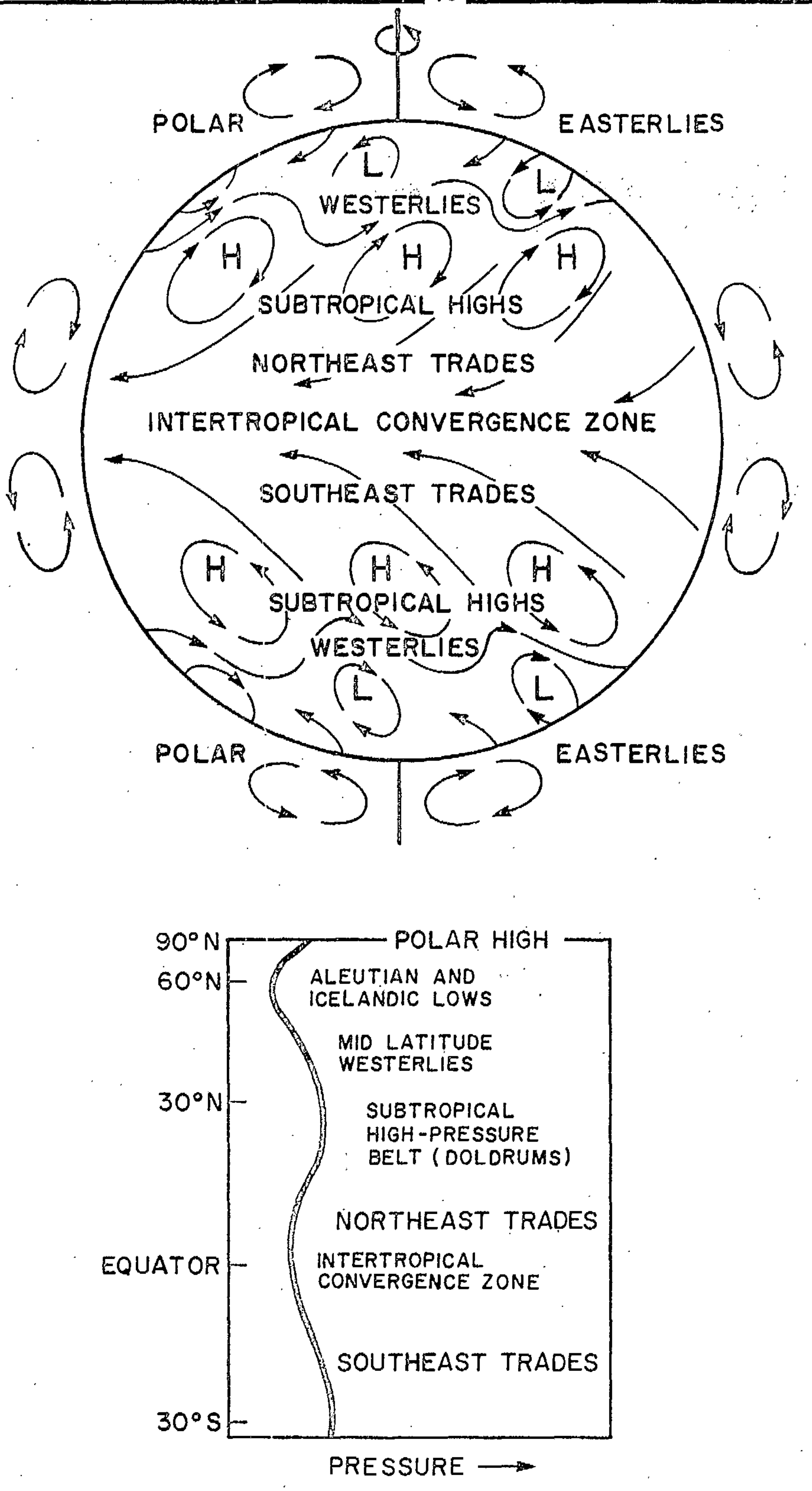
In the mid-Atlantic, there is an important semipermanent subtropical area of high pressure. This is the Bermuda-Azores High, which exerts marked controls over atmospheric circulation patterns around it. Its movements and characteristics greatly affect the northward intrusion of warm, moist tropical air in eastern North America and warm, dry air in central North America. A similar Anchor High is found in the vicinity of the Hawaiian Islands in the North Pacific Ocean.

The high pressures of the Bermuda-Azores High are characterized by light winds and subsiding air that creates a marked temperature inversion at levels between 3,000 and 5,000 m, depending on latitude, air mass characteristics, etc.

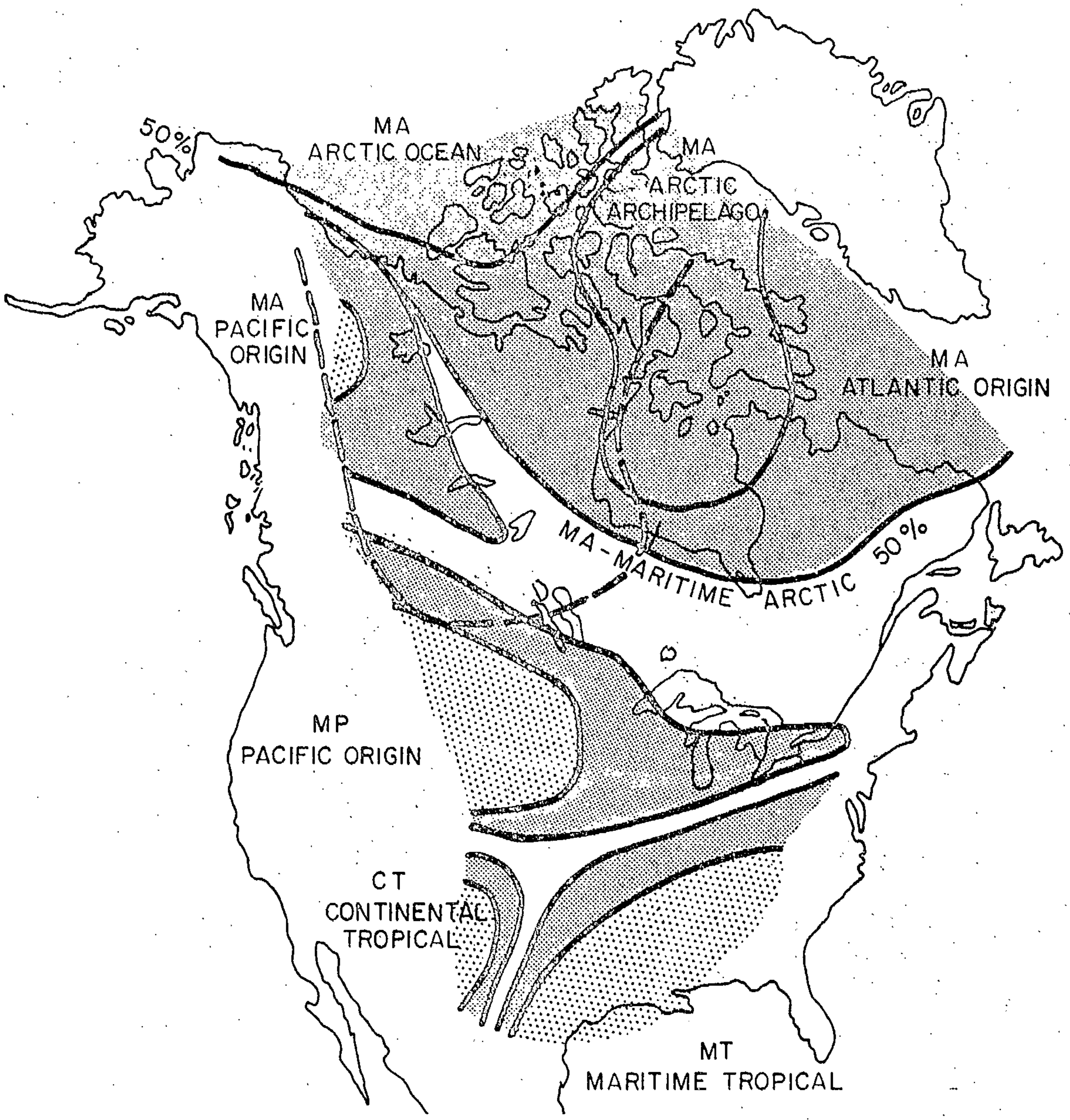
To complete the picture of pressure zones and winds in the northern hemisphere, two semipermanent low pressure areas are identified, viz, the Icelandic Low of the North Atlantic and the Aleutian Low, in the Gulf of Alaska, of the North Pacific. These vortexes anchor the circulation patterns that govern the flow of air from the Polar zone into the midlatitudes.

North American Air Masses

Figure 3 shows typical air mass distribution in July, together with course region of Continental Arctic air in winter.



MAJOR PRESSURE ZONES AND WIND FIELDS FIGURE 2



LEGEND

50% - 75% DOMINATED BY INDICATED AIR MASS

75% - 100% DOMINATED BY INDICATED AIR MASS

— — — SOURCE REGION FOR CONTINENTAL ARCTIC CA (APPLIES IN WINTERTIME ONLY)

EQUAL PROBABILITY AREAS ARE DRAWN FOR JULY

*AFTER BRYSON

TYPICAL AIR MASS DISTRIBUTION IN JULY* FIGURE 3

Maritime Tropical (MT) Air Mass

The Bermuda-Azores High frequently extends westward beyond Bermuda into the eastern continental United States, where occasionally a separate closed high pressure area becomes established. This closed system provides a warm core high with subsiding air that penetrates into eastern and central Canada occasionally during summer for periods of a few to several days. This produces the hot, humid, still weather typical of the warmest and highest moisture content of the four air masses we experience. MT air can be drawn northward by circulation in advance of vigorous low pressures and frontal systems causing heavy rainfalls.

Maritime Polar (MP) and Maritime Arctic (MA) Air Masses

The patterns of pressure distribution in the zone north of the subtropical high, the midlatitude westerlies, are the most changeable in the world. As Mark Twain remarked on the climate of New England, "If you don't like the weather now, wait 5 minutes". At these latitudes, there is a constant succession of high and low pressure areas associated with three types of air masses in the warmer months and four in the winter. Changes from one air mass to another are marked by the passage of fronts, cold and warm, at the surface and aloft. At this point, air masses, in addition to MT, are introduced to complete the discussion of northern hemispheric prevailing pressure patterns and their implications with respect to precipitation events. We have discussed the occasional incursions into our latitudes of the warmest of the four air masses experienced - MT. During the late spring to early fall, the air masses that dominate over Canada are MP and MA. MP air is initially bred over the midlatitudes of the North Pacific Ocean and undergoes several modifications as it moves across North America. It is the second warmest and moisture laden air mass on the continent. A major modification to MP is applied in passage over the Rockies where much of its moisture precipitates. Other less dramatic, but highly significant, modifications are applied by passage over the midwestern agricultural areas, adding moisture in season, the Great Lakes, surface snow covers, etc.

MA air has its origin over the Arctic Ocean and northern Canada and, again, is subject to many modifying influences as it moves across the country. It is a cooler air mass than MP. Sometimes this air has a rather short trajectory over the Gulf of Alaska before moving over the northern Rockies toward the eastern continent. Sometimes MA air moves over, and is modified on its way south by Hudson Bay. Infrequently, this air originates over the higher latitudes of the North Atlantic Ocean and spreads westward into North America under the action of a broad north-easterly wind flow, set up by major storms that stagnate off the Canadian east coast.

Continental Arctic (CA) Air Masses

The fourth and coldest air mass that we experience is CA which, strictly speaking, is a winter season phenomenon only. It forms over snow and ice surfaces as a result of extreme raditional heat loss to space in air over northern Canada, under the influence of high pressure and clear skies, light winds and long hours of darkness. From time to time during the winter, it breaks southward and may even penetrate in modified form into the southern United States. Rarely is there a sufficient easterly component in its circulation pattern to move it westward across the Rockies.

CA air is, by nature, very stable in its source region, characterized by a marked inversion in the lower few thousand metres of the atmosphere. Even during summer, when true CA air does not exist, a coolish type of MA air prevails in the Polar region. Again, it is marked by a relatively stable vertical temperature structure.

Fronts

The air masses are separated by zones of temperature and wind discontinuities called fronts. These are identified as follows: Polar front (P) between MT and MP; Maritime front (M) between MP and MA; Arctic front (A) between MA and CA. Disturbances form occasionally over all of these fronts and cause precipitation of extent and duration dependent on the intensity of the disturbance. The heaviest precipitation in Canada is associated with frontal disturbances into which MT is drawn either at the surface or aloft.

Uses of Climatologic Information in Planning and Design

At this point, it is appropriate to discuss the manner in which the hydrologic aspects of water resource projects are typically analyzed and, particularly, the way in which an understanding of climatological processes impacts on these analyses. It is a fair comment on present practice that, although most water resource projects are designed to regulate and make use of precipitation, there is very little input to either planning or design by way of analysis of climatological processes. Where available, the primary input is flow data and, where this is insufficient, precipitation and, to a lesser extent, temperature data are used. All such data are usually considered simply as a time series, selected from a stationary series extending into the future, without consideration of the processes behind these events.

The reasons for this practice are rather complex and relate, in part, to the typically short time available for analysis and consequent emphasis on using standardized analytical procedures. Such procedures are generally most readily applied to input in the form of a simple series of data points. Meteorologists and climatologists, on the other hand, tend to be much more concerned with the actual processes causing these events. As a result, there is a communication gap between engineers and hydrologists engaged in design and planning, and the meteorological community, wherein lies a greater understanding of the actual processes leading to the observed climate. While for many questions lack of concern with actual atmospheric processes is not critical, there are at least two general areas where the lack can result in major consequences. The first and in Canada the most important is the decrease in reliability of prediction with increased extrapolation from historical experience. The other area is of greater importance in more arid climates, and is concerned with the stability of the climatic record against major changes. This is of concern when proposing development of an area where there is no available means of offsetting the effects of a drought.

Having noted the risks in extrapolation, it is appropriate to discuss methods of flood forecasting, an exercise which almost certainly involves greater extrapolation than any other hydrologic analysis. Two types of flood analyses are normally carried out for major projects: the first based on statistical analyses of historical events, and the second based on an actual examination of possible storms and selection of the worst that can be reasonably conceived. The primary method of analysis is the statistical approach based where possible on a frequency analyses of flow data. This use of flow data has the advantage of integrating over the basin and avoiding the need to consider the rainfall-snowmelt-runoff processes. A typical analyses would be carried out by generating from historical records a list of the annual flow maxima or spring flood volumes and undertaking a statistical analyses of this data based on some 2- or 3- parameter extremal distribution. From this distribution, the design flood with a 10,000-year return period would be obtained. Refinements to this process include the use of flow data from other catchments or precipitation data to improve the estimated shape of the distribution function. Once the extreme peak flows and volumes have been obtained, a synthetic hydrograph is prepared with a similar shape to the larger of the recorded historical floods and adjusted in size to match the design peak and volume. The typical length of record used to generate the flood would vary from 20 to 70 years.

There are a number of unsatisfactory aspects to this approach that have been recognized for a very long time. Key ones are:

- the implicit assumption of homogeneity of the sample population

- the inability to account for physical constraints on the possible flood size

- the very wide confidence bands that result from the limited available data

- heavy dependence on the largest flood of record, which typically is not accurately known.

Concerns over these weaknesses led to the gradual development of alternative approaches based on considering the actual mechanics of storm development and precipitation. In the 1950's, these alternative approaches came into widespread use in the United States. This "Probable Maximum Flood" (PMF) approach when used in Canada requires the development of a critical meteorological sequence which includes the probable maximum precipitation available in the spring combined with an extreme temperature sequence. This is then applied to a snow cover to generate the flood. This approach is rather unique in water resource planning as being the only area where climatological processes are explicitly considered as a normal part of design. While the various steps in the development of PMF are fairly well standardized, there is considerable variation in the detailed methodology used within each step and a consequent need to use judgement at many points along the way. Notwithstanding frequent confusion on this point, the PMF as can be seen from its derivation is not an absolute upper limit in any rigorous sense.

The various steps involved in a typical PMF analysis are outlined in Figure 4, and are described very briefly below:

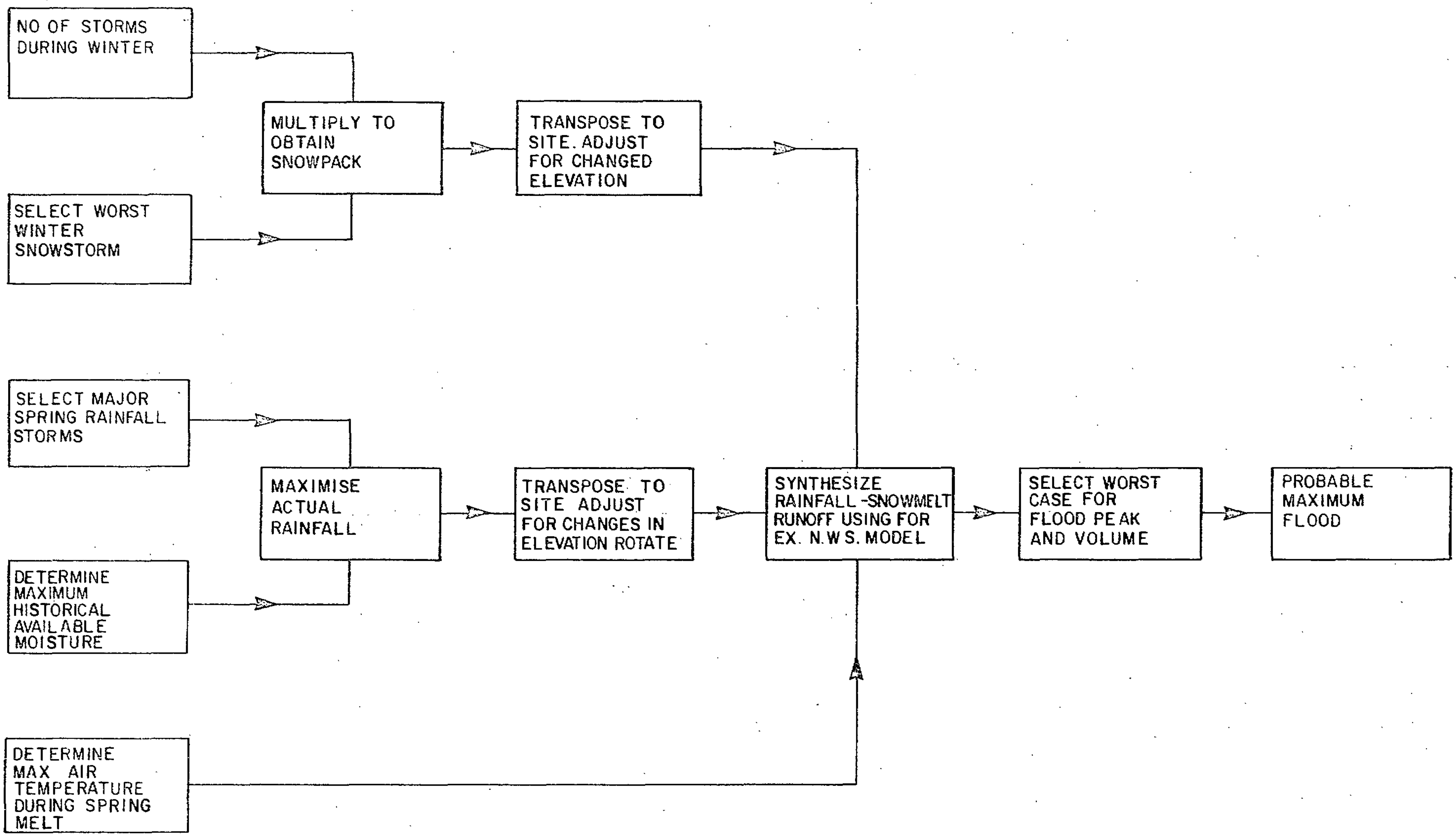
- The first step is to select usually one or two storms from those recorded within the general region. This selection is to some extent a matter of judgement. The greater the geographic area considered, the more storms to select from, but also the greater the extent of extrapolation required at a later step to center the selected storm over the basin.

- Following storm selection, the historical record of ground level moisture content is reviewed, and a maximum historical moisture content during the season of interest is selected. This precipitable moisture is then used to increase the rainfall in the selected storm usually on a prorata basis; that is, assuming the precipitation efficiency of the storm remains the same.

- In Canada, particularly for large catchments, an important step is to then determine an appropriate snowpack. Various approaches are used, one common one being to examine all previous winter storms to determine the worst snowfall that has occurred and then to repeat this storm at intervals corresponding to historic storm intervals. Modifications are made where appropriate to account for changes as the the winter season progresses. It should be noted that the extreme flood flow may well result from a snowpack less than this maximized value.

- The storm and the snowpack are both transposed to the basin and centered to give the maximum flood flows. Some limited rotation of the storm is usually allowed to increase the impact. In carrying out this transposition, corrections are made for changes in latitude and topography. These corrections are to some extent judgements based on very much simplified models of storm behavior.

- The rainfall, a maximized spring air temperature and the snowpack are then used as input to a rainfall-snowmelt-runoff simulation such as that developed by National Weather Service (NWS). Frequently, more than one storm is tested and a range of snowpack depths up to the maximized value used.



MAJOR STEPS IN DEVELOPING A P.M.F. FOR A SPRING SNOWMELT FLOOD

FIGURE 4

- The upper limit flood is then selected for use as PMF against which designs can be tested. At this point, although the PMF has been established, there is no knowledge on the likelihood of a flood of this magnitude occurring. Typically, however, the resultant flood is markedly different from the 10,000-year return period storm and has a peak higher by a factor of 1.5 to 2.0 as shown in Figure 5.

Flood predictions are areas of major economic impact, but there are other areas in water resource development where climatological data are important and a better understanding of the processes involved would be beneficial. One of these is the hydrology input used for project sizing and benefit evaluation. This area has been extensively covered elsewhere, and probably the key element common to most previous studies is that the lost benefits resulting from sizing a scheme using incorrect hydrologic data are usually fairly small. However, the absolute loss in benefits vis-a-vis those anticipated can be substantial and, if downstream user developments are sensitive to available water supply, the value of accurate data is substantially increased.

An area relating to project design which is of particular importance in northern Canada is the question of ice behavior. In northern projects, the design features required to handle ice can easily add 10 percent or more to the project cost. In practice, design is usually based on selecting the worst historical meteorological sequence. The actual development and impact of ice jamming are quite sensitive to the timing of the spring melt and on the antecedent conditions.

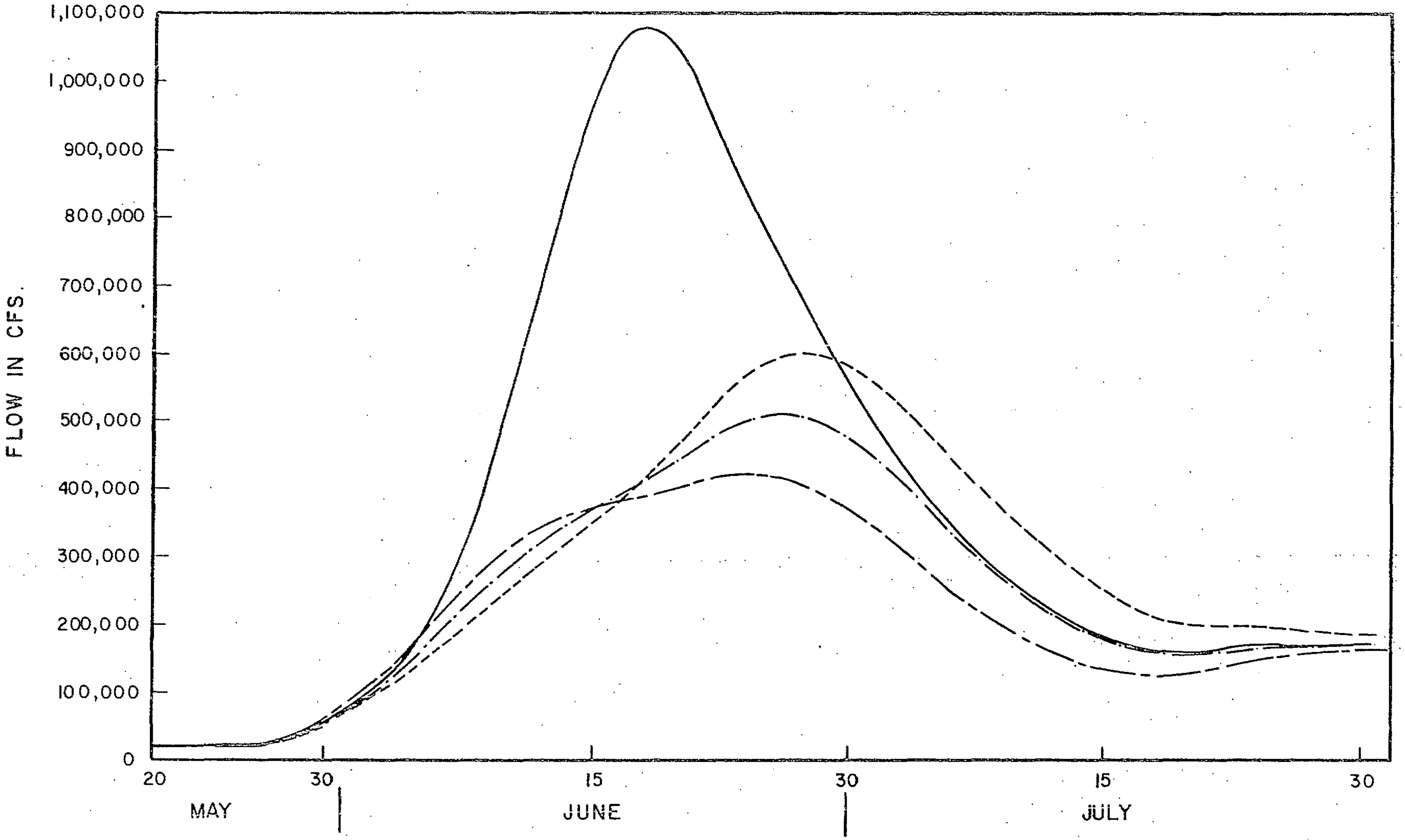
Digressing for the moment from project oriented concerns to broader aspects of water resource planning, one area in large-scale planning is the whole question of climatologic feedback. This can manifest itself where a water resource development, series of developments, or extensive change in land use, by increasing the moisture supply to the atmosphere, can result in an increase in precipitation either within the basin area or in an adjacent area. Present planning practice does not consider this at all.

Potential for Using Better Climatologic Understanding

From the previous section, it can readily be seen that areas of maximum exposure are associated with extrapolating from historical events to extreme events of significantly greater magnitude and, more particularly, in the area of potential for improved climatologic understanding are developed.

Before considering the broader aspects of better understanding atmospheric processes, it is appropriate to mention two areas where an improved data base would be of immediate benefit in project development, and would also in addition assist in improved understanding of actual atmospheric processes. These two areas are as follows:

- A more extensive climatological data collection system in northern Canada, particularly in the spring-to-summer period. Parameters of importance include temperature, precipitation and humidity.



LEGEND

——— MAXIMUM PROBABLE FLOOD

- - - - 1:10,000 YEAR FLOOD

—·— 1:1,000 YEAR FLOOD

—-—- 1:100 YEAR FLOOD

EXAMPLE OF VARIOUS DESIGN FLOODS FOR 70,000 km^2 CATCHMENT IN NORTHERN CANADA

FIGURE 5

- An increase in the number of storms subjected to detailed post-storm analyses. In particular, analyses of storms occurring in northern Canada would be of particular interest.

Improvement in the data base could be integrated immediately in project development, but beyond this there are a number of areas where a better understanding of climatologic processes would materially improve our ability to derive better estimates for design floods. Three particular areas that come to mind are described briefly below, more or less in order of perceived difficulty of implementation.

- An improvement in readily accessible methods of transposition of storms from their actual location to a location over a catchment. Typically, such transposition requires some correction for latitude change and topographic change. While methods are available for orographic correction, based on integration along a line there is no readily available approach to take account of the integrated changes to a storm resulting from transposition to a basin with different topography, and where the actual storm track has crossed different topographic features to reach the basin. As transposition is implicit in almost all PMF analyses, and our aptitude to carry this out also affects the selection of storms that can be considered, an improvement in this process would have immediate benefits.

- The implicit assumption in all PMF derivations is that the basic pattern of storms is consistent over the period of interest including the historical period of record and into the future. While this is a weaker constraint than the similar assumption in carrying out frequency analyses, it is still an important one. It would be of importance when considering such rare events to determine, possibly by examination of total atmospheric motion, whether in considering feasible patterns we should include shifts or gradual drift in trends that might imply different types of future storms or a modification to the inputs obtained from the historic record.

- The final area, where possibly the longer-term benefits would be greatest but unfortunately the difficulties inherent in development are also substantial, would be to develop an approach to link storm process modeling to estimates of return period. At the present time, no means are available to tie PMF to any particular return period, although it should be noted that the PMF is not in any sense an absolute upper limit, and there are a number of examples where the calculated PMF's have been reached or exceeded. As part of this linkage, it would be of very great benefit if the actual storm processes could be included in the estimates of floods with shorter return periods of, say, 100 to 1,000 years, possibly by consideration of the statistics of variability of different types of atmospheric flow patterns.

While the above three areas have obvious applications to flood estimating, there would be a number of spinoffs from research in these areas to our understanding of the effects of variation in atmospheric processes on other areas of water resource development. One area in particular is the estimating of net benefits. Improvements here would, in particular, reduce the risk of developments, particularly for agriculture, based on erroneous assumptions as to the water that would be available. In the international community, this can be of major importance, particularly where a large population is dependent for not only their livelihood, but even for their survival.

Concluding Remarks

In earlier investigations, it has been demonstrated that water resources projects are not as sensitive to likely climatic events as certain other planning factors - demand projects, economic parameters, etc.[2]

Nevertheless, it has been found that the historic pattern of climate-induced events (flows, temperatures, etc) can lead to major discrepancies between expected and actual events. It is clearly desirable that these discrepancies be better understood. Ideally, this improved understanding should then provide a better basis for reducing or eliminating discrepancies so that plans and designs can be more accurate for actual events.

To account for unknowns associated with climatic events, design methods are being continually improved. The generation of synthetic streamflows and the testing of plans and designs for each of a range of possible future sequences of events provide a basis for establishing "expected" benefits. There is now also increasing use of resiliency and robustness concepts in the planning and design of water resources projects.[3]

In spite of all these developments, there will still be major questions about procedures which are developed from empirical or statistical concepts. This is especially true for designs which are associated with extreme events, which normally require extrapolation of the historic information base.

From the examples provided in this paper, it will be evident that improved methods will require improved understanding of fundamental climatic processes. With an improved understanding, it should then be possible to characterize and classify climatic events. It may also be possible to begin developing an improved knowledge base for understanding the incidence, magnitude and duration of types of events (floods, droughts, etc), and for rationalizing the shifts, trends and discontinuities which are observed but are not clearly understood.

This task is enormous and will be costly. However, the benefits of improved knowledge and information should lead to better plans and designs. Results will not come quickly, even with a substantial investment. However, unless a commitment is made, planners and designers will still continue with their developments utilizing partial and uncertain knowledge about climatic processes. Resulting projects, as a consequence, will still be subject to the same costly climate-induced surprises which have occurred so often in the past.

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On the Use of Climate Data in Operational Hydrology in British Columbia

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Introduction

When the Canadian Weather Service established a national climatological network many years ago, to assess and monitor the climate of the country, it probably did not realize the extent to which data from this network would eventually be used in resource management. This network has been built up over the years on a shoe-string budget, using mainly volunteer observers. Stations were established, wherever observers were available, and not necessarily where stations were required to properly delineate the climate of the country. This resulted in a distorted representation within the climate network, particularly in mountainous country, such as British Columbia. The network is over-represented with stations in the populated valleys of the South, and coastal areas, and very under-represented in the mountains and northern parts of the province. B.C.'s total number of climate stations is less than 500. Assuming that these were equally distributed, we would have one station for about 2000 km^2. Nearly all of the stations measure daily precipitation, and comparing network density, with that recommended by the WMO for precipitation networks gives the following results: The minimum density for precipitation station networks in mountainous regions, - as recommended by the WMO-, is one station per 100 to 250 km^2. Under exceptionally difficult conditions one station per 1000 km^2 may be tolerated. We would therefore have to double our network - assuming equal distribution - to meet this very limited goal.

However, daily operational water management procedures require the input of real-time air temperature and precipitation data. Ordinary climatological stations report only monthly by mail. We are therefore restricted to first order stations, which report at least once a day. There are less than 40 first order stations in B.C.

History

In 1964 the Columbia River Treaty between Canada and the U.S.A. was signed. This treaty specifies as follows:

> "A hydrometeorological system including snow courses, precipitation stations and streamflow gauges will be established and operated for detailed programming of flood control and power operations. Hydrometeorological information will be made available to the entities in both countries for immediate and continuing use in flood control and power operations."

No similar operation had ever been attempted in B.C. B.C. Hydro - as the Canadian Entity - is responsible for the implementation of the treaty requirements. There were no more than four daily reporting climate stations in the entire Canadian portion of the Columbia River drainage in 1964, an area of 102,300 km^2. All of these were in valleys, most of them in the southern portion near the U.S. border. But action by the senior governments brought quick improvement of the hydromet networks. The Provincial Government established a good snowcourse network of 10 point courses, usually at mean basin elevation just below the tree-line. The Canadian Weather Service converted a number of ordinary climatological stations to daily reporting weather stations, and provided equipment for three automated high-level stations. These Hydrometeorological Automated Telemetering Stations - or HATS stations - were located at snowcourse sites in major sub-basins of the Columbia River at a mean-basin elevation of about 2000 m. The HATS stations are still operating, reporting snowpack water-equivalents, temperature and precipitation. The only high-level daily reporting station up to that time was a manned mountain station, named Old Glory at 2300 m in the vicinity of Trail, B.C. This station burnt down in early 1968 and was not re-built. Instead daily observations were obtained from Fidelity Mountain, - in the Rogers Pass area -, from an elevation of about 1900 m.

Daily meteorological observations, -24 hour precipitation, maximum and minimum air temperatures-, from stations in the Canadian portion of the Columbia River drainage are currently available from 21 stations. That is one station per 4800 km^2. The total number of climate stations serving the Columbia River drainage in Canada is 39 or one for 2600 km^2.

Next to the Columbia River, the Peace River basin became of major importance for power generation. While the Columbia River is being operated both for hydroelectric generation, and flood control the Peace River provides mainly hydroelectric generation, with flood control being of secondary consideration.

The Peace River drainage above Bennett Dam has a very sparse climatological network. The total number of stations was never more than eight for an area of 72,000 km^2. Five are currently reporting daily, or one for 14,400 km^2. Unlike the Columbia, conversion of ordinary climate stations to daily reporting stations was not possible here, due to lack of stations, and because of communications difficulties. A good snowcourse network was however established by the Provincial Government.

Precipitation Data

Of the parameters observed by climate networks, precipitation is of course of primary interest in water management. All observations made at a climate station are representative of a small area around that station. However, the hydrologist is concerned with the precipitation received by a much larger area, such as a drainage basin.

To deduct basin precipitation amounts from point measurements is an important task in operational hydrology. If one deals with a homogenous area, one has at least three choices to convert point precipitation into average precipitation over a specific area:

1. A simple arithmetic mean from stations in the basin.
2. A weighted mean using the Thiessen method.
3. Obtaining average precipitation from subjectively drawn isohyets.

However, a mountainous drainage is not homogeneous. While it would be possible to use method three, and draw isohyets, it would be difficult to properly consider orographic effects, if only valley stations are available, or if no precipitation stations are available within a basin.

To overcome these difficulties, we have devised a method, which employs all information available from the climate stations as well as the drainage basin. First we determine the ratio of mean annual basin precipitation over mean annual climate station precipitation. In mountainous drainages the basin precipitation will always be greater than low-level station precipitation, as precipitation generally increases with height. The ratio of basin precipitation over point precipitation will therefore be greater than one. Mean basin precipitation values are obtained from historical records of the runoff simulation model FLOCAST, available since 1969. The ratio of basin precipitation over point precipitation is then multiplied by a monthly station weight factor obtained by multiple correlation techniques as used in seasonal runoff volume forecasting procedures. (Program VOLCAST). The resulting daily station weight factors are then used to calculate the daily basin precipitation from available point precipitation observations as input to the runoff simulation model.

The FLOCAST simulation model is being run at least once a day, to predict daily runoff for 21 drainages serving B.C. Hydro's integrated hydroelectric system. The model monitors five days of history, and predicts the runoff five days ahead, and subdivides each basin into predetermined elevation bands. Total basin precipitation is distributed to these elevation bands using a precipitation lapse rate specific to each drainage, that is, a pre-determined factor specifies the portion of total basin precipitation assigned to an individual elevation band. Precipitation lapse rates are determined from carefully calibrated historical runs of the simulation model.

Temperature Data

For the assessment of snowmelt and glacier melt, a certain air temperature must be assigned to each individual elevation band. Daily maximum temperatures from specific climate stations may be used for this purpose. As temperature over a given area and elevation does not vary nearly as much as precipitation, a single climate stations will generally suffice to describe the temperature required for a drainage basin. If the maximum air temperature is used, a lapse rate of 5.47°C per 1000 meters is assumed in determining freezing level heights and the representative temperatures for each elevation band. The model also provides the option to enter a freezing level height rather than a maximum temperature. Again a lapse rate of 5.47°C per 1000 meters is used to assign representative temperatures to elevation bands above and below the freezing level. Freezing levels are obtained from radiosonde observations or may be deducted from 850 mb, or 700 mb synoptic weather maps. Temperatures for upper level elevation bands are increased by 2°C if exposed to sunshine. If both low level maximum temperatures and a freezing level height are entered, the low level lapse rate will adjust to this information, however, constraints are provided to prevent unrealistic conditions.

The freezing level, - other than providing the 0°C level for assigning representative temperatures -, is also a convenient aid to separate rain from snow, and areas of snowmelt are elevation bands above the snowline, but below the freezing level.

Climate Input Data for Volume Forecasts

Monthly data from the climate network forms the basic input to seasonal runoff volume forecasting procedures in B.C. Hydro's VOLCAST program using the following parameters for volume runoff calculations in regression equations:

X_1 Winter precipitation using November through March combined with selected snowcourse water equivalents.

X_2 Spring and summer precipitation using April through September.

X_3 Antecedent precipitation using September through October precipitation of the previous fall period.

X_4 Evaporation index, using February through September mean monthly maximum temperatures.

X_5 Glacier melt index, using April through September mean monthly maximum temperatures.

Monthly weights and station weights are applied to all input parameters. Weights and constants in the regression equations are determined from historical data series by the use of multiple correlation programs, and are being updated each year. The volume forecasting programs are run each month from January 1 through August 1, for 21 drainages of concern to B.C. Hydro.

Conclusion

Volume forecasts form the basis for annual energy planning as well as flood control. Short-term inflow forecasts from runoff simulations are used in the day-to-day operation of reservoirs, to increase generation efficiency by avoiding spill, whenever possible, as well as for flood control.

The improvement of these runoff forecasting methods is largely linked to the improvement of climate networks. Automated stations, - using satellite telemetry (DCP's)-, has greatly facilitated network expansion for real-time data. New methodologies, such as precipitation mapping by weather radar, and snowpack - and precipitation mapping by satellite imagery analyses will certainly provide important tools for operational hydrology in the future, if such developments are properly supported and applied.

A P P E N D I C E S

A On the analysis of basin precipitation

B On the input of monthly climate data into seasonal runoff volume forecasting procedures:
Sample: McNaughton Lake

ANALYSIS OF BASIN PRECIPITATION

From Station Precipitation April 1979

- Basin precipitation amounts based on 1969 - 1978 FLOCAST Summaries
- Station precipitation amounts based on 1963 - 1977 Means.

BASIN Mean Annual PCP	Precipitation Station Used Mean Annual Precipitation Basin Precip. ÷ Station Precip.					
ALU 3661	Alouette L. 2849 1.29	Abbotsford 1568 2.34	Stave L. 2306 1.59			
SFL 4185	Alouette L. 2849 1.47	Abbotsford 1568 2.67	Stave L. 2306 1.82			
COQ 4616	Alouette L. 2849 1.62	Coquitlam 3773 1.22	Buntzen 3022 1.53			
WAH 4082	Hope 1793 2.28	Abbotsford 1568 2.60				
LAJ 1630	Lytton 447 3.65	Lillooet 403 4.05	Alta Lake 1380 1.18	LaJoie 558 2.92		
BR 959	Lytton 447 2.15	Lillooet 403 2.38	Alta Lake 1380 .70	LaJoie 558 1.72	Shalalth 527 1.82	
CMS 2308	Alta Lake 1380 1.67	Daisy 1905 1.21	Clowhom 2258 1.02			
COM 3438	Clowhom 2258 1.52	Powell R. 1210 2.84				
SCA 2410	Comox 1194 2.02	Port Alberni 1973 1.22	Campbell R. 1401 1.72			
CMX 2748	Comox 1194 2.30	Port Alberni 1973 1.39	Campbell R. 1401 1.96			

ASH 2996	Comox 1194 2.51	Port Alberni 1973 1.52	Campbell R. 1401 2.14			
JOR 3021	Sooke 1606 1.88					
WGS 1306	Fauquier 614 2.13	New Denver 833 1.57				
DCD 1868	Kaslo 840 2.22	Duncan 759 2.46				
KTK 1055	Kaslo 840 1.26	Creston 594 1.78	Duncan 759 1.39			
DON 1064	Glacier 1610 .66	Golden 478 2.23	Radium 415 2.56	Spillimacheen 454 2.34		
MCD 1682	Glacier 1610 1.05	Blue River 1071 1.57	Mica 1439 1.17	Golden 478 3.52	Valemount 559 3.01	
REV 2010	Glacier 1610 1.25	Blue River 1071 1.88	Mica 1439 1.40	Revelstoke 981 2.05		
ARD 1697	Fauquier 614 2.76	Glacier 1610 1.05	Castlegar A 706 2.40	Castlegar BCHPA 551 3.08	Revelstoke 981 1.73	
GMS 890	Hudson Hope 557 1.60	Germansen 467 1.91	Prince George 638 1.40	McKenzie 670 1.33	Ware 430 2.07	Ingenika 476 1.87

Station Weighting for Basin Precipitation Analysis

April 1979

BASIN	Precipitation Station Station Weight Used * Basin Precip. Factor = Station Weight x Station Precip.					
ALU	Alouette L. .54 .70	Abbotsford .38 .89	Stave L. .08 .13			
SFL	Alouette L. .13 .19	Abbotsford .62 1.66	Stave L. .25 .46			
COQ	Alouette L. .24 .39	Coquitlam .48 .59	Buntzen .28 .44			
WAH	Hope .38 .87	Abbotsford .62 1.61				
LAJ	Lytton .22 .80	Lillooet .61 2.47	Alta Lake .04 .05	LaJoie .13 .38		
BR	Lytton .23 .50	Lillooet .05 .12	Alta Lake .32 .22	LaJoie .31 .53	Shalalth .09 .16	
CMS	Alta Lake .43 .72	Daisy .30 .36	Clowhom .27 .28			
COM	Clowhom .78 1.19	Powell R. .22 .63				
SCA	Comox .30 .61	Port Alberni .23 .28	Campbell R. .47 .81			
CMX	Comox .57 1.31	Port Alberni .05 .07	Campbell R. .38 .75			

* from seasonal runoff volume forecasting program (VOLCAST)

ASH	Comox .15 .38	Port Alberni .70 1.06	Campbell R. .15 .33			
JOR	Sooke 1.00 1.88					
WGS	Fauquier .38 .81	New Denver .62 .97				
DCD	Kaslo .30 .67	Duncan .70 1.72				
KTK	Kaslo .38 .48	Creston .31 .55	Duncan .31 .43			
DON	Glacier .30 .20	Golden .25 .56	Radium .20 .51	Spillimacheen .25 .59		
MCD	Glacier .25 .26	Blue River .15 .24	Mica .25 .29	Golden .15 .53	Valemount .20 .60	
REV	Glacier .20 .25	Blue River .20 .38	Mica .30 .42	Revelstoke .30 .62		
ARD	Fauquier .25 .69	Glacier .15 .16	Castegar A .25 .60	Castlegar BCHPA .10 .31	Revelstoke .25 .43	
GMS	Hudson Hope .08 .13	Germansen .28 .54	Prince George .06 .08	McKenzie .30 .40	Ware .11 .23	Ingenika .17 .32

PRECIPITATION STATIONS USED

X_1	Alouette Lake
X_2	Abbotsford
X_3	Stave
X_4	Coquitlam Lake
X_5	Lake Buntzen
X_6	Hope
X_7	Lytton
X_8	Lillooet
X_9	Alta Lake
X_{10}	LaJoie Dam
X_{11}	Shalalth
X_{12}	Daisy Lake Dam
X_{13}	Clowhom Falls
X_{14}	Powell River
X_{15}	Comox
X_{16}	Port Alberni
X_{17}	Campbell River A.
X_{18}	Sooke
X_{19}	Fauquier
X_{20}	New Denver
X_{21}	Kaslo
X_{22}	Duncan Dam
X_{23}	Glacier N.P.R.P.
X_{24}	Blue River
X_{25}	Castlegar A.
X_{26}	Castlegar B.C.H.P.A.
X_{27}	Mica Dam
X_{28}	Revelstoke
X_{29}	Golden
X_{30}	Valemount
X_{31}	Kootenay N.P. Westgate
X_{32}	Spillimacheen
X_{33}	Hudson Hope B.C.H.P.A. Dam
X_{34}	Germansen
X_{35}	Prince George
X_{36}	McKenzie
X_{37}	Creston
X_{38}	Ware
X_{39}	Ingenika

EQUATIONS FOR COMPUTATION OF DAILY BASIN PRECIPITATON

A ALU = $.70x_1 + .89x_2 + .13x_3$

B SFL = $.19x_1 + 1.66x_2 + .46x_3$

C COQ = $.39x_1 + .59x_4 + .44x_5$

D WAH = $1.61x_2 + .87x_6 +$

E LAJ = $.80x_7 + 2.47x_8 + .05x_9 + .38x_{10}$

F BR = $.50x_7 + .12x_8 + .22x_9 + .53x_{10} + .16x_{11}$

G CMS = $.72x_9 + .36x_{12} + .28x_{13}$

H COM = $1.19x_{13} + .63x_{14} +$

I SCA = $.61x_{15} + .28x_{16} + .81x_{17}$

J CMX = $1.31x_{15} + .07x_{16} + .75x_{17}$

K ASH = $.38x_{15} + 1.06x_{16} + .33x_{17}$

L JOR = $1.88x_{18} +$

M WGS = $.81x_{19} + .97x_{20} +$

X DCD = $.67x_{21} + 1.72x_{22} +$

Y KTK = $.48x_{21} + .43x_{22} + .55x_{37}$

Z DON = $.20x_{23} + .56x_{29} + .51x_{31} + .59x_{32}$

A MCD = $.26x_{23} + .24x_{24} + .29x_{27} + .53x_{29} + .60x_{30}$

B REV = $.25x_{23} + .38x_{24} + .42x_{27} + .62x_{28}$

C ARD = $.69x_{19} + .16x_{23} + .60x_{25} + .31x_{26} + .43x_{28}$

D GMS = $.13x_{33} + .54x_{34} + .08x_{35} + .40x_{36} + .23x_{38} + .32x_{39}$

APPENDIX V - McNaughton Lake Inflow Volume Forecast Calculation Procedure

The forecast equation for Feb. - Sept. Volume in CFS - Days:

$$Y = 3602455 + 3532.709X_1 + 3931.402X_2 + 7340.254X_3 - 590.465X_4 + 40.259X_5$$

where:

1. Y = Uncorrected Feb. - Sept. volume in CFS - Days
2. X_1 = April 1st Snowcourse water equivalent for:

	Glacier	x	.17	
+	Kicking Horse	x	.17	
+	Mt. Albreda	x	.13	
+	Canoe River	x	.06	
+	Beaverfoot	x	.14	(millimeters)
+	Sinclair Pass	x	.06	
+	Mt. Abbot	x	.12	
+	Fidelity Mtn.	x	.15	

= X_1 (a) x .45 plus

Nov. - March Total Monthly Precipitation, monthly weighted:

Nov. x .10, Dec. x 1.0, Jan. x 1.0, Feb. x 1.0, Mar. x 1.0, for

	Banff	x	.13	
+	Blue River	x	.13	
+	Brisco	x	.10	
+	Canal Flats	x	.06	
+	Glacier	x	.16	(millimeters)
+	Golden	x	.13	
+	Jasper	x	.10	
+	Kootenay NPWG	x	.09	
+	Valemount	x	.10	

= X_1 (b)

$$\therefore \quad X_1 = 0.45X_1(a) + X_1(b)$$

3. X_2 = April - September Total Monthly Precipitation, Monthly Weighted:

April x 1.0, May x 0.9, June x 0.7, July x 0.5, Aug. x 0.2, Sept. x 0.2, for:

	Banff	x	.01
+	Blue River	x	.01
+	Brisco	x	.01
+	Canal Flats	x	.24 (millimeters)
+	Glacier	x	.05
+	Golden	x	.45
+	Jasper	x	.21
+	Koot. N.P. Westgate	x	.01
+	Valemount	x	.01

= X_2

4. X_3 = Previous Sept. - Oct. Total monthly Precipitation, Monthly Weighted:

Sept. x 0.6, Oct. x 0.9, for:

	Banff	x	.17
+	Blue River	x	.04
+	Brisco	x	.20
+	Canal Flats	x	.08
+	Glacier	x	.33 (millimeters)
+	Golden	x	.01
+	Jasper	x	.02
+	Koot. N.P. Westgate	x	.08
+	Valemount	x	.07

= X_3

5. X_4 = Feb. - Sept. Mean Monthly Max. Temperature, Monthly Weighted:

Feb. x 0.4, Mar. x 0.5, Apr. x 1.0, May x 0.9, June x 0.7, July x 0.5, Aug. x 0.2, Sept. x 0.1, for:

	Blue River	x	.15
+	Glacier	x	.42
+	Golden	x	.07 (10ths of degrees C)
+	Valemount	x	.36

= X_4

6. X_5 = May - Sept. Mean Monthly Max. Temperature, Monthly Weighted:

May x 0.1, June x 0.8, July x 0.9, Aug. x 1.0, Sept. x 0.5 for:

	Banff	x	.24
+	Jasper	x	.39
+	Valemount	x	.11 (10ths of degrees C)
+	Golden	x	.26

= X_5

The Effect of Climate on Management and Operation of the Hydro-Québec Water-Resource System

Jean-Louis Bisson
Hydro-Québec
Québec, P.Q.

Hydro-Québec is a public utility company that supplies electricity to the residents of Québec. Almost all of the power generated by Hydro-Québec is hydroelectric; less than 1 per cent comes from thermal plants. As the various parts of the La Grande complex at James Bay come on line, the basins of rivers used for generating power will increasingly take in the northern areas of the province, for which climatic data are very scarce.

Balancing Production and Consumption

Managing a system for the generation and transmission of electricity means balancing energy production with energy consumption so as to ensure maximum dependability and economic efficiency while still respecting the environment. Maintaining such a balance in real time is the optimal operating goal of the system.

But electricity consumption is not synchronous with the natural flow regime of rivers. It is highest in winter, when the natural flows are lowest; it drops off in spring and summer, whereas the natural flows peak in spring and are moderate in summer. Because the system must at all times produce exactly the amount of energy required, the flow of the rivers must be regulated. This task is accomplished with reservoirs, in which the surplus water is stored in spring and from which it is released when needed, mainly in winter.

If the operators of hydroelectric systems knew exactly what the future patterns of electricity consumption and natural runoff would be, they could manage water resources perfectly. They could maximize production of electricity while still respecting the environment and the rights of other water users. This ideal situation does not exist, of course, so the operators must instead strive for optimal resource management, and cope with the uncertainnties of consumption and natural-runoff forecasts.

Forecasting Electricity Consumption

Electricity consumption depends both on socio-economic and on meteorological factors. It is subject to the economic laws governing other types of consumption, and it varies with the weather conditions affecting consumer behaviour.

At Hydro-Québec, we currently forecast long-term patterns of consumption by means of certain socio-economic indicators, such as the number of households, the percentage of households with electric heating, disposable personal income, the relative prices of energy sources, and the industrial-production index. We have also developed a model for variations in consumption due to temperature conditions in the main centres of demand.

Forecasting Natural Runoff

The natural runoff of a river is a residual of the water balance of its drainage basin. To determine the amount of runoff, one must subtract from the precipitation that falls on the basin the amount that evaporates and the amount that is stored there. In principle, to determine the water balance of the basin one should know its energy balance, in order to account for evaporation and snow melt.

At Hydro-Québec we have developed a simple model for forecasting runoff on the basis of meteorological data. The model is parametric, and divides the water into two reservoirs at different levels and three types of runoff. The data are the daily values for precipitation (snow and rain) and for maximum and minimum temperature. We have constructed a model that uses only these data because we have no other climatic data for the basins in which we operate, and the most accessible data for developing a valid base of historical information are these daily temperature and precipitation values. It must be recognized that the energy balance derived from these data is far from accurate.

This model, calibrated with historical data, is used to produce probabilistic forecasts of natural runoff. First, time series are established from the meteorological data, and then the model is applied to them to generate corresponding series for natural runoff. These latter series constitute the predicted statistical distribution of natural runoff and are used in dam management to determine the probabilities of various events. Managers can thereby decide what policies to employ (in effect, what risks to accept) to maximize power generation and minimize operating problems.

Climatic-Data Requirements

Climatic data are required for the following purposes:

1. to determine, in real time, the current water balance of the drainage basins of the rivers used to generate electricity;

2. to determine, in real time, the weather conditions affecting the centres of electricity consumption;

3. to establish a valid base of historical information for testing and calibrating the forecast models for runoff and consumption.

If the data collected by the sensing equipment are to serve these purposes, they must reach the hydroelectric-power company very quickly, so that they can be used in near-real time.

In the determination of the water balance of a drainage basin, values are required for:

1. precipitation, in rainfall and snowfall;

2. snow on the ground;

3. water stored in the soil, or the groundwater level and the moisture in the upper soil layer;

4. evapotranspiration; and

5. snow melt.

In principle, values for the last two variables can be derived by calculation of an energy balance having as its residual either snow melt, evaporation, or both. But this is a difficult process. Snow melt and evaporation can be estimated, however, from the data on temperature, wind, and relative humidity. Measurements of total radiation can enhance the accuracy of the estimates.

Precipitation, however, remains the most important variable, and the one that has the greatest effect on forecasts of natural runoff. The present network of precipitation measurements is quite inadequate for calculating precipitation and spatial variations in precipitation over the drainage basins of the hydroelectric system. I believe that the use of radar in conjunction with point-measured stations (for continuous calibration of the radar echoes) is the most accurate and effective way of determining the spatial distribution of precipitation.

In the determination of electricity consumption, the most important data are the temperature values; the other data needed for accurate determinations are on sunshine, humidity (in summer), wind, and precipitation (especially on power lines).

Forecast Requirements

At present, weather forecasts are used in generating meteorological time series for forecasting natural runoff. But the period covered by these weather forecasts is such that the forecasts are no better than climatology. So first of all, we need weather forecasts that are better than climatology and cover the longest period possible.

Climatic forecasts also could be easily incorporated into our system for generating meteorological time series. Such forecasts could indicate the statistical distribution of the variables used to determine the water balance of a basin. The forecast system we are currently using to manage water resources is based on the fact that the future is similar to the recent past. This is readily accepted by the public. But if we began basing our actions on climatic forecasts, and then some climatic disaster--say a flood--occurred that had not been forecast and ran counter to the trend of the forecast, the public might be inclined to think that the new management policy had increased the danger of floods. We will therefore have to be careful in using climatic forecasts for water-resource management.

The use of climatic forecasts for long-range forecasting of electricity consumption poses problems. Future demand for electricity depends on future socio-economic conditions, which can be greatly influenced by minor changes in climate (for example, the impact on agriculture of a shorter frost-free season). We will therefore have to learn more about the influence of climate on the economy if we want to use climatic forecasts for long-range forecasting of the demand for electricity.

Climate Monitoring, Networks and Specialized Analyses To Support the Needs of the Natural Resource Sector

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Introduction

The aim of this theme presentation is to expose all workshop participants to a lowest common denominator of understanding about climatic data and services available through the Canadian Climate Centre. The current system and proposals for the future will be discussed. It is hoped that this information will help focus working group criticism and proposals for change on deficiencies in the system rather than on deficiencies in perception of the system.

The link between natural resources and climate is strong and obvious. Most aspects of the hydrologic cycle and many of the physical qualities of water are controlled by the atmosphere: precipitation and thus total water supply, timing and extent of runoff, floods, drought, ice cover, evaporation, water quality resulting from air pollution, etc. Fluctuation in the atmospheric processes are thus reflected, though modified, in the hydrologic processes. Resource planners are therefore intimately concerned with climate definition, anomalies and impacts. What information is available to them?

Climate Monitoring and Networks

The Meteorological Service of Canada was born with an Order-in-Council dated May 1, 1871. In his report for the year 1875, the Director of the fledging Service stated the objectives of the meteorological system as two-fold:

1) "The collection of meteorological statistics (including the statistics of storms) and their arrangement in forms suited for the discussion of sundry physical questions. The combination of material collected in a series of years, and the deduction therefrom of the climatic character of the several districts and the furtherance, in other respects, of a knowledge of the facts and principles of climatology generally, and of Canadian climatology in particular;

2) The practical utilization of the facts and principles thus acquired, especially to the prognostication of the weather.

A massive program of scientific information collection was required to meet these objectives. The first official meteorological observations were taken at the Toronto Magnetic Observatory on Christmas Day 1839. As of the end of 1979, the number of stations taking temperature and/or precipitation measurements for AES totalled, 2,570. A glance at the map showing the distribution of these stations (Figure 1) identifies tremendous discrepancies in the network density in different parts of

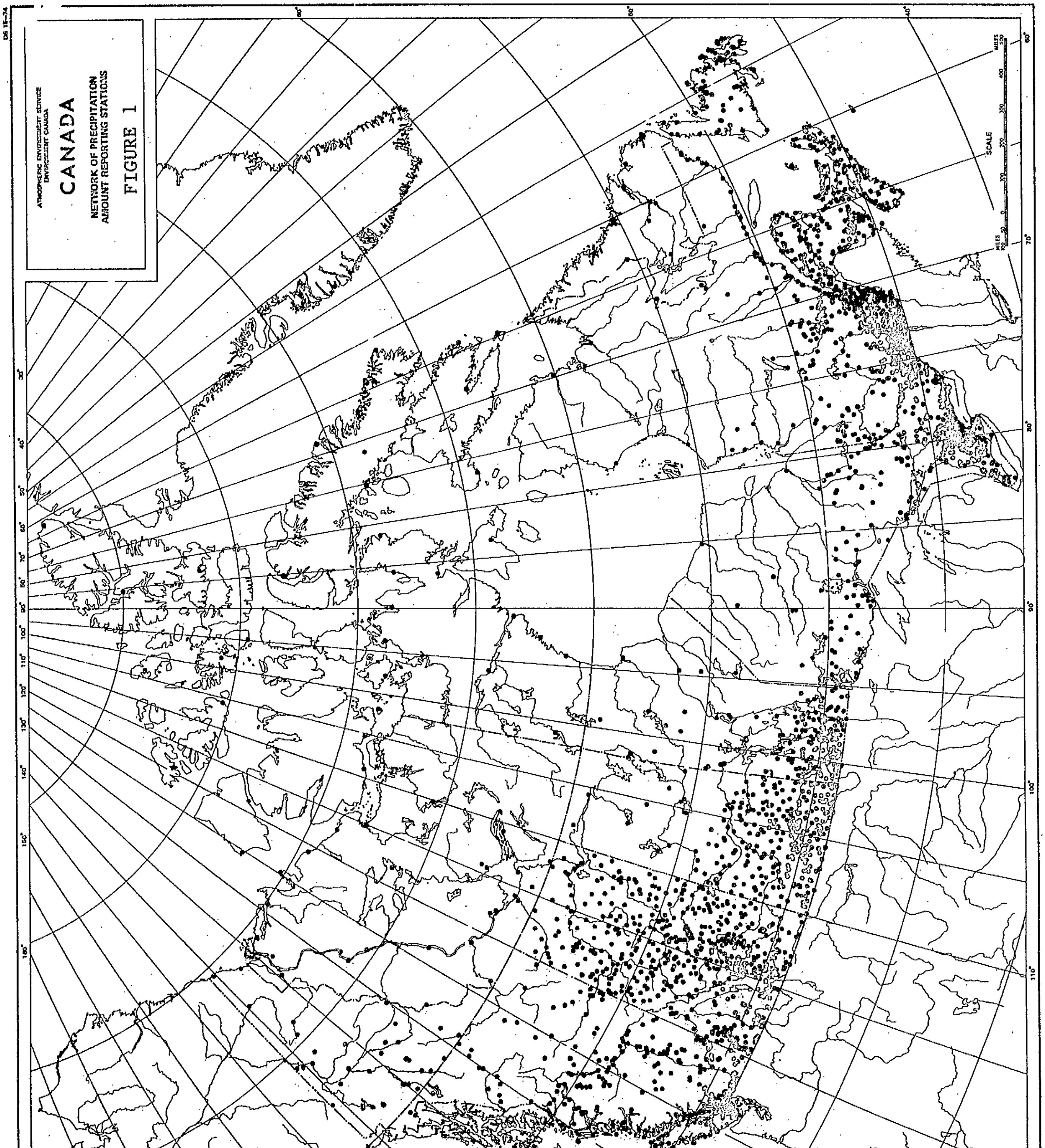

DS 15-74
ATMOSPHERIC ENVIRONMENT SERVICE
ENVIRONMENT CANADA
CANADA
NETWORK OF PRECIPITATION
AMOUNT REPORTING STATIONS
SCALE
MILES

FIGURE 1

the country. Stations are concentrated in areas of high population density. This strategy provides information on climates which impact on the greatest number of Canadians while drawing from a pool of readily available observers. Will this strategy be satisfactory in the future? World Meteorological Organization (WMO) network standards (1 precipitation gauge per 25 km) are met in only a few portions of the network. Can we afford to increase densities to WMO standards in the rest of the country? The remote areas of the country are precisely the ones where resource development pressures are greatest and most dependent on climate, where the ecological balance is most precarious, and where life is most vulnerable to climatic fluctuations. Can we afford not to know more about climate in these areas?

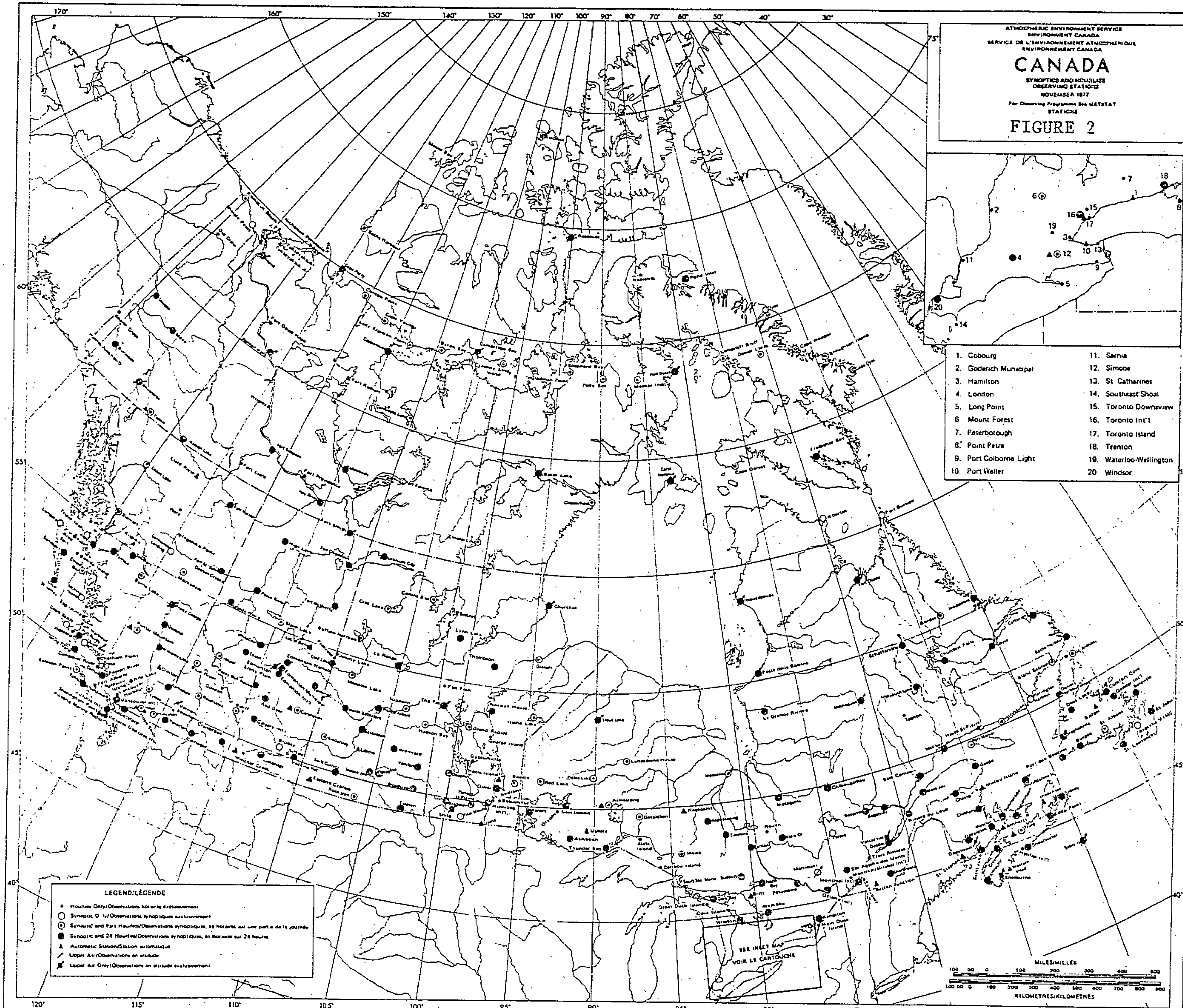
Ordinary climatological stations which form the bulk of the network just described, take daily or twice daily readings of extreme temperature and precipitation amount. Principal climatological stations are ones at which hourly readings are taken or at which observations are made at least three times daily in addition to hourly tabulation from autographic records. This network of 318 stations is shown in Figure 2. Meteorological information with resolution in time greater than one day comes maily from this network. Questions on time distribution of storm precipitation, short duration storm intensity, diurnal variation of various parameters, and wind must be answered using information mainly from this network. Because of the current financial climate, the relevant question seems to be "Can we afford to maintain this network at its present level?"

Automatic stations have been deployed as replacements in the principal station network in smaller population centres and recently, to augment it, in more remote areas. There are 49 such stations now operating; 44 communicate via land line; 5 via GOES Data Collection Platforms (DCP). DCP data are not yet archived but will be in the future. In spite of their fairly high capital cost, their number is expected to continue to increase because of the savings in man years and operation.

Remote sensing plays an ever increasing role in AES meteorological data collection. At the present time, AES operates ten weather radars across the country, six of which are capable of quantitative measurement. Five more semi-quantitative radars have been approved and will be operating in Regina, Brandon, North Bay, Thunder Bay and Sault Ste Marie by the end of 1981. There are plans for eight more to be installed in the mid-1980's. Radar is capable of measuring the areal distribution of precipitation within 100-200 km. AES also has real-time access to data from both geostationary and Polar orbiting satellites launched by the U.S.A. Satellite data could be particularly useful in remote areas where conventional network densities are low. The feasibility of combining radar and satellite data to measure precipitation and track severe weather is now being actively examined.

From Observation to User

The system that has evolved to collect and process conventional


ATMOSPHERIC ENVIRONMENT SERVICE
ENVIRONMENT CANADA
SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE
ENVIRONNEMENT CANADA
CANADA
NOVEMBER 1977
FIGURE 2
1. Cobourg
2. Goderich Municipal
3. Hamilton
4. London
5. Long Point
6. Mount Forest
7. Peterborough
8. Point Petre
9. Port Colborne Light
10. Port Weller
11. Sarnia
12. Simcoe
13. St Catharines
14. Southeast Shoal
15. Toronto Downsview
16. Toronto Int'l
17. Toronto Island
18. Trenton
19. Waterloo-Wellington
20. Windsor
LEGEND/LEGENDE
Automatic Station/Station automatique
SEE INSET MAP
VOIR LE CARTOUCHE
MILES/MILLES
KILOMETRES/KILOMETRES
Thompson
Churchill
Thunder Bay

observations and make the information contained therein available to the user is a complicated one which has sometimes been criticized because of the lag time introduced. When all the necessary operations are considered (collecting the observations for each hour or day of the month from 2570 stations, converting to computer compatible format, checking for accuracy, correcting, archiving in user accessible format, publishing raw data and performing statistical analyses and publishing results) a lag of 8-12 weeks after the end of the month of interest for archiving and 20-26 weeks for publishing becomes more understandable. The quoted periods are for fully quality controlled data from the entire climatological network. Selected data from principal climatological stations are captured off the meteorological communications network and these raw data are available at the Canadian Climate Centre (CCC) on disk within a week of the observation. Climate monitoring publications produced from this information such as "Climatic Perspectives" are currently ready for distribution within 3-4 days of the end of the period of interest. Station monthly summaries from principal climatological stations and regional summaries from regional offices are available at the source within 2-3 weeks of the end of the month.

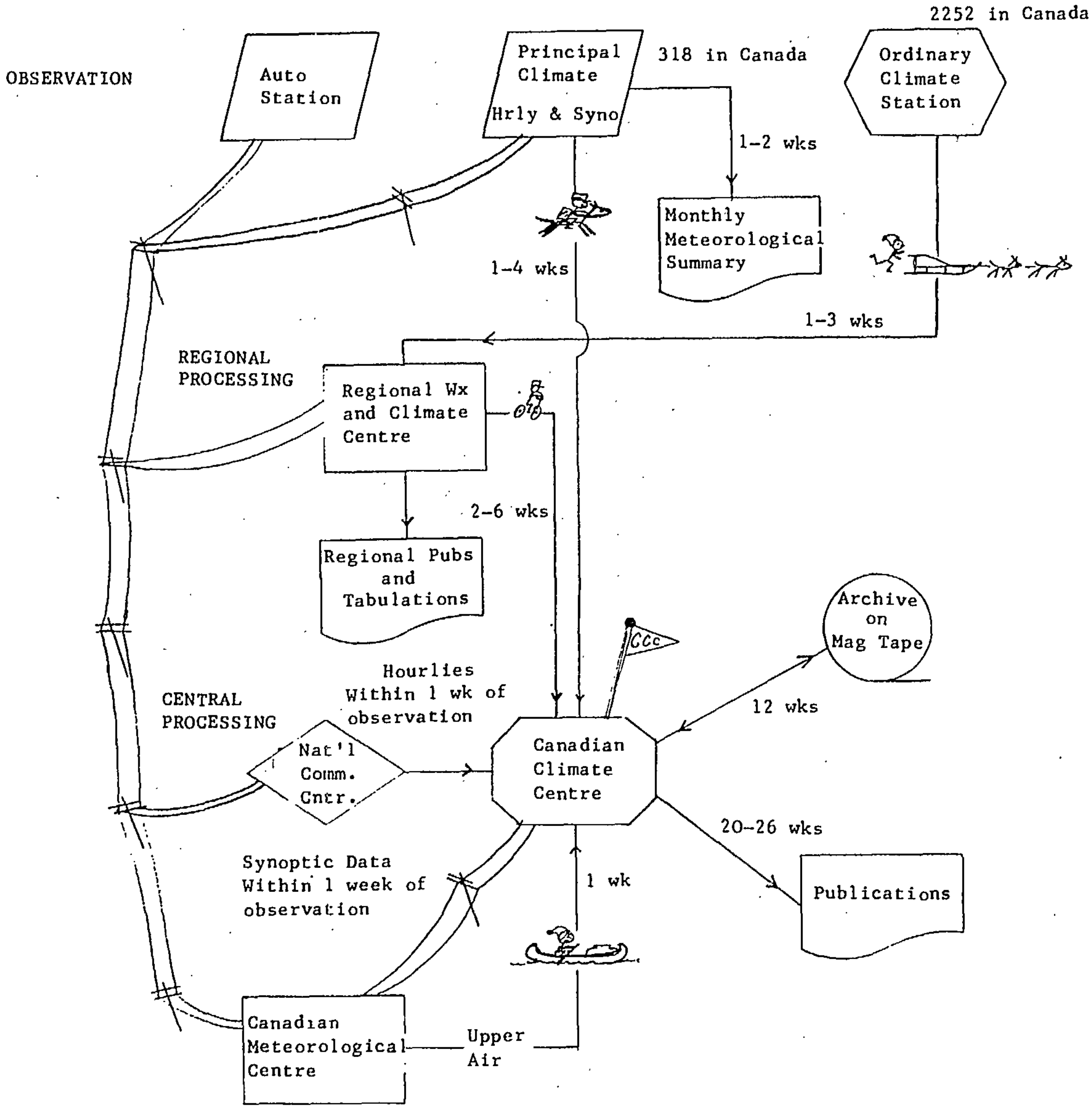
A simplified form of the AES climatic data acquisition system is summarized in Figure 3. Figure 4 is a schematic diagram of the monitoring, quality control, archiving, publication and special analysis functions within the Canadian Climate Centre. Details of both the acquisitions and processing systems frequently change. For example, a scheme to copy climate data to magnetic tape and perform quality control within individual regional offices is being tested. This would save a few weeks in processing time. The basic steps in the system remain the same, however.

The archiving and use of remote sensing data for climatological purposes presents two additional problems. The volume of data involved is huge because of the frequency of sampling in both space and time, and the parameters measured are not the traditional ones. Because of these constraints, both the archiving and use of archived data require sophisticated computer processing. Quantitative radar data from six weather radars in Canada are currently being archived in the CCC. Digital satellite data are not regularly saved within AES. For reasons other than climatological, it appears likely that remotely sensed data bases will continue to grow, probably at the expense of conventional network growth. How much of these voluminous data bases must be saved for climatological purposes? Should actual radiances or derived fields of say precipitation be archived? What priority does remotely sensed climatological data have compared to conventional? How do we compare modern remote sensing data with historical conventional data in climatic change investigations? These and many more questions must be answered by the climatologist and the user community over the next few years.

Once collected, how does AES get the information to the user? Figures 3 and 4 summarize this, as well. Climate publications can be divided into three categories: current, historical and statistical. Current publications are derived mainly from the synoptic data, collected via the communication network and available within a week of the observation. These data are summarized and the resultant information is

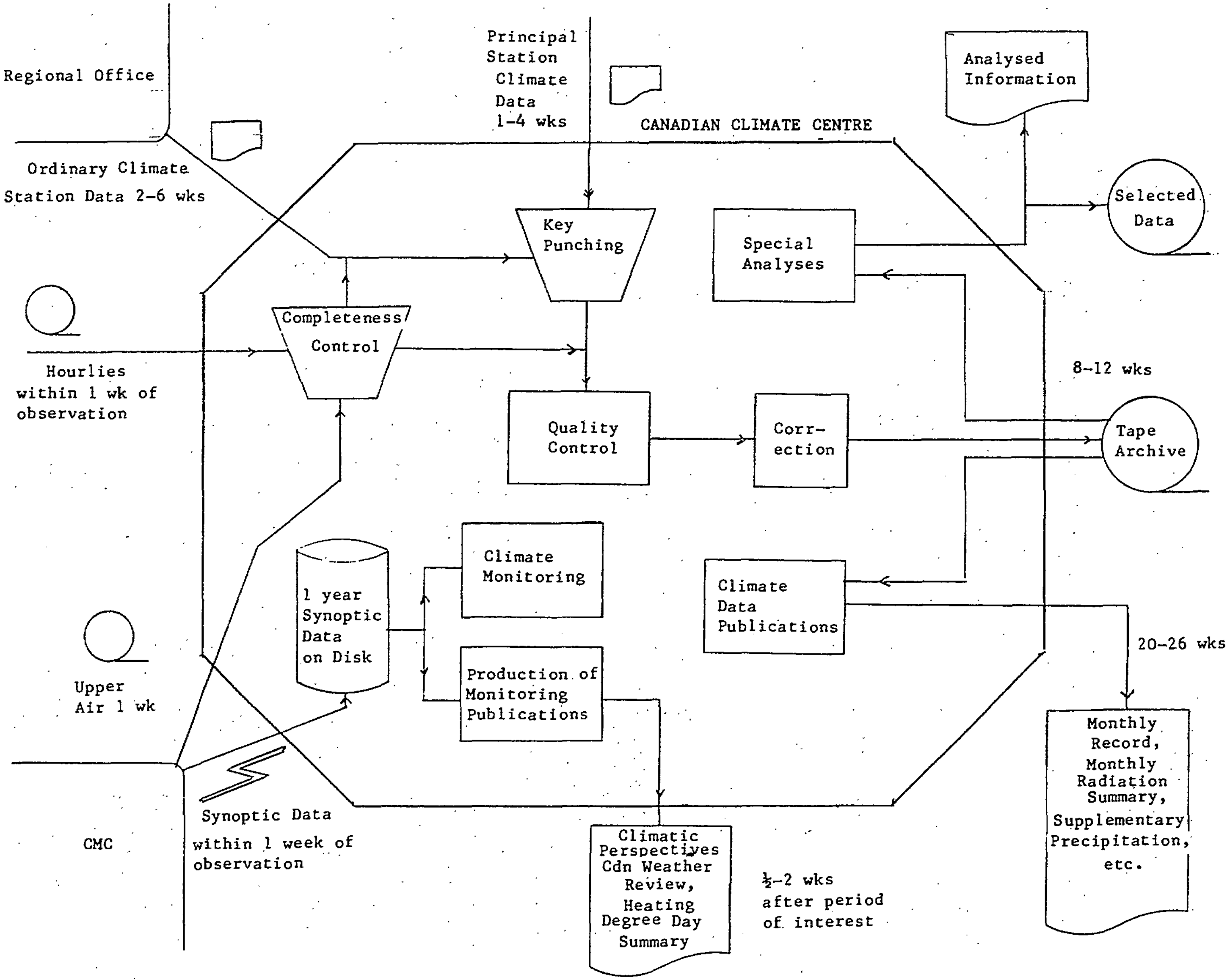
FIGURE 3

ATMOSPHERIC ENVIRONMENT SERVICE
Climate Data Acquisition System



Except for Hourlies and Synoptics, times are after the end of the month of observation

FIGURE 4: CANADIAN CLIMATE CENTRE DATA PROCESSING SYSTEM



distributed weekly, during the subsequent week, in the climate monitoring publication "Climatic Perspectives". Monthly publications such as "Canadian Weather Review" and "Heating Degree Day Summary" use a similarly derived data base and are distributed within ten days to two weeks following the end of the month.

Historical data publications make use of fully quality controlled and archived data which are collected via dogsled, mail, etc. Delays introduced by these procedures mean that publications like "Monthly Record of Meteorological Observations in Canada" are not ready for distribution until 20-26 weeks after the end of the month during which the data were collected. Statistical and other special publications utilize long sequences of the archive data which have been processed to give average or mean conditions, extremes, frequencies, etc., over periods of years or decades. "Daily Normals of Temperature and Precipitation" is a typical publication in this category. Of course the actual archived data are available to users in computer compatible forms within approximately 8-12 weeks of the end of the month of interest. A program to implement "on-line" access to the archive is in the planning stage. These and many other data sources, including examples, are much more fully described in "A Catalogue of Climatic Data Sources of the Atmospheric Environment Service" which was specially prepared for Canadian Climate Program Workshops and will be distributed at the Water Resources Workshop.

Extended Forecasts Using Climatological Information

AES has become increasingly involved in recent years in supplying specialized observations and forecasts to operational flood forecasters across Canada. The introduction of computer models to forecast daily flows has brought a demand for objective long range forecasts of precipitation and temperature on a scale not previously required or available. Forecasts of areal quantitative precipitation and temperature extremes have been produced for all of Canada since 1968 for up to 48 hours ahead. Starting in 1976, these operational forecasts were extended to five days ahead. However, only daily precipitation probability is generated by the atmospheric - dynamic model beyond day two. By associating the probability above a given threshold with the most likely amount climatologically, long range forecasts of precipitation amounts desired for hydrological forecasting can be produced. Precipitation forecasts can be extended to 20 days using simple climatological normal precipitation or by analogy of present and forecast weather to historical climatological sequences.

Special Analyses and New Products

Early in each new decade national meteorological services prepare revised normals for many climatological elements based on data from the preceding 30 years. This decade's processing is about to begin. At the time of processing many other statistical summaries are generated. These summaries will be stored on microfiche by station and element and will include such things as means, totals, decadal means, extremes, standard deviations, percentiles and percentage frequency. Some of elements to be included are: vapour pressure, degree-days, lake evaporation, greatest precipitation in 30 minutes, number of days with maximum temperature of 30 C, wind gusts, etc. Almost 200 separate abstracts are possible. The microfiche will be updated every five years. As well, a new "Climatic Atlas of Canada" will be published based on the 1951-80 normals which will feature not only charts of traditional mean-value quantities but also new statistical, user-oriented presentations. The standard deviation, coefficient of variability or range will appear throughout and, wherever possible, extreme values of important elements, based on the longest possible homogeneous record.

In addition to these standard information sources, there are numerous products and services aimed at and available to specific user communities. Because of the nature of this workshop, only products and services of interest to the water resources and, to a lesser extent, wildlife user communities will be described here. This section will also include a brief description of some of the proposed new products to be produced.

(a) Point Rainfall Statistics

One of the most popular special analyses designed for the water resources community is the short duration point rainfall intensity-duration-frequency statistics calculation. Tipping bucket rainfall data for rainfall durations of from five minutes to 24 hours are used to produce return period estimates of point rainfall at approximately 250 locations across Canada. These statistics are extensively used in the design of culverts, storm sewers and other small drainage basin structures. The usefulness of these statistics has recently led AES into the production of two closely related analyses. One uses ordinary climate station daily rainfall data to produce return period rain estimates for accumulation periods of 1-10 days. Statistical estimates of probable maximum precipitation are also included in this analysis. The other requires daily snowfall, rainfall and temperature information during springtime, and, after application of a simple snowmelt algorithm, produces return period estimates of combined snowmelt-rainfall runoff for the location being considered. Both of these analyses can be produced upon specific request for stations with 15 or more years of data in the climatological archive.

(b) Rainfall Intensity Maps

A project to map the point rainfall intensity frequencies has been initiated. The data base of tipping bucket rain gauge data has rapidly increased recently so that useful mapping on a regional scale is now possible, but a problem with volume of maps arises. A separate map is needed for each available return period (6) and each duration (9) of interest, making a total of 54 maps for each region mapped. This creates problems of cost, analysis time and utility. Previous atlases have used ratios to relate various durations and hence eliminate maps. We are now investigating the feasibility of what we hope will be a more satisfactory method.

In the analysis method used (Gumbel) the return period estimate is a function of the mean of the annual extremes plus a frequency factor times the standard deviation of the annual extremes. The frequency factor is a function of the return period while both the frequency factor and the standard deviation are dependent upon the number of years of record of the station. The dependence on years of record can be eliminated by using a very close approximation relationship. This then permits mapping of the mean of annual extremes and a modified standard deviation of these extremes with two sets of lines on the same map. An accompanying list of the modified frequency factors then makes it possible to present all relevant information for any duration on just one map. The user then extracts the mean, modified standard deviation and modified frequency factor from the map and calculates the return period value using the simple Gumbel equation just described. Is this a satisfactory solution for the user or is there a better way?

(c) Storm Rainfall Analyses

The publication series "Storm Rainfall in Canada" provides an excellent data base for those interested in areal analysis of precipitation data. Over 400 Canadian storms, dating back to the beginning of the century, have been analysed and published in this series. Each published storm analysis contains mass curves of rainfall, an isohyetal analysis of total storm rainfall and depth-area-duration curves for six hour increments through the storm. Using this data base, the frequency distributions and return period analyses of areal rainfall events for durations of 24 to 96 hours and areas of 100, 1,000 and 10,000 square miles are being examined.

(d) Temporal Distribution of Storm Rainfall

Figure 5 represents the preliminary results of an analysis of one hour storms across Canada. The analysis is based on available tipping bucket rain gauge data between 1950 and 1974 for 35 selected stations. Storm days were selected for analysis when either the five minute or 60 minute rain amount exceeded predetermined thresholds. The hour of maximum rainfall was then selected for more detailed analysis using five minute increments of rainfall. The precipitation amounts for the day of the event and the five previous days were abstracted and tabulated at the same time. The curves (one for each station plus regional combinations) show the percentage of events in which at least the indicated percentage of total storm rain has accumulated in the duration shown. Regional curves are produced by simply combining the data of stations in the region. A similar analysis has been performed for 12 hour storms at the same selected stations.

(e) Water Budget Monitoring

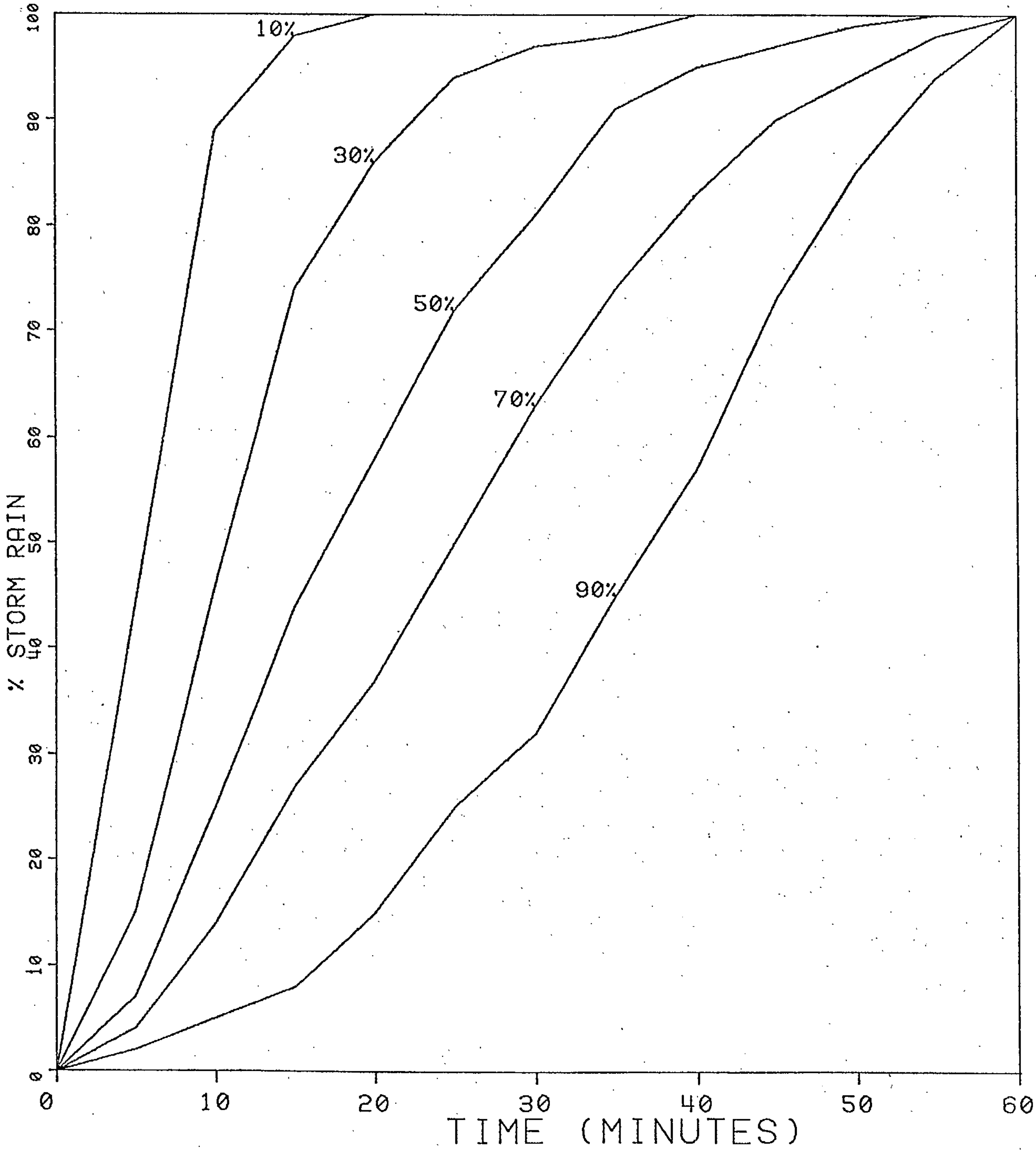
As part of the monitoring role of the Canadian Climate Centre, the processing of near real-time water budgets for approximately 225 synoptic stations across Canada on a weekly basis, has recently been initiated. The water budget technique is based on the Thornthwaite model using daily temperature and precipitation observations as input.

FIGURE 5

MEAN STORM RAIN DISTRIBUTION
PRAIRIE PROVINCES

NO. OF EVENTS =196 SELECTION CRITERIA: 5 MIN 1 HR
(MM * 10) 51 152

CURVES SHOW % OF EVENTS WITH % STORM RAIN ≥ VALUES PLOTTED



Derived components from the model include estimates of evaporation, soil moisture and snowmelt. These water budget components are accumulated and averaged over seven day periods and, using an objective analysis scheme, are available in map form for all of Canada about two days after the end of each period. Also available are the normal water budget components generated from the long term temperature and precipitation normals for the corresponding seven day periods and the deviation from normal values. In addition, the much denser climatological network offers the potential of carrying out detailed regional studies, if required, with the same technique.

(f) Lake Temperature Surveys

Surface water temperatures of the Great Lakes have been monitored and mapped by personnel of the Division since 1966, using airborne radiation thermometer (ART) techniques. For these analyses, lake evaporation is routinely estimated for the regulation of lake levels. More recently a procedure to perform this analysis using meteorological satellite data has been developed, permitting phasing out of the expensive airborne surveys. As well, using satellite data, it is now possible to analyse surface water temperatures from other large water bodies in or adjacent to Canada, such as Lake Winnipeg and the Bay of Fundy.

(g) Snow Cover Mapping

As part of the Canada/New Brunswick flood forecasting agreement, AES has become involved in the development of a technique to monitor river basin snow cover extent in the Saint John River Basin using digital satellite data. To date, the technique uses computer enhancement procedures and a colour graphics display to determine which combination of satellite derived radiances best discriminates between snow covered and non-snow covered terrain in this heavily forested area of Eastern Canada. The computer then generates a snow cover map based on the satellite radiances. As part of the agreement, snow cover maps will be provided operationally this spring to the Fredericton Flood Centre on a cost recovery basis.

(h) Radar Precipitation Analyses

As mentioned earlier, digital weather radar scans from six sites are recorded every ten minutes and archived by AES. Computer software has been developed to convert data from these scans into measures of precipitation rates. These "snapshots" of precipitation can be summed to provide hourly, daily, weekly or even seasonal accumulations but the computer processing is not trivial. The radar information suffers from a certain amount of uncertainty in comparison with point measurements but its strength lies in the accurate depiction of storm motion and areal distribution of the precipitation.

(i) Wildlife Studies

Because of lack of numbers, wildlife interests are not as well served by a large number of "off the shelf" products specifically designed to meet their needs. Instead, special analyses of climatic data are carried out as requested. Table 1 is an example of the results of such a requested analysis showing the incidence of debilitating weather during the Caribou calving and rutting seasons. The table appears in a paper by B.F. Findlay of the Canadian Climate Centre entitled "Role of Climate in Establishing Wildlife Habitats" which was distributed in the proceedings of the "Workshop on the Application of Meteorology to Wildlife Management in Ontario", Internal Report SSU-78-1. Limited quantities of this report are available from:

Ontario Regional Scientific Services Unit
Atmospheric Environment Service
25 St. Clair Ave. E.
Toronto, Ontario
M4T 1M2

(j) Drought Studies

In the past five years, drought has become a "high profile" topic within AES and throughout the world. AES efforts are concentrated in the area of identification and definition of drought conditions using agricultural and hydrologic data to be followed by an investigation of the temporal and spatial characteristics of the relevant climate parameters. Specifically, emphasis will be placed on the documentation of frequency, duration/timing and extent of historical droughts, on correlation with mountain snowpack and atmospheric circulation patterns, and on the study of the level of feasibility of prediction. Development and application of a drought classification for use in the relative evaluation of historical droughts and monitoring of dry spells which may be incipient droughts is also an area of future activity.

(k) Consultation

In addition to these specific current or anticipated products, personnel of the Canadian Climate Centre and of the Scientific Services Divisions in each Regional Headquarters (Vancouver, Edmonton, Regina, Winnipeg, Toronto, Montreal and Halifax) are available for consultation. Appropriate topics would include evaporation measurement and calculation, snowmelt, precipitation measurement errors, network design, impact of climate on wildlife and others too numerous to mention. Major, site-specific studies are also possible on a cost recovery basis. An example of such a study would be probable maximum precipitation analysis for a major hydroelectric project. Such a study involves transposition and maximization of historical storms, maximization of orographic effects and maximization of seasonal snow accumulation and snowmelt.

Additional Information

This paper was designed to be only an overview of the products and services provided by the Canadian Climate Centre. Publications, tabulations, etc., are described more fully in "A Catalogue of Climatic Data Sources" referenced earlier and to be distributed at the workshop.

Table 1

Incidence of Debilitating Weather during the Calving and Rutting Seasons

Year	DEWAR LAKES						BROUGHTON ISLAND					
	Hvy	Snowfall	Incidence Rain & Cold		Wind	Chill	Hvy	Snowfall	Incidence Rain & Cold		Wind	Chill
	C	R	C	R	C	R	C	R	C	R	C	R
1961	X	*	2	0	23	32	X		0	0	9	17
1962			4	0	17	26		X	0	0	16	15
1963	X	*	1	0	21	24	X	*	0	2	0	11
1964			0	0	16	30		X	2	2	7	19
1965			2	0	15	30	X		0	0	7	23
1966		X	0	0	17	27	X	X	0	0	9	14
1967	X	*	6	0	23	30	X	X	2	(A)	0	18
1968	*	X	5	0	19	18	X		0	0	11	8
1969	X	X	0	0	17	32	X	X	0	0	6	15
1970	X	X	1	0	23	26	X	X	0	(A)	14	19

C = Calving season R = Rutting season

X Above normal snowfall in May - June or October - November

* Above normal snowfall in April or September

(A) 2 or more occurrences in September

(Masterton and Findlay, 1976)

For additional information on climate and its relation to natural resources the points of contact are the Scientific Services Division in each Regional Headquarters or, within the Canadian Climate Centre, Chief, Hydrometeorology Division for climate and water resources or Chief, Applications and Impacts Division for climate wildlife. Up to date addresses and phone numbers are contained in the Canadian Climate Centre brochure to be distributed at the workshop.

INVITED DISCUSSION PAPERS

WRITTEN SUBMISSIONS

On the Evaluation of the Influence of Large-Scale Dam Projects on Weather and Climate

E. Vowinckel and S. Orvig
Department of Meteorology
McGill University, Montreal, Quebec

There are several aspects to the study of the effects of man-made modifications of the movement of liquid water on or below the earth's surface.

The first consideration is concerned only with the surface energy budget. In the following these terms are discussed:

QE: Turbulent latent heat transport
QS: Turbulent sensible heat transport
ULF: Terrestrial (long wave) radiation (up)
FG: Heat conduction below the surface
SGA: Solar radiation incoming at the surface
ALB: Surface albedo
DLF: Atmospheric (long wave) radiation (down)
PR: Precipitation
RO: Runoff

All modifications of surface conditions will

a) change the available energy, or shift its distribution in time
b) change the expenditure side of the balance, namely the allocation of energy to QE, QS, ULF, FG
c) most likely (a) and (b) will happen at the same time

If neither (a) nor (b) occurs, the modifications of the surface conditions will remain meteorologically and climatically irrelevant.

In terms of available energy, the critical element is the albedo. It will change with even the slightest modification. A field of wheat is different to one of potatoes. These differences are too small, however, and reverse too frequently to be of significance in the present context. Three changes are significant, however:

1) change from land to water surface by dam construction
2) change from forest to agricultural land (especially from coniferous forest)
3) change of agricultural land to irrigated land

It should be noted that especially the effect of a water surface becomes more marked towards the north, due to the high albedo of ice and snow and the large quantities of heat required to remove ice and snow in the spring.

In the case of water, therefore, the initial effect due to the low water albedo, namely that the available energy will be increased, becomes diminished in the north. It would be interesting to investigate at which latitude the influence of a lake becomes negative for the surface energy budget.

An assessment of this factor requires only generally available normal meteorological observations, and an effective energy budget program for a water body of the size of the dammed lake. Such a program can, as our experiments have shown, be relatively simple and still give the correct answer for the date of freezing and melting of the water body, with an error limit of a few days or a week.

Detailed on-site measurements are not required since ice formation is dependent on the characteristics of the water body and on the macroclimate and weather. An assessment is therefore possible for nearly all places in Canada in advance of actual surface modification.

The change from forest to non-forested land (other than hydro-delelopment and flooding) is less severe as far as the available energy is concerned. In coniferous areas it is the winter albedo which is increased by clearing the forest. It should be remembered, however, that in Canada land clearing for agriculture is and was on a small scale in the coniferous belt, for geographic reasons. Furthermore, in winter when the effect would be large, the available energy is poor, hence the net effect small. No delay in albedo-decrease in spring is experienced comparable to that over water.

If deciduous forest clearing is considered, the albedo-changes are even smaller. We have no experience in this respect. Since this type of clearing has taken place on a large scale on this and other continents, however, and is still very much going on, more exact observations and subsequent numerical experimentation is highly desirable in the context of man-made influence on climate and weather.

By far the most significant changes are on the expenditure side of the budget. A reasonably accurate calculation of the energy budget of a lake, using normal meteorological observations, is feasible with the available programs without further observations. This means that a statement of the splitting of available energy into FG, ULF, QE, QS is not too difficult if (this is important) the water body is sufficiently small so that air mass modification along the trajectory remains negligible. Strictly speaking this is only true for very small lakes. However, air mass modification can be introduced in the program for the surface layers with the accuracy required for further calculations along the trajectory. We found from our experiments that an air mass modification program must be incorporated for trajectories > 5 km.

Let us now consider the total drainage area of a river. Neglecting groundwater flow, a bulk water budget is easily obtained for a catchment area: QE = PR − RO.

The transfer into an energy budget equation would only be possible if the ground were permanently saturated, so that potential QE could be assumed. This condition is hardly ever given over longer time and a larger area. We tried here to operate with another assumption, namely that the temperature of the active layer is, on the average, equal to the screen temperature. This permits the calculation of ULF, and the energy budget can then be used to solve for QS, at least for periods over which FG is known (to be zero) or can be approximated from the surface temperature.

Then: QS = SGA*(1-ALB) + DLF - ULF - QE

If orders or magnitude are considered, the results are satisfactory. In most cases this is not sufficient, however, because:

1. The effects may be small over the year, but quite pronounced seasonally.
2. The effects may vary significantly in the area, and those variations are of interest.
3. The influence is not restricted to hydro-development, but irrigation or other uses of the water may be contemplated. This will cause energy budget changes in regions outside the dam area, and these should be assessed.

The only solution we can see for this problem is to calculate the surface energy budget from EBBA or a similar program for the diverse surface conditions of the present and the modified areas and to compare these, in a similar manner to what we have done for the Nile source basin and the area of The Pas, Man. (Vowinckel and Orvig, 1972, 1976, 1979).

Here lies the main difficulties where further work is required. The calculations are very insensitive to the type of transfer equations used for QE and QS. Extensive experiments with different equations all showed similar results. However, the calculations are highly sensitive to:

1. Type of rainfall, duration and intensity.
2. Water holding capacity of the ground, and number of sub-surface layers specified.
3. Mode of water extraction from the ground, as a function of soil type and vegetation.
4. Influence of slope on runoff, where it is presumably mesoscale slope which counts.

In this area substantially more observations and experimentation are required. It must be remembered, however, when setting up experiments, that the diversity of both soil and vegetation is very great indeed and not the remotest possibility exists of calculating in detail for, so to speak, every square metre. This insight is not new, everyone who has dealt with irrigation, agriculture of forestry knows this well.

The requirement is therefore for methods which give bulk transfers for reasonably homogeneous areas. It is a difficult balancing, because if surface descriptions are too crude, the whole purpose is lost as the differences which are looked for are eliminated by the parameterization. On the other hand, if the description is too detailed, neither observation nor calculation is feasible.

The approach is to write quite detailed programs with many parameters and test them systematically to see which variables have a real influence, with actual weather conditions and real soil and vegetation. This type of research is being done by us at McGill.

Once the energy and water budgets are evaluated for the different sub-sections of a catchment area, the areal distribution of these types must be adjusted until a match is achieved with the observed RO. According to our experience this is not too difficult.

It is then straightforward to insert the new surface conditions, generated by dam, irrigation, etc., and to determine two factors:

a) change in RO
b) change in type of energy input into the atmosphere.

From the discussion above it is apparent that the micro-meteorological changes resulting from dams, etc., are implied in the calculations. If air mass transformation in the lowest layers is required, this can at least be approximated by various programs developed here in graduate theses. The critical point, however, if further down the line, namely whether or not meso- and macroscale influences can be caused by the flux changes discussed so far, and what type of influences, if they do occur.

That this takes place was shown by Bergeron for the influence of forest blocks in the Upsala area in Sweden, many years ago. No doubt similar observations have been made in many localities. Another example is the increase in Cu frequency in the Gezira of Sudan, over irrigated areas.

The calculation and assessment of this requires mesoscale cloud models with the surface fluxes as input. We have not programmed this, but it would be essential if detailed assessment of the changes in the atmosphere are required. It seems reasonable to assume, however, that such modelling and observation is within the realm of present possibility. Whether it is sufficiently cost-efficient to justify the calculations is another matter.

It is beyond dispute that these mesoscale influences of noticeable and significant magnitude exist as a result of changes made by dams and irrigation. The problem is mainly to put numbers on it. The final question, in the end perhaps the most significant, is whether large-scale weather and climate are influenced.

Two questions can be distinguished: first, a dam would cause a very small change in total amount of annual absorbed solar radiation over a larger area, even of the size of a small Canadian province. Most likely it would be below observational accuracy. It therefore seems justified, as a first approximation, to say that this influence on the atmosphere would also be small. However, it seems more correct to consider the energy availably at the surface during a moderate time interval of a week or more. Then the heat storage and destorage in water becomes a prominent factor, and the changes in energy flux will be more noticeable, even over a large area.

The second point is the significance of changes, not in the amount but of the type of energy put into the atmosphere. Here the change between QE and QS is the most important. Again, more light can be shed on the problem only by the use of general circulation models. In this case a run with energy input only via ULF and QS should be compared against moist surface conditions where QE also transports energy.

It is an interesting question, whether or not the present numerical models are capable of examining this problem. Somehow it seems doubtful, and it certainly ought to be investigated and discussed by meteorologists with different fields of expertise.

References

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The Need for a National Climatological and Hydrometric Data Base in Canada

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Northern Pipeline Agency
Calgary, Alberta*

Weather services are not being utilized to the extent possible in the management of Canada's water resources. This is due in part to the separation of the responsibilities for the provision of weather services, which lie with the Atmospheric Environment Service, from those for the provision of water management services, which lie with the provinces, local governments, and other federal agencies.

This paper proposes the establishment of a national data base containing both hydrometric and climatic information to reduce this problem. Provincial and local governments would participate in the operation and maintenance of the data base as well as with related aspects of its use.

The paper begins by summarizing the needs for climatic information in water resource applications and outlines the deficiencies of existing data sources. It then outlines the role of the respective levels of government in the operation and maintenance of the proposed data base and concludes by discussing the merits of the data base.

Use of Climatic Information in Water Management

The most frequent applications of climatic information in water management are in the design of water resource systems and for water resources planning and operation. Established procedures exist for the use of climatic information for design and planning purposes. The procedures for operational applications are not so advanced and need to be improved. Such improvements once introduced would more closely relate climatology to watershed management.

Important design applications are the establishment of criteria for water control structures, storm sewers, bridges and culverts. Commonly the requirement is for normal or extreme values of a climatological parameter for substitution into event models or other established engineering procedures.

A typical planning area where climatic information is particularly important is flood plain delineation. The high cost of reimbursement for flood damages has prompted many governments to restrict development on flood plains. The flood plain must be defined and in areas where a lack of streamflow information exists, a common technique is to estimate the flows from climatological data.

* Present Position: Meteorologist, Environmental and Social Affairs, Petro-Canada, Calgary, Alberta.

An operational area which requires considerable climatic information is streamflow forecasting. These forecasts are most frequently used for the purpose of issuing flood warnings and operating reservoirs. Some of the problems impeding the development of streamflow forecast programs in Canada include the lack of familiarity on the part of the user with calibration procedures, real time weather data handling procedures, and the real time weather network. It is expected that the advent of data acquisition systems utilizing telephone or satellite communication links and the availability of weather radar data in digital form will at least partially overcome the latter two problems thereby increasing the demand for streamflow forecasts in the future.

Conceptual watershed simulation models, which are designed to represent the physical processes in the watershed, are frequently used for streamflow forecasting. These models are usually combined with other models such as a snowmelt model, a model to compute mean basin precipitation, a routing model, and with data handling routines to facilitate both calibration and real-time forecasting. These combinations are referred to as "systems". Two such systems in common use in the United States are the National Weather Service River Forecast System (NWSRFS) and the Streamflow Synthesis and Reservoir Regulation (SSARR). Both are designed to utilize weather service data and operate on six hour time steps coincident with the synoptic cycle, and as a result are further classified as being continuous.

Although continuous simulation models have been used mainly for streamflow forecasting there is no reason why they cannot be used for other purposes including design and planning. As an example, there is emerging in the field of watershed management, a methodology which enables planners and resource managers to examine the effects of various strategies in resolving competing social, economic and political demands. Typically it uses computer based models which take into account natural flows, population growth projections, industrial water requirements, sewage treatment demands and flood control to study the effects of land use change, addition of reservoirs, reservoir operating strategies, drainage and other factors. Linkage with a continuous streamflow model provides an effective means of permitting the analyst to study the effects of climatic variability as well.

Deficiencies in the Existing Sources of Climatological Data

Nearly all of the climatological data in Canada are stored in a data base maintained by the Atmospheric Environment Service (AES) which includes data contributed from a number of cooperating agencies. The AES has set standards pertaining to instrumentation, observational procedures, quality control and formatting so that the user is assured of receiving good quality data in a computer compatible format. In a similar fashion Water Survey of Canada in cooperation with other agencies collects streamflow data which are quality controlled and archived in a standard format but at a location separate from the AES archive.

There are a few other agencies, some with watershed management responsibilities, which collect data but have not adopted instrumentation or observational standards. As a result their data are of uncertain quality and frequently not in format suitable for use in conventional programs.

A serious shortcoming that has long been recognized by those engaged in hydrological applications in Canada is the lack of climatological data. The climatological network has evolved over the years without consideration having been given to the hydrological requirements in most areas.

As a result, there is an almost universal lack of radiation, snow water content and evaporation data. Even temperature and precipitation data, which are more plentiful, are only near acceptable levels in populated areas.

Those using watershed simulation models for forecasting find that they must obtain data from at least two sources in order to carry out calibration. The existing climatological data are usually contained in the AES archive and are suitable for application with some minor exceptions. The streamflow data from the Inland Waters Directorate archive are not suitable for forecast systems because they consist of daily mean rather than instantaneous flows. The instantaneous data can be obtained from regional offices but this provides an additional inconvenience to the user.

A Proposed National Data Base

The federal maintained data archives were established to provide a data inventory for national needs and for many years served provincial needs as well. Recently there has been an increasing number of demands placed on provincial and local governments to provide improved water management services. The federal archives no longer provide adequate data to support the provision of these services. In this section a national data base is proposed which would involve all three levels of government.

The proposed archive would be maintained by the Federal Government and preferably by the Atmospheric Environment Service since its archive already contains the bulk of the data requirements. Additional data would be contributed from the Inland Waters Directorate and should include at least instantaneous streamflows at synoptic hours. The existing standards for instrumentation, observational procedures, quality control and data formatting by both agencies would be adapted. The data would be sorted on at least a geographic, and preferably a watershed basis. Users would be able to obtain copies of the historical data and subscribe to annual updates as is now the case with AES data.

The Federal Government would be responsible for preparing supporting documentation which provides station histories, monthly and annual climatological statistics, and instrumentation and observational standards. It would develop a generalized forecast system that is easily calibrated and easily transported from watershed to watershed. It would conduct research and development designed to improve various components of the system and issue updates on a regular basis. It would also be responsible for conducting training programs to enhance the transfer of technology to the other agencies.

The provincial governments would be responsible for the coordination and control of local programs, with the possible exception of those in international and interprovincial basins where both the Federal and other affected provincial governments would also be involved. They would ensure that instrumentation and observation standards were maintained possibly through the use of centralized inspection services and equipment contracts. They would conduct training programs and perform research and development for specialized provincial needs. Network design should be carried out at this level but in cooperation with members of the local governments. Specialized services relating the interpretation and use of data should also be a provincial responsibility.

The local governments would be responsible for planning the network requirements and installing and maintaining instrumentation. They would also be responsible for carrying out the observational programs.

Merits of the Proposal

Such a proposal offers several advantages, foremost of which, is that it formally shifts the responsibility for network design to the local level where the responsibility for overall watershed planning generally lies. This would permit network design to be made part of the planning process and result in a network more suited to local watershed management needs.

Another advantage is that common procedures for processing and applying the climatological and streamflow data can be developed and made available to all levels of governments. Currently, the cost of such procedures is too high for even many provincial governments to undertake on an individual basis.

Transfer of technology from the Federal to the local governments would be facilitated. Currently the Atmospheric Environment Service is very much isolated from engineers, resource managers and planners employed by local and provincial governments. As a result, the procedures for obtaining and climatological data are not well understood. Training programs could be more easily set up once common procedures were established and could be directed to the members of the private sector, colleges and other learning institutions, as well as government agencies.

Finally, once a common approach had been established to resolve the data handling problems, the shortcomings of some of the physical applications such as the calculation of snowmelt, movement of water in frozen soil and so forth, which are well known in the climatological community would be more widely recognized and it would be easier to obtain funds to deal with them.

Summary

Climatic information is used for the design of water resource systems and water resources planning and operation. These applications would be facilitated by the availability of a consolidated source of climatic and streamflow information in Canada. It is proposed that a national data bank be established for this purpose.

The federal government would maintain the bank but provincial and local governments would be participating agencies with responsibilities for network planning, data collection and specific needs related to their jurisdictions.

The federal government, in addition to setting national standards for instrumentation, observational procedures and performing the data processing, would develop a generalized forecast system which is easily calibrated and transposable to most Canadian watersheds.

Such a data base and related services would facilitate a coordinated approach to dealing with many of our water management problems. In particular it would result in a climatological and hydrometric network more suited to water management needs, provide a more efficient means for provincial and local governments to obtain support and enhance the transfer of technology to users of climatic and hydrometric information.

Lakes and Marine Applications
Hydrometeorology Division
Atmospheric Environment Service
Downsview, Ontario

A large number of hydrometeorological problems are associated with lakes, reservoirs and marine areas. Services provided by the Hydrometeorology Division include information consultations, referrals and studies on topics such as the role of precipitation, water surface temperature and evaporation and variations of water levels; winds and their effects, such as waves, set-up and seiche, currents and littoral drift; and ice formation and dissipation.

Since 1966, a program of remote sensing of lake surface temperatures has been underway. Recently, the use of airborne radiometer surveys (ART) was supplemented by and is now being replaced by the processed results of infrared satellite imagery.

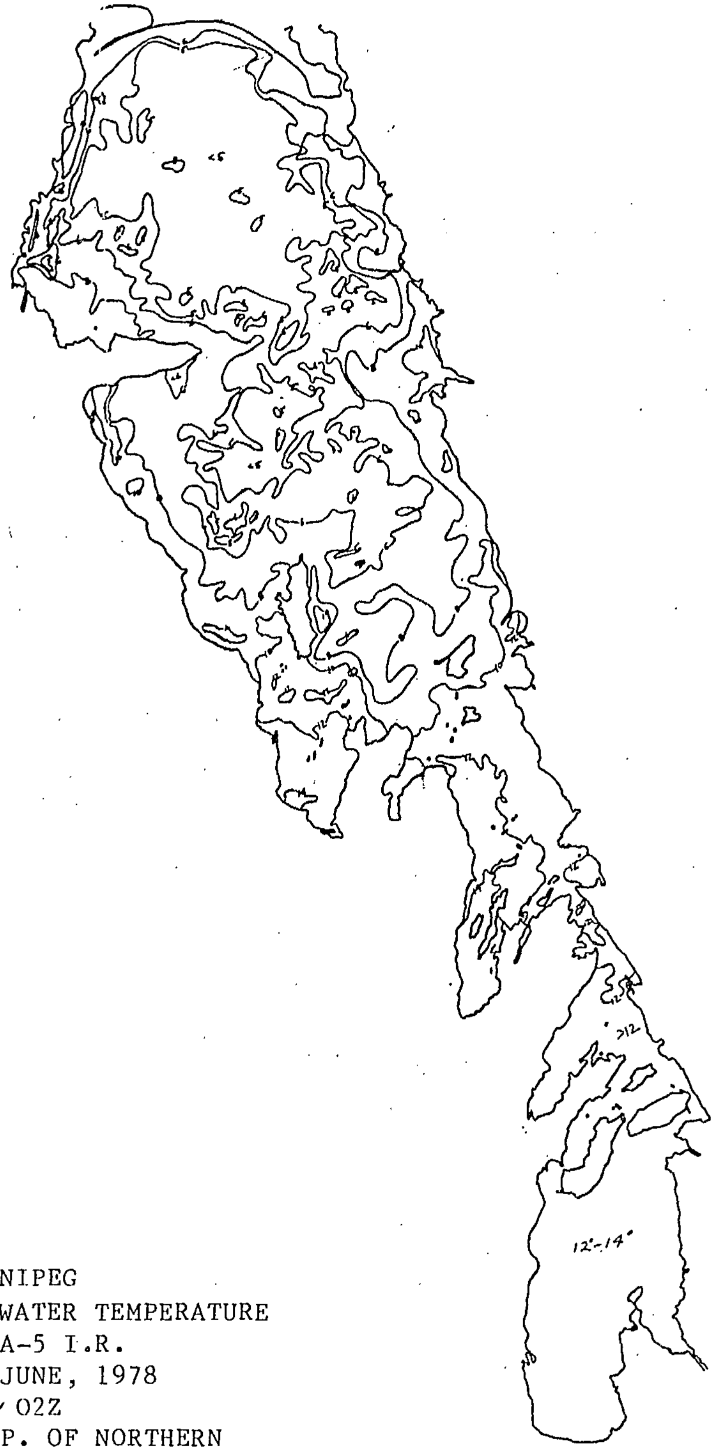
Water surface temperatures are a key element in determining the nature and course of many physical and ecological processes. The use of climatological and near real-time water surface temperature data is only beginning to be exploited.

Attached are some sample outputs of the ART and satellite water temperature sensing programs, and a compilation of Great Lakes evaporation and of Great Lakes basin precipitation.

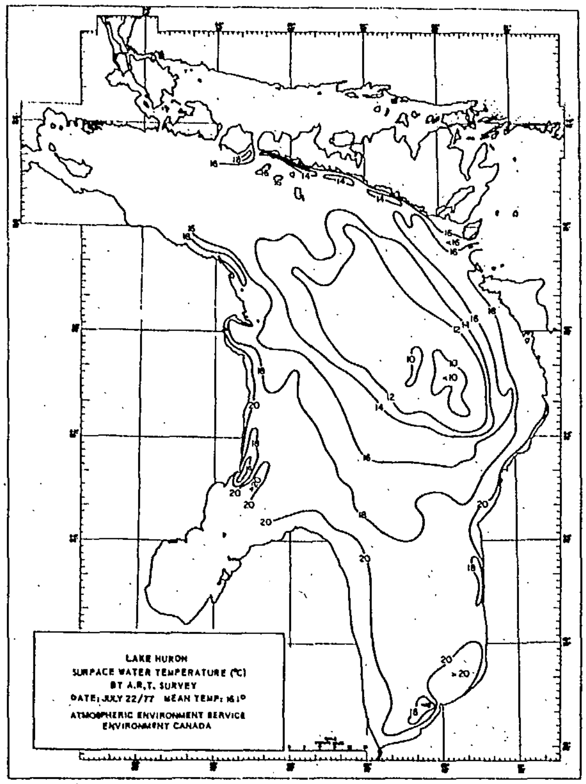
Inquiries and comments on the utility of these services are welcomed. Please direct these to:

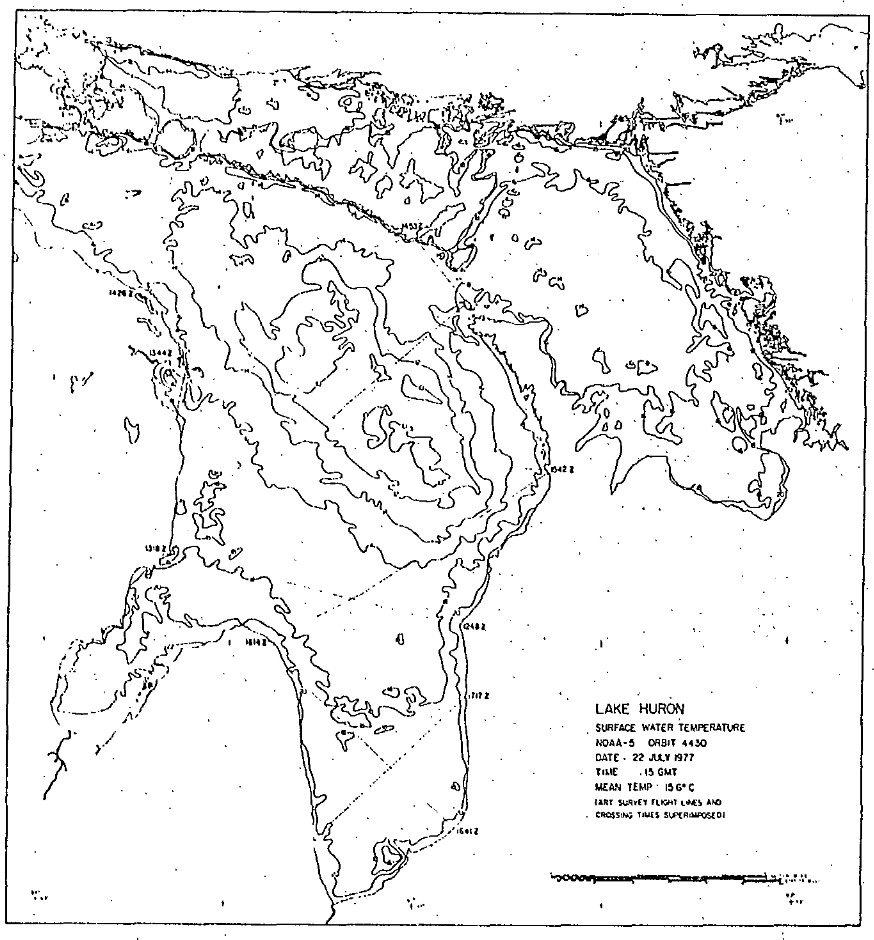
Mr. A. Saulesleja
Supt., Lakes and Marine Applications Section
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario
M3H 5T4

(416-667-4618)



LAKE WINNIPEG
SURFACE WATER TEMPERATURE
FROM NOAA-5 I.R.
DATE: 2 JUNE, 1978
TIME: ~ 02Z
MEAN TEMP. OF NORTHERN
BASIN: 7.5°C


LAKE HURON
SURFACE WATER TEMPERATURE (°C)
BY A.R.T. SURVEY
DATE: JULY 22/77 MEAN TEMP: 16.1°
ATMOSPHERIC ENVIRONMENT SERVICE
ENVIRONMENT CANADA


LAKE HURON
SURFACE WATER TEMPERATURE
NOAA-5 ORBIT 4430
DATE - 22 JULY 1977
TIME .15 GMT
MEAN TEMP · 15.6° C
(ART SURVEY FLIGHT LINES AND
CROSSING TIMES SUPERIMPOSED)

Environment Canada / Environnement Canada
Atmospheric Environment / Environnement atmosphérique

MONTHLY AND ANNUAL EVAPORATION FROM THE GREAT LAKES BORDERING ON CANADA

ÉVAPORATION MENSUELLE ET ANNUELLE DES GRANDS LACS SUR LES FRONTIÈRES DU CANADA

IN MILLIMETRES — EN MILLIMÈTRES

LAKE SUPERIOR/LAC SUPÉRIEURE

PERIOD PÉRIODE	JAN JAN	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUNE JUIN	JULY JUIL	AUG AOÛT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUELLE
1965-1978	127.4	87.4	62.2	21.6	16.1	-38.0	-68.7	-18.9	45.5	78.5	118.6	118.2	547.2
1978 *	126.5	63.8	56.6	29.5	-23.6	-29.7	-69.1	-36.1	22.4	74.2	131.8	113.8	460.1
1979 *	106.7	80.3	49.3	18.3	1.5*	1.5	-36.1	-64.3					
MAX	153.7	132.3	87.6	46.7	54.6	-14.2	-34.0	15.5	90.2	124.0	143.5	144.0	706.3
YR/AN	1966	1968	1975	1975	1967	1969	1971	1970	1976	1967	1967	1967	1967
MIN	96.3	66.8	22.1	6.3	-23.6	-56.9	-105.2	52.6	-9.1	35.3	69.8	89.4	430.7
YR/AN	1973	1969	1973	1968	1977	1966	1968	1968	1977	1973	1972	1969	1968

LAKE HURON/LAC HURON

PERIOD PÉRIODE	JAN JAN	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUNE JUIN	JULY JUIL	AUG AOÛT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUELLE
1965-1978	110.1	72.3	41.6	3.9	13.1	-17.4	4.8	49.0	75.8	95.7	103.9	96.2	649.0
1978	104.6	54.6	47.5	23.1	-25.4	-13.0	-10.2	26.7	75.9	108.2	107.2*	83.6*	588.4
1979	94.5*	91.7*	-1.0*	-7.9*	6.3*	6.3*	-10.7*	-5.1*					
MAX	144.0	101.9	63.2	33.3	48.5	4.8	68.8	85.1	106.7	140.7	152.7	132.8	758.7
YR/AN	1966	1965	1972	1975	1966	1965	1971	1971	1969	1965	1968	1968	1965
MIN	62.2	44.2	-10.7	-14.0	-25.4	-48.0	-26.3	10.7	41.9	55.1	63.5	32.5	540.0
YR/AN	1967	1976	1973	1970	1978	1968	1970	1973	1977	1971	1974	1971	1977

GEORGIAN BAY/BAIE GEORGIENNE

PERIOD PÉRIODE	JAN JAN	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUNE JUIN	JULY JUIL	AUG AOÛT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUELLE
1965-1978	95.2	71.4	47.1	7.6	15.2	-11.1	19.8	56.4	85.7	98.4	110.6	104.2	700.5
1978	95.7	51.8	54.6	25.7	-23.4	22.6	16.5	52.3	103.1	116.3	126.2*	90.7*	733.9
1979	78.0*	93.2*	18.0*	-6.1*	-5.1*	-5.1*	-29.2*	-12.7*					
MAX	131.3	101.3	72.1	30.7	70.4	22.6	52.1	78.5	129.5	126.5	157.2	150.4	770.3
YR/AN	1968	1968	1972	1975	1967	1978	1971	1967	1973	1975	1971	1968	1968
MIN	49.8	46.7	-12.4	-21.3	-23.4	-32.0	-21.1	-27.2	54.4	68.1	65.3	52.3	627.4
YR/AN	1967	1975	1973	1968	1978	1967	1970	1972	1968	1971	1974	1974	1977

LAKE ERIE/LAC ERIÉ

PERIOD PÉRIODE	JAN JAN	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUNE JUIN	JULY JUIL	AUG AOÛT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUELLE
1965-1978	74.0	51.8	20.2	2.2	60.8	68.4	73.9	100.1	147.0	148.7	118.1	82.3	947.5
1978	92.5	63.2	30.2	-3.6	35.8	114.0	85.9	95.5	170.7	191.3	134.1*	131.3*	1140.9
1979	84.6*	83.6*	-18.5*	-32.0*	33.8*	78.5*	77.2*						
MAX	123.7	83.6*	65.3	28.4	97.5	114.0	127.5	151.1	180.8	191.3	182.6	131.3	1140.9
YR/AN	1977	1979	1969	1971	1966	1978	1966	1969	1976	1978	1971	1978	1978
MIN	30.7	11.4	-19.3	-32.0	20.6	45.0	30.5	91.4	102.4	68.1	68.6	31.2	809.3
YR/AN	1967	1976	1973	1979	1965	1972	1970	1974	1965	1971	1966	1965	1972

LAKE ONTARIO/LAC ONTARIO

PERIOD PÉRIODE	JAN JAN	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUNE JUIN	JULY JUIL	AUG AOÛT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUELLE
1965-1978	99.9	71.2	38.1	4.8	4.8	10.0	25.9	65.0	94.2	93.7	86.0	86.8	680.4
1978	103.6	66.5	43.7	26.2	-24.4	-4.6	6.6	24.9	105.9	96.8	99.3*	85.1*	629.6
1979	98.3*	90.4*	7.9*	-10.9*	-16.5*	-4.3*	5.1*						
MAX	142.2	111.0	66.0	40.9	47.8	11.2	66.5	101.6	195.8	145.0	122.7	119.1	825.7
YR/AN	1966	1968	1969	1975	1966	1975	1968	1970	1973	1965	1967	1968	1966
MIN	61.7	41.1	-19.8	-12.2	-24.6	-36.8	-41.9	5.1	20.1	51.3	53.8	45.7	433.5
YR/AN	1967	1976	1973	1976	1975	1972	1977	1977	1977	1975	1975	1974	1977

* Calculations based on estimated water temperatures

000083-9718

Environment Canada / Environnement Canada
Atmospheric Environment / Environnement atmosphérique

MONTHLY AND ANNUAL PRECIPITATION ON THE CANADA PORTIONS OF THE LAND BASINS OF THE GREAT LAKES AND OTTAWA RIVER

PRÉCIPITATION MENSUELLE ET ANNUELLE SUR LES PARTIES CANADIENNES DES BASINS CONTINENTALES DES GRANDS LACS ET DE LA RIVIÈRE OUTAOUAIS

IN MILLIMETRES / EN MILLIMÈTRES

PERIOD PÉRIODE	JAN JAN	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUNE JUIN	JULY JUIL	AUG AOÛT	SEPT SEPT	OCT OCT	NOV NOV	DEC DEC	ANNUAL ANNUELLE
LAKE SUPERIOR/LAC SUPÉRIEURE													
1920-78	49.8	39.3	45.5	49.5	64.0	84.3	82.6	81.0	88.9	67.1	68.5	50.5	768.3
1969-78	56.9	37.8	50.0	43.4	73.4	90.2	89.7	87.6	96.5	71.6	66.5	51.8	815.4
76	64.5	49.3	93.0	49.8	20.8	105.7	71.9	41.7	63.5	41.2	38.4	53.9	693.7
77	46.5	56.4	94.5	53.1	56.4	121.9	84.1	135.9	131.3	52.3	86.9	63.8	983.1
78	28.5	15.2	37.4	29.7	86.4	86.6	107.7	103.2	68.2	44.8	57.2	47.2	712.1
79	31.8	48.7	92.4	50.9	80.0	89.0	73.3						
LAKE HURON/LAC HURON													
1920-78	68.3	53.3	59.4	62.2	68.3	75.9	78.2	73.4	93.0	76.2	81.5	73.4	863.1
1969-78	82.6	81.5	64.8	60.2	78.2	76.2	85.8	84.6	95.2	76.7	79.8	78.5	944.1
76	88.9	80.0	111.3	37.1	87.1	70.8	92.0	62.0	107.2	60.2	67.6	68.6	932.8
77	73.4	64.3	82.3	54.1	31.5	63.0	97.3	140.2	115.3	75.2	118.1	98.3	1013.0
78	78.6	18.9	52.4	43.8	76.2	77.0	80.5	113.3	144.8	71.0	65.9	92.2	914.6
79	85.1	42.1	84.7	107.8	78.3	96.8	63.4						
LAKE ST. CLAIR/LAC ST-CLAIR													
1920-78	66.8	56.7	67.1	75.2	73.9	80.0	76.7	77.0	75.2	65.5	72.9	72.1	859.1
1969-78	74.4	54.6	81.0	75.4	60.7	81.8	78.0	68.6	79.2	58.9	83.1	86.4	882.1
76	106.9	77.0	118.9	79.8	89.9	99.6	140.7	52.6	94.0	67.3	41.4	57.4	1025.5
77	62.2	50.3	90.4	95.5	34.8	73.2	74.2	76.5	179.8	56.9	95.3	92.5	981.6
78	115.6	16.0	57.4	63.4	66.2	60.7	45.7	45.7	110.0	64.4	58.7	89.2	793.9
79	62.4	23.0	75.4	136.5	93.0	52.4	57.7						
LAKE ERIE/LAC ERIÉ													
1920-78	69.8	60.4	71.4	76.2	73.1	76.2	77.7	76.4	77.4	67.6	75.7	73.7	875.6
1969-78	74.2	55.6	85.6	75.9	77.0	78.5	76.7	74.7	103.6	70.9	83.6	91.7	948.0
76	103.1	73.4	131.1	80.9	90.9	84.3	111.3	59.4	98.0	75.4	41.2	57.9	1006.8
77	55.9	52.8	90.7	95.3	38.1	88.4	84.3	127.0	197.9	61.0	97.5	104.7	1093.6
78	94.7	18.7	60.9	68.7	74.5	43.4	46.3	78.3	136.1	75.8	70.9	91.7	860.0
79	73.3	29.7	74.5	117.8	91.9	59.6	42.4						
LAKE ONTARIO/LAC ONTARIO													
1920-78	67.1	56.6	61.7	66.0	69.6	68.3	72.4	69.6	75.9	65.3	73.9	71.4	817.8
1969-78	70.4	56.9	77.0	67.3	73.7	77.2	69.1	74.9	78.2	67.8	77.2	92.5	882.2
76	83.8	76.7	117.9	54.9	88.2	87.5	75.3	59.6	84.7	66.4	38.1	67.7	900.8
77	69.4	46.0	82.6	64.4	38.1	65.8	60.0	122.3	133.6	67.2	115.4	127.4	992.2
78	120.4	13.1	53.8	62.3	67.5	44.2	42.1	102.1	104.1	63.3	62.9	79.1	814.9
79	99.8	40.1	50.8	98.4	82.3	55.7	39.8						
OTTAWA RIVER/RIVIÈRE OUTAOUAIS													
1920-78	61.7	54.4	59.7	59.9	66.8	86.6	93.5	84.8	93.5	72.9	74.4	69.8	878.0
1969-78	65.0	59.4	67.1	57.7	77.0	97.8	98.0	85.6	90.7	72.1	74.4	82.3	927.1
76	69.1	93.5	105.2	29.2	101.9	89.7	91.2	81.8	90.9	69.6	55.6	79.3	957.0
77	66.0	57.4	68.1	68.8	29.2	97.0	70.1	100.8	86.6	59.2	91.4	91.4	886.0
78	86.4	11.4	53.3	58.4	51.6	89.7	88.9	111.5	92.8	57.9	61.4	91.4	854.7
79	85.6	23.4	63.9	94.8	91.8	89.5							

000063-9718

Water Budget Project
Hydrometeorology Division
Atmospheric Environment Service
Downsview, Ontario

The Hydrometeorology Division is currently processing near real-time water budgets for approximately 225 synoptic stations across Canada and 115 northern U.S. stations. This effort is part of the monitoring role of the Canadian Climate Centre to quickly assess variations of climatic parameters in time and space with respect to hydrological activities. The water budget technique is based on the Thornthwaite model using daily temperature and precipitation observations as input. Derived components from the model include estimates of evaporation, soil moisture, snow pack water equivalent and snowmelt. These water budget components are accumulated and averaged over seven day periods and, using an objective analysis scheme, may be made available in map form for all of Canada about two days after the end of each period. Also available are the normal water budget components generated from the long term temperature and precipitation normals for the corresponding seven day periods and the deviation from normal values.

The choice of the Thornthwaite model was influenced by its simple data requirement of only temperature and precipitation which are available from a large station set on a real-time basis. In addition, the much denser climatological network offers the potential of carrying out detailed regional studies, if required, with the same technique. The deficiencies of the Thornthwaite model are well recognized and it is not expected to produce absolute estimates of the derived components. The intention of using a simple model is to increase the information available from the basic temperature and precipitation fields by incorporating the water budget concept. In considering these derived fields then, the emphasis is on the deviation from normal values and the relative week to week changes.

Attached are sample outputs from the model. Figure 1 shows the estimated snow water equivalent at the end of April, 1979. Figure 2 gives the 14 day change in the snow water equivalent for the period April 17 to 30, 1979 and identifies three centers of intense snow pack depletion. These centers corresponded with the wide-spread flooding experienced across Canada. Recall the flooding in the Peace River, and the Red River Valley, the Sturgeon River, the Goulais River, the Ottawa River and the Saint John River during that period. Figures 3 and 4 show respecitively soil moisture estimates and the deviation from normal of the three estimates for the beginning of the water year. These soil moisture estimates are given as a percentage of the soil water holding capacity. Table 1 is an example of a normal seven day water budget computed for Toronto.

Comments on the utility of these products or any further inquiries are welcomed. Please direct them to the contact given below:

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Superintendent, Hydrometeorological Projects Section
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario
M3H 5T4

(416) 667-4521

Accumulated Snow Water Equivalent
Estimates (mm) for the Period Ending 30 April 1979

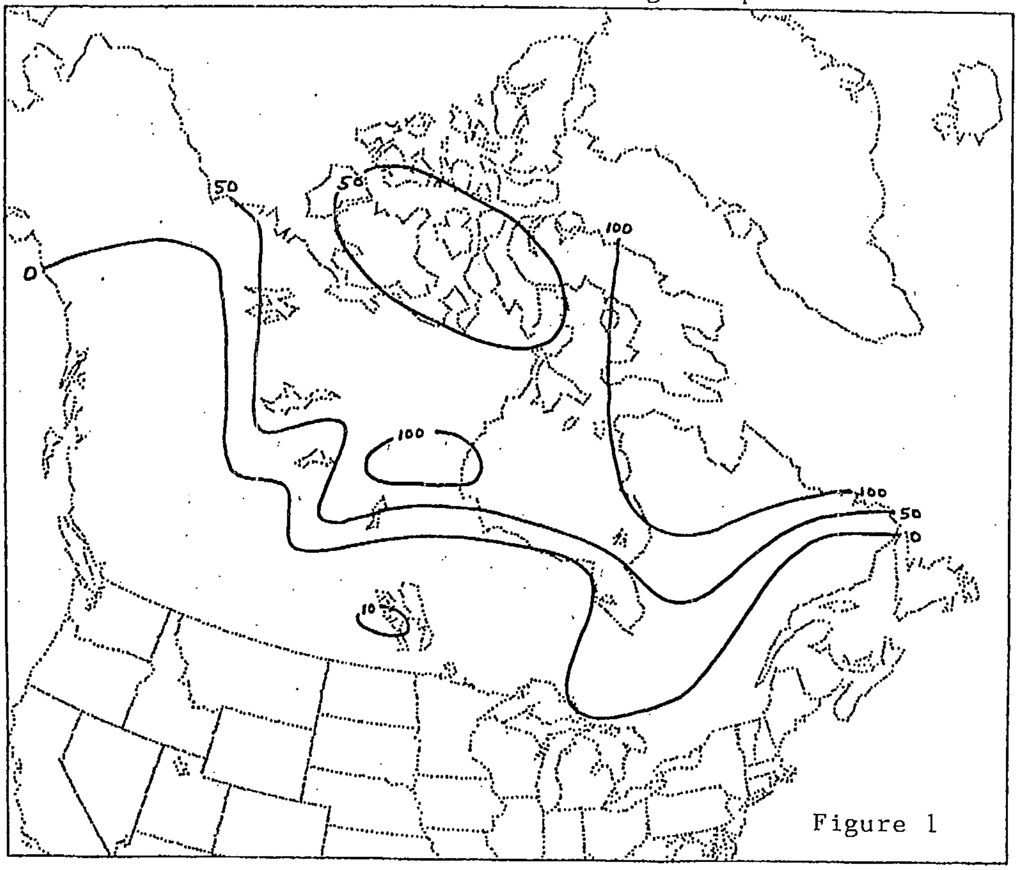


Figure 1

14 Days Change in Snow Water Equivalent Estimates (mm)
for the Period 17 April 1979 to 30 April 1979

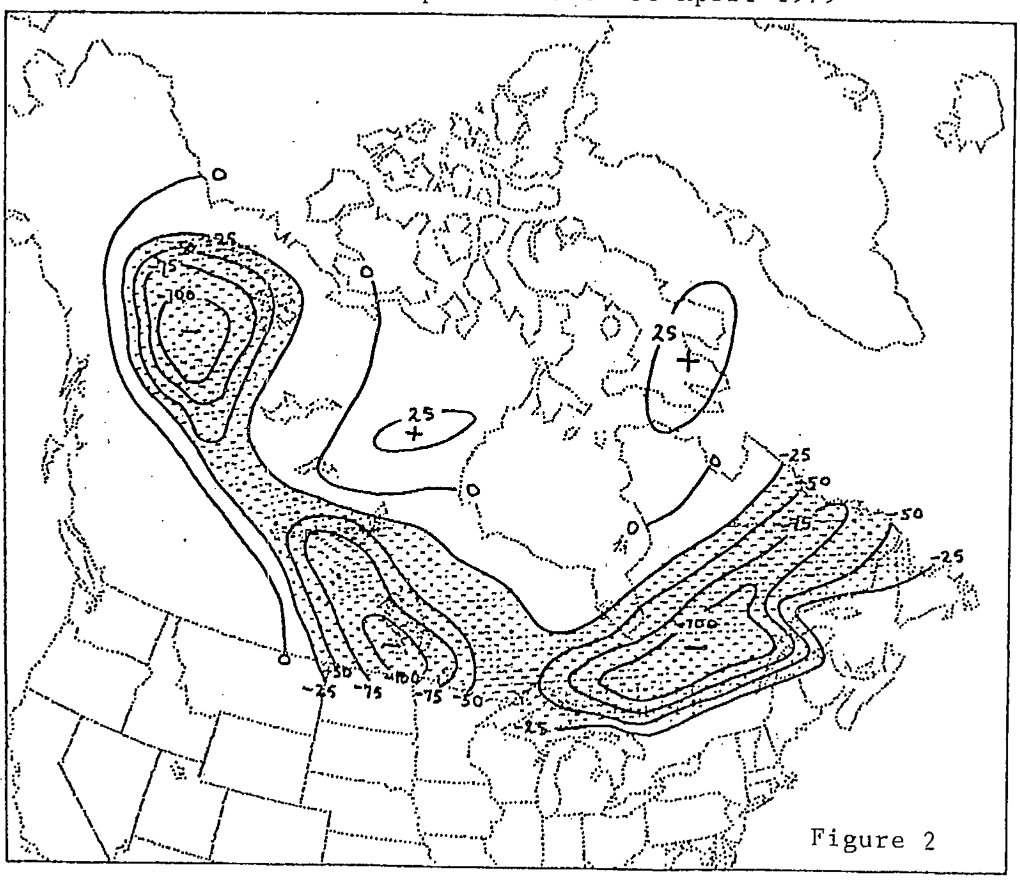


Figure 2

Soil Moisture Estimates (Percent of WHC)
for the Period Ending 1 October 1979

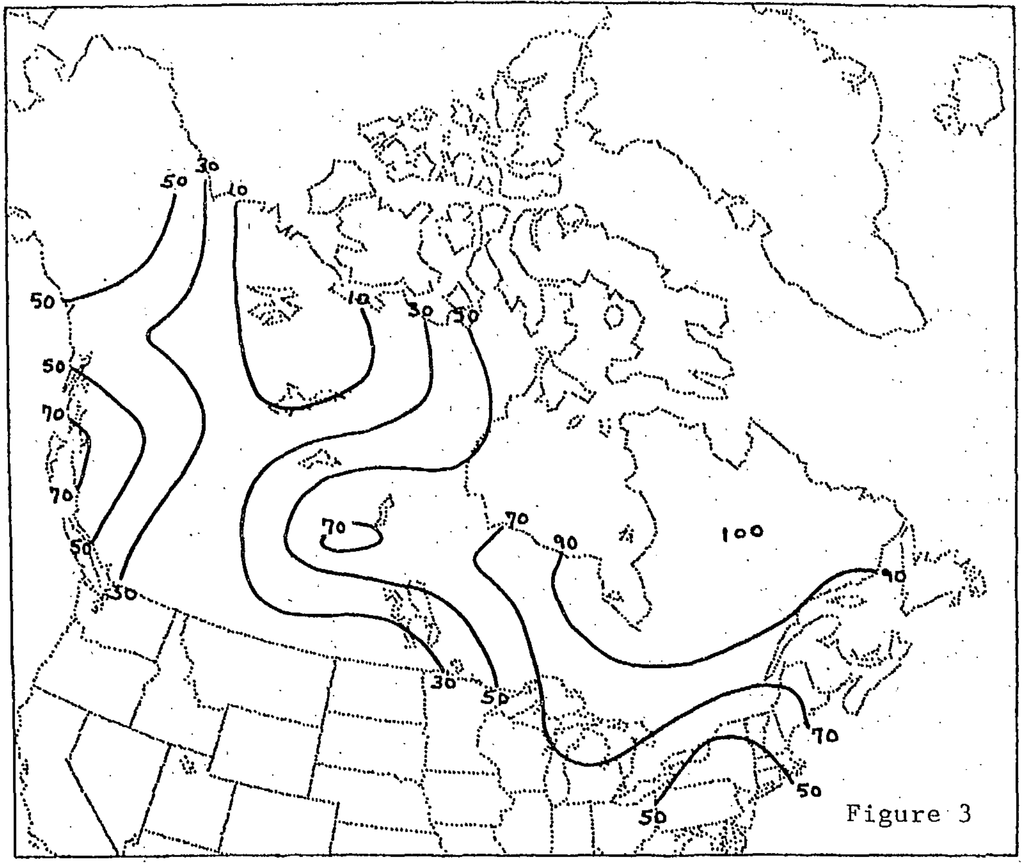


Figure 3

Soil Moisture Estimates Deviation From Normal (Percent)
for the Period Ending 1 October 1979

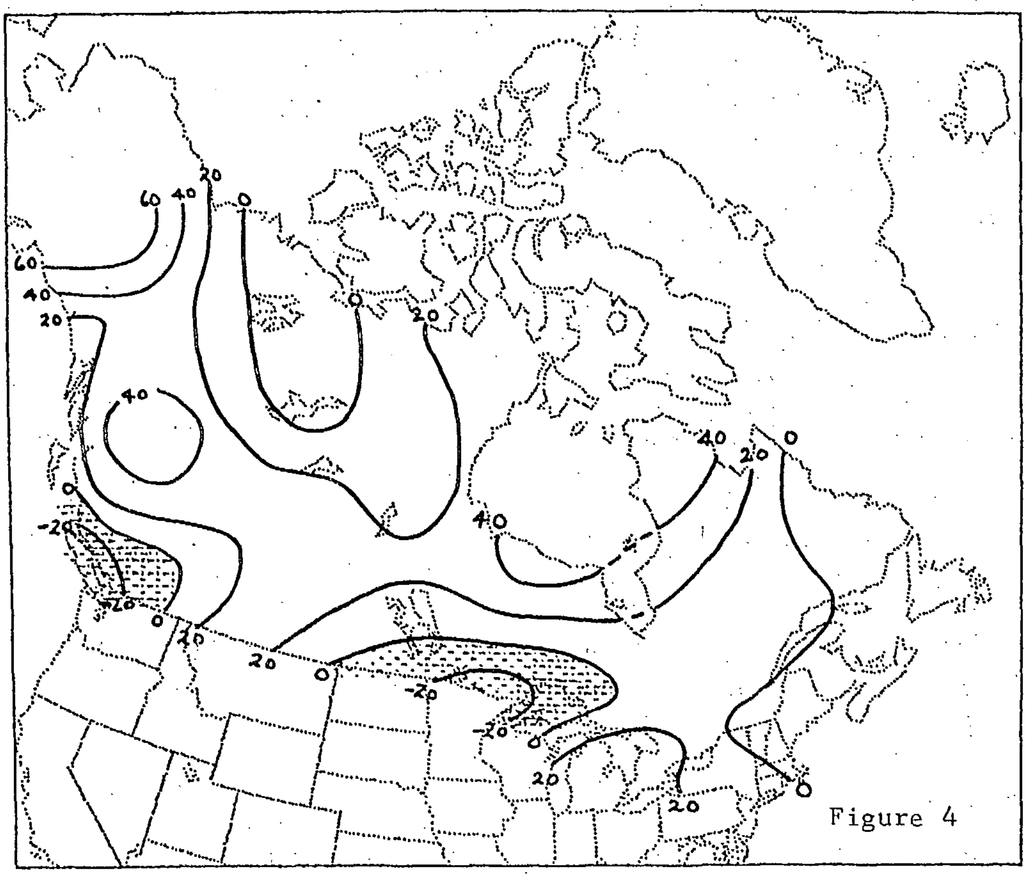


Figure 4

Table 1: Normal 7 Day Water Budget

Definition of Terms

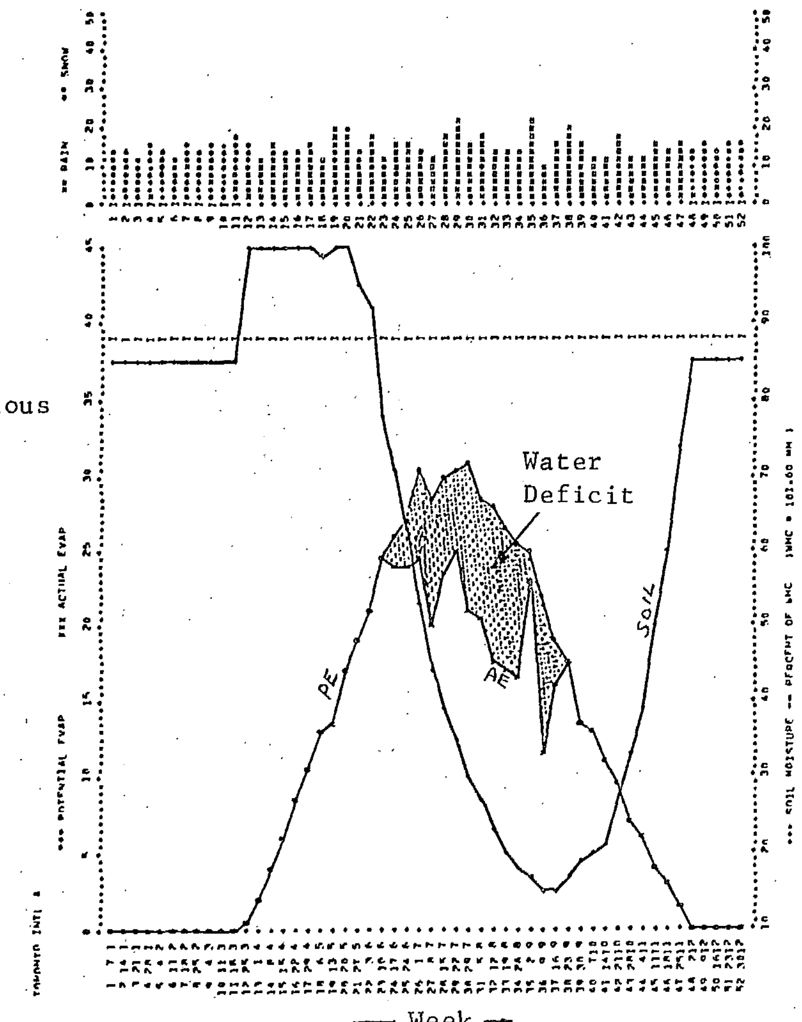
- **WK** – week number
- **DATE** – day-month of end of period
- **TEMP** – mean daily temperature for period (°C)
- **RAIN** – total rain for period (mm)
- **SNOW** – total snow water equivalent for period (mm)
- **PCPN** – total precipitation for period (mm)
- **ACC P** – accumulated precipitation from beginning of water year (Oct. 1)
- **SNO ST** – accumulated water equivalent of snow pack (mm)
- **SMELT** – total snowmelt for period (mm)
- **PE** – total potential evapotranspiration for period (mm)
- **AE** – total actual evapotranspiration for period (mm)
- **P-PE** – total rain plus snowmelt minus potential evapotranspiration for period
- **SOIL** – soil moisture storage at end of period (mm)
- **D SOIL** – change in soil moisture from previous period (mm)
- **DEF** – water deficit for period (mm)
- **SURP** – water surplus for period (mm)

71624 TORONTO INTL A

LAT.... 43 41 WATER HOLDING CAPACITY...101.60 MM INITIAL SOIL MOISTURE CONTENT... 86.88 MM HEAT INDEX... 38.8

LONG... 79 38 UPPER/LOWER ZONES...12.70/88.90 MM INITIAL SNOW STORAGE........... 54.80 MM A............1.100

WK	DATE	TEMP	RAIN	SNOW	PCPN	ACC P	SNO ST	SMELT	PE	AE	P-PE	SOIL	D SOIL	DEF	SURP
1	7- 1	-5.2	0.0	13.0	13.0	191.2	67.8	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
2	14- 1	-6.9	0.0	11.7	11.7	202.9	79.5	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
3	21- 1	-6.6	0.0	10.5	10.5	213.4	90.0	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
4	28- 1	-6.3	0.0	14.5	14.5	227.9	104.5	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
5	4- 2	-7.7	0.0	12.7	12.7	240.6	117.2	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
6	11- 2	-6.0	0.0	11.0	11.0	251.6	128.2	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
7	18- 2	-5.8	0.0	14.3	14.3	265.9	142.5	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
8	25- 2	-5.2	0.0	11.4	11.4	277.3	153.9	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
9	4- 3	-3.0	0.0	14.2	14.2	291.5	168.1	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
10	11- 3	-3.3	0.0	14.7	14.7	306.2	182.8	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
11	18- 3	-1.2	0.0	15.2	15.2	321.4	198.0	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
12	25- 3	.7	10.3	3.1	13.4	334.8	173.9	27.2	.7	.7	36.8	101.6	14.8	0.0	22.0
13	1- 4	2.3	11.3	0.0	11.3	346.1	110.4	63.5	2.2	2.2	72.6	101.6	0.0	0.0	72.6
14	8- 4	3.8	15.7	0.0	15.7	361.8	10.9	99.5	4.0	4.0	111.2	101.6	0.0	0.0	111.2
15	15- 4	5.5	13.9	0.0	13.9	375.7	0.0	10.9	6.1	6.1	18.7	101.6	0.0	0.0	18.7
16	22- 4	7.3	14.8	0.0	14.8	390.5	0.0	0.0	8.5	8.5	6.3	101.6	0.0	0.0	6.3
17	29- 4	8.2	15.4	0.0	15.4	405.9	0.0	0.0	10.7	10.7	4.7	101.6	0.0	0.0	4.7
18	6- 5	10.3	11.6	0.0	11.6	417.5	0.0	0.0	13.1	13.1	-1.5	100.1	-1.5	0.0	.0
19	13- 5	10.5	19.3	0.0	19.3	436.8	0.0	0.0	13.5	13.5	5.8	101.6	1.5	0.0	4.3
20	20- 5	12.7	20.2	0.0	20.2	457.0	0.0	0.0	17.1	17.1	3.1	101.6	0.0	0.0	3.1
21	27- 5	13.7	13.3	0.0	13.3	470.3	0.0	0.0	18.8	18.8	-5.5	96.1	-5.5	0.0	.0
22	3- 6	14.8	17.7	0.0	17.7	488.0	0.0	0.0	20.8	20.8	-3.1	93.0	-3.1	0.0	.0
23	10- 6	17.0	11.1	0.0	11.1	499.1	0.0	0.0	24.3	24.3	-13.2	79.7	-13.2	0.0	.0
24	17- 6	17.9	16.8	0.0	16.8	515.9	0.0	0.0	26.0	24.0	-9.2	72.5	-7.2	-2.0	0.0
25	24- 6	18.6	15.5	0.0	15.5	531.4	0.0	0.0	27.2	23.8	-11.7	64.2	-8.4	-3.4	0.0
26	1- 7	20.8	13.7	0.0	13.7	545.1	0.0	0.0	30.7	24.4	-17.0	53.4	-10.7	-6.3	0.0
27	8- 7	19.5	11.2	0.0	11.2	556.3	0.0	0.0	28.4	20.2	-17.2	44.4	-9.0	-8.2	0.0
28	15- 7	20.7	18.2	0.0	18.2	574.5	0.0	0.0	30.1	23.4	-11.9	39.2	-5.2	-6.7	0.0
29	22- 7	21.8	21.4	0.0	21.4	595.9	0.0	0.0	30.3	24.9	-8.9	35.8	-3.4	-5.4	0.0
30	29- 7	21.7	15.7	0.0	15.7	611.6	0.0	0.0	30.9	21.1	-15.2	30.4	-5.4	-9.9	0.0
31	5- 8	20.3	17.4	0.0	17.4	629.0	0.0	0.0	28.3	20.7	-10.9	27.1	-3.3	-7.6	0.0
32	12- 8	20.5	13.6	0.0	13.6	642.6	0.0	0.0	28.0	17.5	-14.4	23.3	-3.9	-10.6	0.0
33	19- 8	19.9	14.2	0.0	14.2	656.8	0.0	0.0	26.5	17.0	-12.3	20.5	-2.8	-9.5	0.0
34	26- 8	19.4	14.0	0.0	14.0	670.8	0.0	0.0	25.3	16.3	-11.3	18.2	-2.3	-9.0	0.0
35	2- 9	19.5	22.4	0.0	22.4	693.2	0.0	0.0	24.8	22.8	-2.4	17.8	-.4	-2.0	0.0
36	9- 9	18.0	9.1	0.0	9.1	702.3	0.0	0.0	22.1	11.4	-13.0	15.5	-2.3	-10.7	0.0
37	16- 9	16.2	15.6	0.0	15.6	717.9	0.0	0.0	19.1	16.1	-3.5	14.9	-.5	-3.0	0.0
38	23- 9	15.2	19.6	0.0	19.6	737.5	0.0	0.0	17.4	17.4	2.2	17.2	2.2	0.0	.0
39	30- 9	12.6	16.2	0.0	16.2	753.7	0.0	0.0	13.7	13.7	2.5	19.7	2.5	0.0	0.0
40	7-10	12.2	13.0	0.0	13.0	13.0	0.0	0.0	12.8	12.8	.2	19.9	.2	0.0	.0
41	14-10	11.0	12.5	0.0	12.5	25.5	0.0	0.0	11.1	11.1	1.4	21.3	1.4	0.0	.0
42	21-10	9.6	17.2	0.0	17.2	42.7	0.0	0.0	9.3	9.3	7.9	29.1	7.9	0.0	0.0
43	28-10	7.7	11.2	0.0	11.2	53.9	0.0	0.0	7.0	7.0	4.2	33.3	4.2	0.0	.0
44	4-11	6.9	12.6	0.0	12.6	66.5	0.0	0.0	6.1	6.1	6.5	39.8	6.5	0.0	0.0
45	11-11	4.7	15.1	0.0	15.1	81.6	0.0	0.0	3.8	3.8	11.3	51.1	11.3	0.0	.0
46	18-11	3.9	13.1	0.0	13.1	94.7	0.0	0.0	3.0	3.0	10.1	61.2	10.1	0.0	.0
47	25-11	2.2	15.7	0.0	15.7	110.4	0.0	0.0	1.6	1.6	14.1	75.3	14.1	0.0	.0
48	2-12	-.6	3.4	8.4	11.8	122.2	0.0	8.4	.2	.2	11.6	86.8	11.6	0.0	.0
49	9-12	-.4	0.0	14.5	14.5	136.7	14.5	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
50	16-12	-3.7	0.0	12.6	12.6	149.3	27.1	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
51	23-12	-4.8	0.0	13.9	13.9	163.2	41.0	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
52	30-12	-5.3	0.0	13.8	13.8	177.0	54.8	0.0	0.0	0.0	0.0	86.8	0.0	0.0	0.0
	TOTALS	7.6	543.0	209.5	752.5			209.5	603.7	509.6	148.8			-94.2	242.



Global Environmental Monitoring System: World Inventory of Snow and Ice Masses

The world inventory of perennial snow and ice masses is part of the Global Environmental Monitoring System (GEMS). In that there are large glacierized areas of the earth's surface for which there are few, if any, climatic records, glaciers can provide a means for monitoring the climate in these areas. Trend surface analysis of existing data sets, for Switzerland and the Soviet Union, has shown up many elements of the mountain climate system not apparent from weather station or macro-scale analysis. Following are brief accounts of Russian and Swiss applications (Appendix 1 and 2).

The Canadian snow and ice inventory program could be a useful element in a national climate program and should not be overlooked in climate program discussions. Further information on the Canadian snow and ice inventory program may be obtained from:

Mr. C. Simon L. Ommanney
Head, Perennial Snow and Ice Section
Snow and Ice Division
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K1A OE7

Appendix 1

Problems and Results of Studies of Mountain Glaciers in the Soviet Union

A Summary

Results of studies of mountain glaciers' surface regime, undertaken in the USSR for the last 15 years, are shown in the paper. Observational data of the IGY ,IHD and IHP are broadly used, while the Catalogue of Glaciers of the USSR provides the basic information. The Catalogue comprises 110 issues. About 70% of it has been already published and the rest of the issues have been accomplished by now. According to the Catalogue, glaciers of the USSR occupy the area of about 78,000 km^2, the quota of mountain glaciers makes up over 22,000 km^2. The general number of mountain glaciers, with the area over 0.1 km^2, is about 24,500. Mountain glaciers of the USSR contain about 2600 km^3 of ice which accumulate about 2250 km^3 of water.

Morphological classification of mountain glaciers, adopted in the Catalogue of Glaciers of the USSR and its correspondence to the further simplified classification, used in the World Atlas of Snow and Ice Resources, is explained. Methods, determining the firn line height, are considered. The data on the firn line (identified with accumulation line), are held in the Catalogue of Glaciers of the USSR. The Kurovsky method was proven the best of all known indirect methods for determining the firn line at the present stage of a certain retreat of mountain glaciers. To my mind, the Hess method is applicable to glaciers close to stability.

Glaciers coefficient, i.e. relation of the accumulation area to the ablation area, is compared for the glaciers of the Caucasus and Alps. The value of this coefficient for the studied Alpine glaciers equalled three in the last century, while at present it does not exceed two as a rule. For the majority of Caucasian glaciers the glacier coefficient varies from one to two. On a small Marukh Glacier K=1 and mass balance is near 0. In the Central Caucasus, the value of K on the glaciers of southern slope is two times higher than the values of the same index on the northern slope: 2.4 and 1.2 respectively. It may be connected to more ample precipitation on the southern slope and, consequently, smaller contribution of concentration precipitation to glacier nourishment.

To estimate the latter process, we have to introduce a concentration coefficient, representing the relation of the mean snow storage on a glacier to the annual total of precipitation at the height of the accumulation line. It equals 1.5 for valley glaciers and 3-4 for corrie glaciers.

The Catalogue of Glaciers has stimulated the development of a glaciological method, calculating precipitation in the alpine area, based on the concepts of Ahlmann and further developed by A.N. Krenke and V.G. Khodakov. The method proceeds from the equality of accumulation and ablation on the accumulation line. A special formula for the calculation of total melting according to the mean temperature of ablation season has been introduced. The temperature at the height of accumulation line is obtained by

way of extrapolating it from the level of the nearest weather station. The cooling of 1-2^{o} on a glacier as compared to rocky surface is taken into account.

Having calculated the total value of melting, which equals accumulation at the height of accumulation line, we proceed to precipitation by way of dividing the obtained value by the concentration coefficient of snow on a glacier. We can thus obtain quite a detailed picture of precipitation in the alpine area, due to the data on thousands of glaciers. Such calculations have been performed for the whole territory of the USSSR in a small scale and in a more detail for the Caucasus and Pamirs.

The amount of precipitation, especially solid; is revealed to be much higher in the mountains than in the abutting plains and piedmonts. The precipitation maximum of Eurasia, exceeding 300 mm, coincides with Scandinavia and Alaska; the same water content is registered in N-W margins of the Caucasus, Pamirs, Tien-Shan and Altay.

The data of the Catalogue of Glaciers of the USSR and the above mentioned method permitted to prepare for the Pamirs and Caucasus maps of the height of accumulation line, air temperature in summer and of precipitation at this height. They made it possible to determine the direction of the main moisture flows in the mountains, to reveal their stream-like nature, occurrence of atmophseric waves in front and behind orographic obstacles, and other meso-scale regularities, which cause complex a field of precipitation and are reflected in glaciers' morphology and position.

In the Pamirs, where over 10,000 glaciers with the general area of 9170 km^{2} are situated, we have revealed ten-fold decrease of precipitation in the alpine area, from 3500 mm in the North-western periphery to 300-500 mm in the arid East Pamirs. The altitudinal maximum of precipitation has not been revealed - even at the height of 6000 m a.s.l. accumulation exceeds 1000 mm/y.

In conclusion, the problem of compiling the Catalogue of Surging Glaciers, the use of aerial photography and space images for this purpose, is considered. The features of surging glaciers, used for interpretation of images, are enumerated. Guidelines for the compilation of this catalogue are now worked out in the USSR.

V.M.Kotlyakov

Appendix 2

Inventory of Permanent Snow and Ice: Switzerland

A Summary*

Introduction

The present development of population, industry and agriculture is accompanied by an ever increasing demand of water. For example, over the last 25 years the water consumption of the city of Zurich has doubled. Water also plays an important part in electricity generation. In the 1972/73 hydrological year, hydro-electric stations provided 64% of the electric power consumed in Switzerland. During the winter half-year 1972/73, 24% of the electricity used in the whole of Switzerland was provided by reservoirs that collect glacier meltwater.

Some 80% of the earth's fresh water reserves are in the form of snow and ice. Although only 3% of this permanent snow and ice is situated outside Antarctica and Greenland, this relatively small amount is of great importance because of its proximity to populated areas, important not only as a source of water and power but also in its connection to climate and tourism. It is, therefore, essential to make a detailed account of the present status of the permanent firn and ice masses. The inventory for Switzerland is presented here. This work is an outcome of the International Hydrological Decade (IHD), 1965-1974, during which an attempt was made to assess the amount and distribution of water in all forms. In this context, glacier ice should not be regarded as an artificially tappable reserve but rather as a source of water which continues to flow during dry summers too.

An inventory of all firn and ice masses in Switzerland contributes towards the study of the relatinship between glacier and climate and will also prove important in connection with the international programme of research into climatic change. A further application lies in providing ready criteria for the selection of individual glaciers for special studies.

Area of Study

The Swiss Alps include the source region of the two great European rivers - the Rhine and the Rhône. The meltwaters of the glaciers in the east and south flow into the Danube and the Po river systems. The west - east trough of the Rhône - Rhine valleys divides the Swiss Alps into the Berner-, Urner- and Glarneralpen in the north, and into the Walliser-, Tessiner-, and Bündneralpen in the south. The largest coherent ice masses occur in the regions with highest peaks, such as the Walliseralpen, Berneralpen and the Bernina Group. The imposing valley glaciers are confined to these areas. Numerous smaller individual glaciers and firn fields of many various shapes are spread over the remaining areas with generally lower peaks.

The distribution of precipitation in the Swiss Alps is closely related to the topography. In general, there is an increase of precipitation quantities with altitude. The large east - west valleys receive least precipitation as they are sheltered towards the north and the south. The main valley of the Valais has the smallest amount, i.e. about 50 cm/year. High altitude glacierized areas have up to 400 cm/year (Jungfrau region). The weather in Switzerland is dominated by west to northwest winds, thus generally the north side is the windward and the south side the leeward. In spring and autumn the situation is sometimes reversed. The two sides of the Alps are distinguished by different precipitation characteristics, on the north the frequency is greater but the annual amount is less than in the south where individual events have higher intensity. The precipitation maximum occurs on the north side during the summer, as in the rest of Central Europe, but in spring and autumn on the south side, as in northern Italy. The northern side of the Alps shows a smaller annual variation in temperature than the southern side.

Description of Work Procedure

This report embraces all surface firn and ice masses in Switzerland with a minimal area of one hectare. In the autumn of 1973 all the glaciers of Switzerland were photographed from the air. Thus it was also possible to determine the position of the firn line, i.e. the highest position of the transient snow line. Using the photographs the extents of the glaciers showed on the maps could be corrected to a uniform time. The corrected map sheets at scales 1:25,000 and 1:50,000, respectively, were then used as basis for measurements.

Discussion of Parameters

With minor exceptions the recommendations of the Unesco guidelines were followed. Furthermore, moraine type, mean glacier elevation and mean length were added. The mean glacier elevation serves for comparison with similar data from the turn of the century.

During the summer 1973, the glaciers in several areas were periodically photographed by mountain hut guardians to establish the highest position of the transient snow line - and thus the best date for the aerial photography. On the flying date, practicallly all the glacierized areas showed minimum snow cover. For information about tongue activity data are partly available from the observation network of the Swiss Glacier Commission.

The volume and mean ice thickness are known for only a few glaciers in the Alps and in most cases ice thickness for the tongue area only has been published. The total volume of these glaciers was calculated by the interpolation method of Bruckl from the partial data available. Where little or no measurements were available the glacier volume was obtained from a statistical relationship between glacier area F and mean ice thickness H. For glaciers smaller than 0.5 km^2 an ice thickness of 5 m was assumed, whilst that of glaciers larger than 23 km^2 was assessed individually.

Analysis of Individual Parameters

Firn Line 1973

The cumulative climatic effect of several years is reflected in the mean altitude of the equilibrium line of a glacier. The equilibrium line and

*Ed. note: this is an editorialized summary; references and diagrams have been deleted.

firn line are almost identical for temperate glaciers. The glacier balance year 1972/73 was not an extreme year although the height of the firn line, the temperature and the precipitation were somewhat above normal. It seems reasonable, therefore, to use the 1973 firn line as a key for investigating the glacier - climate relationship.

The mean firn line altitude, computed as the arithmetic mean of the 670 values observed, was 3015 m a.s.l. The standard deviation of 239 m indicates considerable spatial fluctuations, due to, among other things, geographic location within Switzerland and exposition. The firn line - location relationship accounts for an obviously higher proportion of the variance than does the firn line - exposition relationship. Polynomial trend surfaces were used to depict the large-scale variations of the firn line within Switzerland. Treatment of all the 670 firn line values as one set yielded unsatisfactory results and consequently a division into five regions with individual trends was made. In general, the firn line elevation decreases with increasing distance from centres of strong glacierization. A first order trend surface shows a tendency to rise from north to south. The firn line increases also from west to east. Large local deviations from the trend are shown mainly by small glaciers and firn patches because of their special nature resulting from the combined influence of exposition and peculiar accumulation. Regional deviations can also be partly explained in terms of these two factors.

Mean Glacier Elevation

Jegerlehner in 1902 attempted to show the course of the climatic snow line in the Swiss Alps on a map of equal snow line elevations, "Isochionenkarte". He determined the height of the snow line in such a way that the ratio of accumulation area to ablation area was 1:1. The mean glacier elevation for 1973 is based upon the same definition. An attempt was made to discover evidence of a change in climatic conditions by comparing the Jegerlehner map with a trend surface for the mean glacier elevation for 1973. The 1973 mean glacier elevations are on average only 10-20 m higher. This amazingly small difference becomes, however, less significant on account of methodological shortcomings of the comparison. In areas without larger glaciers Jegerlehner used the summit-method to determine the climatic snow line. In addition, he partly took account of glaciers outside of Switzerland. On the other hand, the trend of the mean glacier elevation for 1973, established using a 6th order polynomial, is unreliable for the edges of the glacierized areas.

Accumulation Area Ratio (AAR)

The average of the 483 AAR values measured in the Swiss Alps is 40. This value corresponds to a mean firn line elevation of 3100 m a.s.l. For glaciers in equilibrium with an AAR value of 66 the corresponding firn line would be 270 m lower. Hence the mass balance for 1972/73 was strongly negative. However, the balance year 1972/73 was not essentially different from the 1962-1973 average. Consequently, all Swiss glaciers were during these 12 years subject to climatic conditions which would result in negative mass balances. Because the 1973 value of 40 may be a slight underestimate, the method of Richter (AAR = .50) gives a reliable approximation for the present period of time. On account of this the mean glacier elevation is useful for the study of the glacier - climate relationship.

A small variation in the firn line elevation causes a large change in the accumulation area. The AAR value, therefore, is a highly sensitive gauge of mass balance fluctuations. Since it is moreover less dependent upon local influences such as glacier size, exposition and regional location, it is a better climatic indicator than the firn line.

Change of Glacierization, Glacier Types and Superlatives of Glaciers

The glacierized area of Switzerland has been reduced during this century by 475 km^2 (26%) to 1342.15 km^2, which still constitutes about 3% of the total area of Switzerland. The shrinkage is smaller in areas of strong glacierization than in less glacierized regions. The frequency distribution of glacier types shows that it is not the valley glacier (3%) but rather the mountain glacier (42%) which constitutes the typical glacier of the Alps. In addition, the total area of the mountain glaciers (42%) is close to that of the valley glaciers (48%). The mean thickness of all firn and ice masses in Switzerland amounts to about 50 m.

WORKING GROUP REPORTS

Canadian Climate Program - Water Resources Workshop
Working Group 1.1 - Climate and Its Impact on Large River Developments: Planning and Design

In attendance at the working group session on February 28, 1980:

Chairman:	Hal Coulson	
Rapporteur:	John Power	
Participants:	J. Jasper	W.D. Hogg
	A.R. Waroway	K.G. Brittain
	R. Marsh	A. Coulson
	V. Klemes	P. Hansen
	L.B. Davies	C. Pesant

1. Introduction

There were two position papers presented, one by L. Davies of B.C. Hydro and the other by J. Power of Environment Canada. Copies of these are attached to this report.

2. General Discussion

A number of points were brought out in the course of the discussion leading up to the formulation of the recommendations. These points are summarized below.

- when designing structures, one must determine probable maximum floods using climatic data such as maximum values of temperature, precipitation, and thus snowmelt.

- B.C. Hydro is currently developing hydrometeorlogical networks to assess the probability of floods during construction of diversion facilities. This saves money wasted on possible overdesign of these facilities.

- one must decide on what acuracy of design flow is required before asking what accuracy of climatic information is needed.

- how do we make good estimates of parameters of the distribution of flow which will be in effect in 20 years when a design project comes into operation?

- there is very little instrumentation in mountainous watersheds (e.g. Bow River) for use in developing PMF's. Alberta has started increasing its own hydromet data networks, since this represents regional interests.

- AES has the mandate to collect data in transition zones, but realistically, doesn't have the money or the manpower.

- some basins should be very well instrumented and the results may be extrapolated over larger areas based on the physics of the situation.

- a desired objective should be to supplement the present climate network based on specific user needs relating to future projects.

- a list could be made to indicate to what use any additional climatic data would be put, both now and in the future. For example, the sensitivity of the hydrologic model used in the St. John basin has been determined to allow answering of the question of what accuracy of input met parameters is required for a given accuracy of flood forecasting. If the hydromet network is sufficient for use in flood forecasting model, it is probably sufficient for use in other studies. In the course of the WMO-WWW study on the St. John basin, particular data gaps in the network were identified.

- large river project designsin Quebec are in remote regions. The surface water network is usually much better than the meteorological network. There is a great need to improve the latter.

- what climatic information do we need to estimate extreme events, regardless of the hydrologic method used (e.g. flood frequency, conceptual modelling of the energy budget). It should be kept in mind that correlations valid for medium floods may not be valid for extreme floods.

- should not aim for an overall national network up to WMO standards. Should increase data coverage in specific areas known to be of interest.

- there is a great need simply to know long term average flows. One should separate the need for more data from the need for better models.

- there is a need for better areal information on temperature and precipitation for input to hydrologic models.

- one must have recording stations in the various climatic zones before one can test any physical models describing transition from one zone to another. It is best to have small scale heavily instrumented regions to develop and test physical models.

- climatologists should come up with various possible alternatives of storm patterns, fronts, etc. Then hydrologists could come up with functions to transfer these into design hydrographs. This is obviously a very difficult problem.

- wind speed and direction data is required for reservoir design. This type of data is very site specific and should be collected on site.

- hydro utilities must now perform detailed environmental impact studies. These require much more climatological information.

3. Recommendations

The following recommendations were agreed upon:

1. There should be more studies of the spatial variation of climatic data especially the spatial variation of extreme value data.

2. More research is required into remote sensing methods, including satellites and radar, for determining areal distribution of climatic variables.

3. Climate program planners should be made aware of long term plans for water resource projects, to help them plan future expansion of their climatic network.

4. The technology for automatic data collection systems for use in remote regions should be improved.

Discussion: Increased attention must be given to archiving and retrieval of such data.

5. Climatological networks are required on two scales: a) a broad national base network; and, b) intensive short term networks to solve specific problems, for example, environmental impact assessments.

Discussion: We should keep in mind that some large projects may have significant environmental and possibly climatic impacts, which should be considered at the planning stage.

6. Studies regarding climatic change should be carried out and should be related to the lifespan of any future water resource project.

7. Studies should be conducted to improve climatic models. More knowledge is needed to develop improved hydrologic models to better transfer climatic information into streamflow information

Attachment 1

B.C. Hydro & Power Authority's Needs for Climatological Data

Development Department, Hydroelectric Design Division
Engineering Group

General

The Development Deparment of B.C. Hydro has the responsibility of planning for the development of entire river basins or of single sites on rivers in order to meet the forecast needs for electrical energy for the Province. In this capacity, it is required as far as possible to schedule the planning and development of sites on rivers at least 20 years in advance of the forecast demand. The Department also makes studies to assess the safety of existing projects and to plan the rehabilitation or redevelopment of certain projects.

Specific Needs for Climatological Data

a) Realistic estimates of the amount and costs of hydroelectric energy available from proposed developments can be made only if there is at least a 30- to 40- year record of streamflow, according to WMO* standards. For rivers where there are not streamflow records of that length, but where climatological records cover a 30- to 40- year period, it is often possible to extend the streamflow records by statistical methods or by the use of a computer model of the basin using the climatological records as input data.

b) Safe operation of existing and proposed spillways at dam sites is predicated on the evaluation of probable maximum floods (PMF's) originating from the catchment areas above the sites. PMF studies are now routinely done with the use of calibrated computer basin models which stimulate the natural hydrological processes whereby rainfall and or snowmelt inputs are converted to streamflow output. Calibration of such models requires the reconstruction of a number of historic hydrographs of main stem and tributary streamflow stations from simultaneous daily rainfall and snowmelt amounts. Since snowmelt is not a measured amount in climatological practice, it is evaluated from daily temperature, solar radiation, wind speed, and evaporation measurements. PMF estimates are made with the calibrated models, using maximized values of precipitation and snowmelt derived from a study of historic records of temperature, precipitation, and radiation, for climatological stations within and surrounding the basin, and from historic storm depth-area-duration curves.

It is thus apparent that reliable estimates of PMF's for projects in a river basin can be made only if there are climatological records from all representative sub-basins in the basin for a period of sufficient length to include both high and low runoff conditions, generally not less than four or five years.

*World Meteorlogical Organization - Guide to Hydrometeorological Practices, p. III-2.

c) In recent years, B.C. Hydro has established climatological networks in catchment areas upstream from proposed projects in order to make possible short-term forecasting of snowmelt and rainfall runoff with a view to reducing the size or diversion channels and tunnels. Data from such networks is scheduled to be transmitted by satellite or microwave telemetry, and used in a computer model of the basin in order to provide short-term forecasts of possible flood runoffs which might occur during the two- or three-year period of operation of diversion tunnels. With such forecasts, it is thought that timely protective measures could be implemented to prevent damage to coffer dams and enclosed structures. The saving in cost effected by reducing the size of a concrete-lined tunnel or channel, for which there is a low probability of its being used at full capacity during its 2- or 3-year life, is much greater than the combined cost of implementing such protective measures as raising coffer dams and of establishing and operating real-time climatological networks.

d) Climatological Data Needs for the Assessment of the Safety of Existing Dams. For the assessment of the safety of existing dams, preliminary estimates of spillway design floods are being made for projects throughout the Province. Later, more detailed hydrometeorlogical analyses will be made to estimate PMF's or Standard Project Floods for most of the existing projects. This will require an adequate coverage of daily precipitation and temperature data for the estimation of Probable Maximum Precipitation and for the calibration and testing of a computer basin model as outlined in Section (b) above.

e) Climatological Data Needs For Environmental Studies. For environmental impact studies of proposed hydroelectric and thermal projects, climatological data such as temperature, precipitation, rainfall intensity, snow depths, wind direction and speed, and evaporation are needed. However, some of these data are required for a few years only, and often at locations where such data are not normally needed for other purposes; for example, snow depths might be needed at low elevations to assess wildlife winter habitat, or wind speeds and directions might be needed at a proposed thermal station to study cooling tower plumes or stack emissions.

Climatological Station Data Used by B.C. Hydro

a) Long-Range Power Potential and PMF Studies

For river basins where long-range planning studies involving hydroelectric power potential and probable maximum flood (PMF) estimates have been or are scheduled to be carried out - such as the Peace, Columbia, Stikine-Iskit, Liard and Homathko basins - climatological station data used for preliminary studies have been those from existing and historic AES stations. However, as the basins scheduled for study have generally been in remote mountainous areas, the AES station coverage has been generally sparse, particularly as most stations have been situated in valley bottoms, with the major portions of the mountainous catchments entirely unrepresented. For the Peace and Columbia studies in the early 1960's, B.C. Hydro attempted to establish additional climatological stations in the few locations where reliable observers were available. Long-range power potential estimates had to be based on extremely short periods of streamflow record supplemented by estimates based on correlations with records of adjacent streams, since virtually no climatological records were available for either basin for improving the correlatons. Since the power units installed on the two rivers have been selected on the basis of these long-term estimates, the ultimate hydraulic efficiency of the system is largely dependent on these estimates.

The PMF estimates for both the Peace and Columbia basins were made using computer models of the basins with hydrologic inputs obtained from the few climatological stations within the basins. The models were calibrated from historic streamflow records and PMF estimates made from AES estimates of critical meteorlogical conditions introduced into the calibrated models. The Comptroller of Water Rights of the Province of British Columbia was unwilling to accept the preliminary PMF estimate for the Peace River basin because he felt that it was based on inadequate climatological data, and insisted on a last-minute increase in the spillway size because of the alleged unreliability of the estimated PMF, at considerable additional cost to B.C. Hydro.

For studies undertaken in the late 1970's - Stikine-Iskut, Liard, Homathko - the necessity of increasing the climatological data coverage in those basins has been recognized, and attempts have been made to plan for the installation of automatic climatological stations at representative locations in the basins. This planning has unfortunately coincided with stringent budget restrictions imposed on both Federal and Provincial data collection agencies. Active cooperation with those agencies by B.C. Hydro has resulted in plans for the establishment of networks of climatological stations (as well as streamflow stations and snow courses). For the Stikine-Iskut basin where planning is at the most advanced stage, the planned climatological network would consist of the following:

1. 6 existing AES stations with paid or volunteer observers, all in valley-bottom locations.

2. 13 automatic recording stations, at representative locations in each of the major component sub-basins with air temperature, wind and solar radiation instruments to be supplied by the Resource Analysis Branch (RAB) of the Provincial Ministry of the Environment, recording rain gauges to be supplied by RAB and by the federal Atmospheric Environment Service (AES). B.C. Hydro is scheduled to pay costs of installation, and of annual operation.

b) <u>Assessment of the Safety of Existing Dams</u>

Preliminary assessments of spillway design floods for existing dams are being made, using streamflow data and empirical methods or in some cases using climatological data from B.C. Hydro and AES stations to estimate the probable maximum precipitation which is then transformed into a design flood.

For future detailed review or analysis of PMF's or Standard Project Floods (SPF's) for existing projects, it is hoped that additional climatological stations will be installed in critical basins. Some of the data requirements for PMF and SPF studies may be met by the proposed upgrading of the operations; hydrometeorological network as outlined in the following submission by Mr. Sporns.

L.B. Davies

Attachment 2

High Elevation Meteorological Stations

G.J. Young and J.M. Power
National Hydrology Research Institute
Ottawa, Ontario

There are very few permanent meteorological stations at high elevation (i.e. at mountain-top level) within the alpine areas of Alberta, British Columbia and Yukon. Many users have need for information from such locations both for short-term operational purposes and for establishing long-term climatic trends.

The need for high elevation stations and the practicality of establishing a monitoring network should be discussed at the Workshop. Following are some notes suggesting some user interests in the area of the Continental Divide. These notes are not comprehensive and areincluded only to serve as a basis for discussion.

High Elevation Meteorological Stations: Continental Divide

Agencies Interested	Nature of Interest
A.E.S.	Lack of high level information; correlation with radiosonde Hydromet. interest. Mountain climate studies
Alberta Environment	Streamflow forecasting (a) volumes (b) floods
I.W.D.	Streamflow modelling (a) snowmelt modelling (b) glacier contribution Avalanche research
B.C.	Streamflow forecasting
Calgary Power	Streamflow forecasting
Parks Canada	(a) interpretation for public on the spot (b) safety (i) Avalanches (ii) Skiing conditions (iii) Helicopter - mountain rescue

Main Considerations

1. Must be rugged - to withstand high winds/rime
2. Must be a proven system - not experimental
3. Must need no maintenance for months at a time.

Types of Location

1. At or near mountain top level, i.e. 10000'
2. Minimum of local influences so as to be as representative as possible
3. Must be suitable for helicopter landing
4. Existing facilities must be considered; e.g. Sunshine Village site; sites of radio repeater statons, e.g. Mt.Stephen sites of seismic installations in B.C. around Mica.

Number of Locations

1. Best to think of an eventual network of perhaps A to B stations stretching along continental divide from Waterton to north of Jasper. Is there use in thinking of E.W. transects from coast inland?
2. Suggest an initial two stations, in Lake Louise area and in Columbia Icefield area.

Sensors

Wind speed; (over an hour) gustiness
Wind direction (over an hour)
Barometric pressure (instantaneous)
Air temperature (over an hour)
Relative humidity (over an hour)
Precipitation (totalizing) are precipitation measurements worthwhile on mountain top?
Additional sensors; radiation sensors; sunshine duration

Transmission/Recording

Complete record of hourly information must be stored
Information for last hour must be automatically transmitted and available on command
V.H.F. has some advantages over GOES for real time information and repair work
Information should be compatible with other systems, e.g. CRONMS in Columbia
Display of information for local users
Transmission of information to more distant users.

Canadian Climate Program - Water Resources Workshop
Working Group 1.2 - Climate and Its Impact on Small Stream Developments: Planning and Design

In attendance at the working group session on February 28, 1980:

Chairman:	Keith Lathem	
Rapporteur:	D. Garry Schaefer	
Participants:	G. Young	M. Orecklin
	J. Whiting	A. Warkentin
	A. Davis	S. Kirby
	J. Peters	J. Card
	P. Staite	G. Holecek
	N. Lyons	R. Humphries
	O. Sigvaldason	D. Graham

1. Introduction

Following a brief description of its task by the chairman, the working group first turned its attention to a definition of small streams and then to a consideration of the types of projects and other purposes for which data are required. This was followed by discussion of the most relevant climatic variables, leading naturally to considerations of network requirements, data availability, research needs and institutional relationships. Finally, recommendations were developed in the context of a review of the key points covered during the session.

2. Definition and Purposes

Small streams were considered by some to include everything other than the few largest river and lake systems in the country; others suggested including only watersheds of less than 500 square miles. While this difference could not be resolved, the group concluded that since specific needs would be dealt with individually, the exact definition of watershed size was not critical.

Data are needed for the planning and design of a myriad of projects on small streams. A sample from those listed includes storm sewers, bridges and culverts, water reservoirs, effluent disposal ponds, irrigation and reclamation projects, small hydro-electric projects, developments related to fisheries, wildlife and recreation, water diversions, projects affecting ponds, lakes and sloughs and linear developments affecting streams (i.e. pipelines and transmission corridors). The need for data to carry out environmental impact assessment was identified in addition to the needs for engineering design.

3. Significant Climatic Variables

Rainfall, including both its temporal and spatial distribution, was considered to be the most significant climatological variable in the context of the planning and design of small stream developments. Snowfall and, in particular, its water equivalent, accumulation, ablation and melt, were closely associated. The need is most frequently related to the reconstitution or simulation of streamflow values, which is of primary significance to design and planning. It is generally the case that precipitation data are more readily available over a greater duration than are streamflow data.

Temperature, wind, humidity, radiation, evaporation and icing were generally considered to be of secondary significance when compared to precipitation, although some are of major value in simulating streamflow or for other purposes in specific projects.

4. Data Requirements and Network Planning

The group recognized the need to consider the degree of climatological variability and the nature of hydrological characteristics when assessing network needs in particular areas. The necessity to ensure input from the relevant agencies and user groups on a regional basis was stressed as was the requirement to ascertain intended data uses as preconditions to the development of network plans.

Network requirements for the measurement of precipitation vary markedly from case to case. Space and time scales must be related. In general, daily and monthly data are most used, particularly in rural areas but there is a growing requirement for hourly or more frequent sampling for model input in smaller watersheds, particularly in urban areas concerned with convective storms. In watersheds with pronounced retention by lakes, intensities over short durations are not normally required; in flashy streams the opposite is true. A combination of high resolution radar and satellite data with long term information from selected benchmark stations was suggested as an alternative to the continued operation of large numbers of traditional stations. In general, the Atmospheric Environment Service strives for 30-year normals from climatological stations. Selected longer-term benchmark stations are needed to assess variability and change. At least ten years of data are required from rainfall intensity stations before one can begin to adequately assess short duration rainfall statistics. Longer data series enable better estimates of severe events (PMP) to be made.

Networks were felt to be inadequate in many instances, particularly in sparsely populated, remote and northern regions. In some provinces, resource management requirements have led to the development of provincial networks to augment the national climatological network. In some urban areas, municipal governments have augmented rainfall intensity networks for storm-water management purposes. Efforts should be made to insure the compatibility of standards in these various networks; the suggestion was made that the CCC act as lead agency in the promulgation of the required manuals. It was recognized that the ability to monitor events in real time and to issue short term forecasts (i.e., as with radar in urban areas) has a significant bearing on network requirements even at the planning and design stage. Although it is difficult, if not impossible, to put a dollar value on data for design purposes, it was recognized that value often increases as time goes on due at least in part to unexpected new uses. Methodologies do exist whereby the expected costs and benefits can be related to an evaluation of the desirability of continuing the operation of network stations.

The value of and requirement for snow course data were seen to vary across the country. In general, it was felt that designers could and should make more use of snow data. Currently both depth and water equivalent values are used particularly in volume forecasts and in probable maximum flood calculations. In some prairie regions, winter precipitation may provide a better estimator of spring runoff than snow course data although in southern Alberta and southwestern Saskatchewan sublimation losses require direct snowpack measurements. Orientation of courses with respect to local terrain features is a significant concern. In mountainous areas, snow courses are required to properly assess the water equivalent of the snowpack at representative elevations. Little direct information is available on snowpack ablation even though it is a significant quantity in areas such as the southwestern prairies. Snow pillows may provide some indirect evidence of ablation rates when combined with other data.

Requirements for temperature data related to streamflow simulation in flat country are reasonably well met, at least in southern Canada, by existing daily and hourly stations; in mountainous terrain there is a lack of the higher elevation data needed to establish lapse rates for watershed models. Concern was expressed that the use of daily maximum and minimum temperatures to compute daily means for degree-day indices would lead to error, particularly in the north. The use of regional correction factors based on the hourly weather network was suggested. The general lack of ground surface temperatures (as compared to values at the height of the Stevenson screen) was noted. New microprocessor technology was cited as an approach that could be used to obtain specific and/or integrated temperature values.

Evaporation data needs were seen to be related to the climatic region involved. Although the overall variability of evaporation is lower than, for example, that of precipitation, the need for measurements is considered to be greater in areas where evaporation far exceeds evapotranspiration and where irrigation is required (i.e. southern Alberta). In order to better understand the evaporation data provided, it was thought that more use should be made of additional variables such as wind, humidity and radiation. These variables often also have direct applicability as, for example, in the use of wind data in the siting of sewage lagoons or in the assessment of shoreline erosion.

New data requirements arising from the need to carry out environmental impact assessments include more widespread sampling of precipitation chemistry (e.g., an expansion of CANSAP) and more readily available information on upper winds and storm tracks to assess the potential acid rain impacts of individual sources on small watersheds. Proxy data was seen as one way to evaluate the current situation in the context of longer term trends and fluctuations.

5. Data Management, Climatological Analyses and Research

It was clear that the working group looked to the Canadian Climate Centre as a focal point in the areas of data management and climatological analyses. There was agreement that the CCC should promulgate standards and procedures for the collection, processing and publishing of climatological data. There was a desire for one-stop shopping in the form of a national archive of all climatological data, including that collected by other agencies, with standardization where possible and flagging where it is not. In practical terms it was agreed that the existing data should at least be catalogued by the CCC with an indication of how it may be retrieved. The general desire was for the data to be placed in an on-line, telephone-terminal accessible and simply coded format that would allow all users ready access to the archive. Such technology is now the state-of-the-art for numerous large data bases. The possibility of future computer-to-computer linkages with provincial or regional archives held in various parts of the country, was raised. In this way, adequate access might be provided closer to the user.

In many instances what is required is not more data but a more thorough analysis of existing data. There was some concern that statistical studies often do not improve understanding. More in-depth analyses of climatically induced hydrologic events are required (e.g., storms and floods). The potential role of remote sensing data in climatological studies was recognized as was the concern that much of it is not being archived and hence is being lost to future use.

The need was expressed for the CCC to assume a clearinghouse role for research problems. Some of the research would be done in-house; other projects would be forwarded to universities or other agencies. There was concern that the subvention program be expanded to provide support for a broader spectrum of researchers and projects. In terms of subject areas, the working group identified needs with respect to the evaporation process, snowpack ablation, storms and data collection technology.

The need to continue the dialogue opened between hydrologists and climatologists was stressed by all. In some cases, climatologists have been trying to provide answers to questions only imperfectly understood while the problems of the hydrologist have not been clearly put to the climatologist. In general, it is clear that the CCC must market the information to be applied by the user, but guidelines as to appropriate levels of market promotion are not always available. The transfer of technology to practicing hydrologists and climatologists continues to be a difficult problem. Short courses and workshops oriented toward the non-specialist were viewed as useful although problems will remain when trying to apply the more complex models and study findings.

6. Recommendations

1. The density and sample frequency of precipitation networks should be evaluated in relation to user needs and hydrologic basin classification.

2. The CCC should be responsible for coordinating the collection and cataloguing of all climatological data for Canada, including data collection by other agencies, and should make it available in a readily usable form.

3. Effort should be made to increase the amount of informaton suitable for the determination of evaporation and snow accumulation and ablation.

4. There should be an increase in the archiving and use of radar and satellite data in urban and surrounding areas.

5. The CCC should increase its efforts in improving the transfer of knowledge gained from research to planners and designers.

6. The CCC should play a lead role in assisting other agencies in standardization through recommendations with regard to sensors, maintenance programs, calibration and the formating and publishing of data.

7. There should be increased research activity by climatologists in small basins to develop a more fundamental understanding of climatic processes including the probabilities of the rainfall events which induce significant hydrologic events (storms).

Canadian Climate Program - Water Resources Workshop
Working Group 1.3 - Proxy Climatic Data and Their Implications for Planning and Design

In attendance at the working group session on February 28, 1980:

Chairman:	John M. Powell	
Rapporteur:	W.E. Lowe	
Participants:	J.D. Campbell	W.F. Warwick
	M.A. Church	G.S. Strong
	L.D. Delorme	M.K. Thomas
	G. Holdsworth	J. Honsaker

1. Introduction

The discussion opened by consideration of the fact that there is an increasing need to produce proxy data (especially of the quantitative kind) to extend the historical climate base and that present climatological services (such as AES) will not provide proxy data. A suggested function of the Canadian Climate Program was for them to take the initiative to develop or coordinate a group which can provide climatological proxy data. However, there has been no definitive support, to date, for this suggestion. Currently there are a number of isolated groups within various sectors which produce some aspects of this type of information but, because of their responsibilities to respond to other mandates or objectives, or because of inadequate dollars and man-year support, they cannot devote their full time to collection of paleoenvironmental data.

2. Recommendations

a) Research should be directed towards increasing our ability to extend the historical climate base through collection and analysis of proxy data.

The primary sources of quantitative proxy data currently available were identified. These include: dendrochronology, lake cores (palynology, entomology, shelled invertebrates, sedimentology) ice cores and glaciology, speleothems, archeological evidence and the historical written record. Using this expertise informatoin relevant to climate and climate change could be obtained for up to 10,000 years BP. The resolution (time intervals) could be as fine as one year (tree rings and ice cores) and 5-10 years using sedimentology. Particular limits should not be set but will arise from the techniques used. Where possible, various techniques should be employed to help verify the resolution of the techniques.

The role of the CCP and especially the Canadian Climte Centre was discussed in the collection of proxy climate data. It was clearly identified that the Centre itself would not have the resources necessary to provide expertise in all areas; rather, expertise would be that currently residing elsewhere (in the government, academic and private sector) with resources being channeled through the CCP. The Canadian Climte Program would then act as an instigator and coordinator rather than a controller. The CCC would not assume an operational role but, because of the highly specialized techniques (most being successfully used elsewhere in Canada) which can be used for the determination of proxy climate data and which cannot be centralized, its mandate should be to initiate and encourage new research and to centralize and/or archive these and the results. Some depositories currently exist for ice cores, marine and sediment samples, etc. There is a need to go to one central office in Canada, for Canadian data, which can identify where such sources exist.

Mechanisms whereby the coordination function of CCP could be effected were discussed. A society (similar to CANQUA) could be such a mechanism.

b) Mechanism as to how CCP can best participate in making available more proxy climate data should be examined; a coordinating rather than a controlling role appears appropriate for the CCC.

The real need for the provision of quantitative proxy data in the immediate future was stressed. The sites selected for study must move beyond those chosen because of personal preferences. Currently, even personal preference as to where one collects proxy data is severely restricted because of financial constraints. Until adequate research support is forthcoming locations will be chosen more by chance and by opportunity than as the result of careful planning.

Some form of overall grid (at least for lake sediment) must erected in order to achieve uniform coverage. (However, overlap of techniques used at one site can be of great advantage in terms of calibration). Eventually, a grid system should be introduced (e.g. 2-1/2^{o} latitude grid system); until this is done the thrust should be towards obtaining proxy data for regions of greatest economic importance.

c) Better planning and development of methods for the identification of where proxy data is needed is necessary.

The need to increase our ability to distinguish amongst all the variables in proxy data (temperature, rainfall, soil acidity, etc.) was discussed.

d) Research should be directed towards distinguishing amongst the variables in proxy climate data.

The value of historical data in adding to our knowledge of past climate conditions was discussed. This was identified as taking the form of ice data from ships log, the price and abundance of furs from trading company records, surveys records, etc. At present, historical data on tornados found in written local histories is being examined.

It was stressed that this type of qualitative proxy data must be clearly distinguished from the currently less available quantitative data.

Mention was made of the Lesser Slave Lake Flood Study report by W. Nemanishen and L.S. Meeres in which the value of proxy data in helping to solve this historical hydrometeorlogical conundrum is identified. Dominion

Land Survey and railway survey records were used, along with with dendrochronological evidence, to help establish the significance of the 1935 flood, and recommendations made as to further proxy data work to confirm the hydrometeorlogical features of the Lesser Slave Lake floods.

One current general problem was determined to be the lack of compatibility of water resources and climate data. One role of CCC was postulated as being to determine the possibility of aiming for greater coincidence of data. Linked to this is the requirement for better methods of format, display and availability of proxy climate data.

e) A thrust towards developing greater compatibility between water resources and climate data is needed.

f) Improvements must be made in methods of display and availability of climate data, including proxy data; this could be a CCC role.

One main thrust of the Canadian Climate Program was proposed as being to advise on methods which most effectively extend backwards the historical record. This will encourage the use of a number of different methodologies.

An important question which needs resolution was determined as being the development of the linkage between proxy data and present climatic and hydrological conditions through areas such as interpretation, correlation and "ground-truthing". Information such as insect occurrence (if they have a specific niche) and tree ring analyses can be of value here. Work at the Bay of Quinté is producing this sort of information.

g) Efforts should be made to develop functions linking proxy data with the full instrumental record.

A thrust towards improvement and standardization within the various methods available for determination of quantitative proxy climate data was identified as a requirement. As a part of this, there is a need for encouragement of the exchange of data between agencies. This was proposed as being an important component in the role of CCP.

Communication received from Dr. Ommanney, Perennial Snow and Ice Section, NHRI, outlined work from Soviet Union and Switzerland sources where glaciers have been monitored to study the relationship between glaciers, climate and climatic change. There was general support for a periodic inventory of glacier fluctuation and relationship to climate in Canada.

A real need was apparent for the identification of where various expertises resided and where help could be obtained in data analysis and interpretation (e.g. access to a climatological statistician) and a complete listing of all the various analytical techniques available and where they are currently operational.. It was also very obvious that additional resources were needed by various agencies to improve their proxy data analysis capabilities.

h) A service is needed which can provide expertise to help interpret proxy climate data and which can convert it into viable form; the logical place for such an activity is CCC.

Canadian Climate Program - Water Resources Workshop
Working Group 2.1 - Climate and Its Impact on Large River Development: Operation and Management

In attendance at the working group session on February 28, 1980:

Chairman:	D. Witherspoon	
Rapporteur:	W. Nemanishen	
Participants:	E.K. Overgaard	L. White
	U. Sporns	B. Traynor
	T. Nguyen	P. Doyle
	L.H. Wiens	Jean-Pierre Fortin
	R.F. Hopkinson	Jean-Louis Bisson
	P. de Souza	P. Galbraith
	D.A. Murray	M.C. Quick

Recommendations and Discussion

A. Service

Recommendations

1. Improve the following networks in those resource sectors or geographic regions that can demonstrate positive economic and social requirements: precipitation, temperature, solar radiation, total insolation, soil moisture, water budget, energy budget, snow water equivalent, snow cover, humidity, evaporation and ground water.

2. Improve instrumentation for automatic real-time sensing and transmission of: snow covered areas, precipitation, temperature, dewpoint, radiation and windspeed.

3. Develop remote sensing in real-time to develop area distribute data and access by inexpensive data communication to AES National Data Base.

4. Develop up to six month climatic outlooks for water resource management.

5. Have some networks to monitor on both sides of a mountain range and at various elevations, rather than many valley stations.

Discussion Relative to Each Recommendation

1. a) Before specific network improvements are undertaken, it should first be established that the improvement has a definite economic benefit. First priority should be given to networks required for such areas as hydro, irrigation, flood forecasting, etc. (U. Sporns). If the networks are for research, it should first be demonstrated that the anticipated benefits will greatly exceed costs (Jean-Louis Bisson).

b) AES, at present, provides only about one-third of the hydrological cycle parameters required for real-time rainfall and snowmelt runoff. In addition to the existing temperature and precipitation networks, there is need for solar radiation, total insolation, soil moisture, water budget, energy budget and snow water equivalents (U. Sporns). There is also need for relative humidity (Prof. M. Quick).

2. a) In the resource management sector, automatic real-time sensing and data transmission is imperative as even the operations of dams are remotely controlled (Jean-Louis Bisson).

b) Many climate stations that are manual, have frequent changes of observers, which lead to data inconsistencies. At many stations, the observers are absent on weekends as AES has installed recording equipment. The instruments could be remotely interrogated if appropriate equipment installed (U. Sporns).

c) Consistency in data very important. CPR operated a station at Glacier in Rogers Pass from 1894. Now stationis relocated and the data is not consistent with the early data (Prof. M. Quick).

3. a) Most precipitation networks for large scale hydro projects are in remote wilderness area. Resource managers must have real-time data on areal rainfalls (Jean-Pierre Fortin).

b) In designing climatological networks, the capabilities of remote sensing should be recognized as an aid to augment ground-truth (Prof. M. Quick).

c) In the St. Johns River Basin in New Brunswick, data from scattered stations is analyzed on a square grid (P. Galbraith).

d) In B.C., the data is analyzed by area-elevation bands (U. Sporns).

e) In the east, radar digitizes on a square grid (Jean-Pierre Fortin).

4. a) In the operation of very large hydroelectric projects, weather forecasts providing up to six months forewarning are essential. In the case of the Churchill River diversion in Manitoba, it takes three weeks to drain the system. During this period, the system is vulnerable to flash floods (E.K. Overgaard).

5. a) In mountain regions, precipitation is a function of elevation and slope orientation to the storm track. Rather than expanding precipitation networks along the bottoms of valleys, the networks should have some stations partway up mountains and near the top. Also, the network must be designed to avoid rain-shadows by instrumenting both flanks of certain mountain ranges (Prof. M. Quick). Networks must have N-S and E-W slope stations (Jean-Pierre Fortin).

B. Research

Recommendations

1. Combine or integrate radar, satellite and point data measurements.

2. Research sensor and DCP development and evaluation for measurement of: precipitation, snowpack, temperature (max. and min.), soil moisture, dewpoint, wind and radiation (in this order of priority).

3. Evaluate methods of estimating evaporation and evapotranspiration.

4. Continue instrumented research basins in areas of inadequate knowledge such as glacier runoff.

Discussion Relative to Each Recommendation

1. a) Research should be undertaken to integrate radar and satellite sensed data with point measurement and the results be available on a real-time basis to users (Jean-Louis Bisson).

2. a) There is an urgent need for sensor development for DCP's. For example, there are no max.-min. temperature sensors, even though these two parameters are universally used (U. Sporns).

b) More work is required on gamma ray snow surveys (Jean-Louis Bisson).

3. a) At present, AES operates Class A evaporation pans but who uses this data (U. Sporns)!

b) Penman commented that these pans are consistently the most inaccurate measurement of evapotranspiration (D. Witherspoon).

4. a) Glaciers contribute runoff during drought years, so research on the glaciers' contributions should be made (U. Sporns).

b) Hydrometeorological models for runoff forecasting are needed (E.K. Overgaard).

C. Institutional

Recommendations

1. Leadership needed in operational remote sensing of climate parameters (including DCP's).

2. Need one agency to be responsible for coordination of flood control (would involve joint Federal-Provincial authorities).

3. Need a national policy to insure high quality river data for calibration of river models.

4. Need better coordination between climate and hydrometric network groups (i.e. AES & WSC-prov.).

Discussions Relative to Each Recommendation

1. a) There is a need for guidance in establishing standards for instruments in remote stations. With the exception of Quebec, there are no standards for DCP's. Other provinces in Canada use a piecemeal approach. The Canadian Centre for Remote Sensing is not user-oriented. Consequently, some other Canadian agency should be designated a leader (U. Sporns).

2. a) A single federal agency should be respnsible for flood forecasting as several federal agencies now have both the technical expertise and data. This agency should be similar to the U.S. River Forecast Centres (U. Sporns).

3. a) To calibrate models to accurately forecast river flow requires that the discharge of tributary streams be available. At present, Water Survey of Canada operates a station for only a few years on a tributary and discontinues it (Prof. M. Quick).

4. a) Snow course data quality varies across Canada. The best quality is in B.C. where one man directs all measurements (Prof. M. Quick). In Ontario, there are five groups measuring snow courses (D. Witherspoon).

b) AES should get rid of the 0.1 conversion factor to obtain snow water equivalent from snow depth (Prof. M. Quick).

D. Others

Recommendation

1. Need a national data base archives which would preserve all relevant data on major hydrometeorological events (data archives to include all remote-sensed data).

Discussion Relative to this Recommendation

1. a) To calibrate models the researchers require access to data base archives including remote-sensed data (Jean-Pierre Fortin). This data should not be discarded.

b) The data archives should not be limited to precipitation and temperature only, as this will seriously restrict Canadian drought-flood and runoff forecasting research. At present, very little of the IHD Research Basin data is in easily-retrieval data sets from archives (Prof. M. Quick).

Canadian Climate Program - Water Resources Workshop
Working Group 2.2 - Climate and Its Impact on Small Stream Developments: Operation and Management

In attendance at the working group session on February 28, 1980:

Chairman:	W.C. Thompson	
Rapporteur:	W.I. Pugsley	
Participants:	P. Dubreuil	G. Sykes
	B. Kitchen	W. Love
	E.T. Wagner	B. Thomson
	H. Foerstel	M. Makowsky
	P. Gryniewski	D. Lennox
	R. Pentland	W.E. Kerr

1. Discussion

a) Service

Improvement in the availability of certain types of data in near real-time was the main concern of this working group. A general consensus was the need for more data in both space and time with special note made of the deficiency of the radiation network which could improve model design estimates of probable maximum floods by better estimates of snowmelt. There was general agreement as to the importance of precipitation data in giving additional lead time in operational forecasting on small streams within an example given of the Regina area during snowmelt. More precipitation radar data in digital form for direct input to hydrological computer models are needed to provide mesoscale resolution of storm rainfall.

The recent increase in data collection platforms (DCP) and input of computer compatible data especially in Ontario, Alberta and Quebec were noted along with the need to upgrade climate networks to real-time and to standardize DCP sensors and to take advantage of the improvements in technology. The possibility of having a dense mobile DCP network that could be relocated to critical areas where needed was not considered practical because of high installation costs in remote areas.

Regarding the adequacy of the archived climatological data, several members noted a big improvement in the format and readability of the data tapes provided by the Canadian Climate Centre although difficulties exist in accessing the data quickly.

It was pointed out that with the development of regional or provincial networks and new technology, there is a need for an overall network plan that would establish standards for formatting, archiving, processing and quality control.

A need to monitor difficult to measure parameters such as snow water equivalent, soil moisture and lake evaporation was noted with the suggestion that fields derived from climatological data or satellite imagery would partially fill this gap.

b) Research

Concerns were expressed for better measurement of snow because of undercatch problems and the need for denser mesoscale networks especially in urban areas. There is a need to improve estimates of snowmelt through more research into the use of radiation as a melt predictor. The deficiency of mesoscale operational forecasts of snow amount in the short term was also noted. More research was advocated into the use of satellites to estimate snow characteristics and soil moisture along with the need to develop more economical and durable ground truthing sensors.

Climatic forecasts of one to three months are needed as well as forecasts of lake evaporation to schedule releases of water.

It was suggested that weather modification research should be continued to establish the feasibility of this technique for augmenting precipitation.

Further work is needed to estimate rainfall from radar as well as to develop a digital rain/snow precipitation gauge that would supplement the radar. Standardize and perfect the gamma radiation snow/water content survey procedure and make it a regular survey method in areas such as southern Ontario with results available by telephone within hours of the aircraft landing.

c) Institutional Changes

Although the working group noted that existing coordination between agencies worked well, eg. the NRC Associate Committee on Hydrology (ACH), the Prairie Provinces Water Board (PPWB) and the U.S./Canada gamma snow survey project, there are problems in obtaining data on a routine basis. This led to the suggestion that a national point of contact be established for obtaining data and that data collection be better coordinated. This does not preclude the need for regional archives. It was noted that the Hydrological Operational Multipurpose Sub-Program (HOMS) being organized through the WMO will soon address this need both internationally and within Canada.

There are difficulties in recruiting hydrological engineers with a sufficient knowledge of meteorology and meteorological instruments. It was suggested that universities or colleges incorporate such courses for engineers, resource managers, and planners studying water resources.

2. Recommendations

a) Service

- General Requirements - need real-time observations in computer compatible format and easier access to archived data
- Data Collection - make better use of development of DCP's and digital sensors
- Monitoring and Analysis - snow water equivalent estimates
  - soil moisture estimates
  - lake evaporation

b) Research

- Snow - better sensors
  - areal estimates
  - melt factors including effects of radiation

- Rain - radar

- Forecasting - mesoscale short range forecasting
  - regional climatic prediction

- Remote Sensing - snow water equivalent
  - soil moisture

c) Institutional

- National point of contact for archived (HOMS)

- Coordination - data collection

- Training - more university courses in hydrometeorology for engineers, planners and resource managers.

Canadian Climate Program - Water Resources Workshop
Working Group 2.3 - Climate and Its Impact on Forest Watershed Management

In attendance at the working group session on February 28, 1980:

Chairman:	D.L. Golding	
Rapporteur:	A.V. Mann	
Participants:	G.R. Hillman	R.B.B. Dickison
	R.W. Longley	D. Wilkinson
	R.H. Swanson	A. Plamandon
	D. Harvey	N. Van Waas
	P. Mills	

1. Recommendations

a) Service

General concern was expressed by the group over the lack of climatological information for watershed management in most forested areas of Canada.

Recommendation 1. Extend hydrometeorological networks in remote areas, including high elevation mountain areas, such as Northern Quebec, Northern British Columbia, Yukon and the Mackenzie Basin.

Recommendation 2. At selected stations within existing networks in forested areas add instrumentation for net solar radiation, wind and water vapour.

Recommendation 3. Characterize regional climatology of areas where water yield may be significant by installing a dense network of hydrometeorlogical stations on the basis of physical criteria, e.g. valleys, coastal regions, elevation bands and potential reservoir areas, for a sufficient number of years to establish relationships between precipitation-elevation, precipitation-runoff, snowmelt-energy balance, etc. Then relocate all but a few stations to broaden the extent of detailed knowledge. The remaining stations should be sufficient to obtain mean values within 10% of full network values.

b) Research

Recommendation 4. Continue development of improved automatic instrument systems for measuring snow, precipitation, wind, radiation, etc. in remote areas.

Discussion: Two questions were addressed here: the need for more exact measurements, better instruments and techniques, and the need for reliable automated instrument systems for remote areas. It was felt that satisfactory instruments were available for almost any purpose but what was really lacking were reliable systems that could be deployed in remote areas and at high elevations and left unattended for weeks and months at a time.

c) Institutional

Recommendation 5. Encourage technology transfer by interagency cooperation and co-funded projects. Direct involvement of other researchers in projects is essential.

Discussion: Several participants expressed the need for interdisciplinary research. This means close inter-agency coordination at the research scientist level.

Recommendation 6. Encourage regional climatological associations for exchange of information, data availability and reports, published or unpublished. Establish a clearing house for the loans of climatological instruments. The regional climatological association should be a recognized component of the CCP. In the absence of a regional association, AES should accept this coordinating responsibility.

Recommendation 7. Examine the structure of funding arrangements for university research. Present year to year granting strategy is not compatible with some watershed research studies which require 5-8 years security for meaningful results.

Canadian Climate Program - Water Resources Workshop
Working Group 2.4 - Climate and Its Impact on Water Quality for Inland Fisheries

In attendance at the working group session on February 28, 1980:

Chairman:	B. Ayles	
Rapporteur:	D.W. Phillips	
Participants:	J. Barica	D.C.L. Lam
	B.F. Bidgood	W.M. Schertzer
	P. Jablonski	

1. Objectives

The objectives of the working group were:

1) to identify climate service, data, and research needs related to water quality for inland fisheries.

2) to formulate recommendations for the design of the Canadian Climate Program to include action for an improved climate data and information service, for a research endeavour that will aid in understanding climate and its effect on inland fisheries and for a mechanism by which these actions can be coordinated in a national climate program.

2. Introduction

Each participant was asked to make some opening remarks describing his interest in climate, water quality, and inland fisheries; and relating problems in using climatological information and data in research, applications, or service work. A summary of the statements appear in the Attachment.

The Working Group then set out to draft a set of recommendations under the following headings: service, research and institutional.

3. Recommendations and Discussion

a) Service

i) The climate data acquisition network should be expanded in the North by upgrading existing stations and creating new ones.

The group identified a list of climatic variables, especially important to fisheries biologists, but abandoned any discussion of considerations of accuracy, frequency and density of data because of time constraints. Parameters to be considered are: snowpack, precipitation intensity, precipitation chemistry, water levels, solar radiation, wind, humidity, water temperature and atmospheric pressure.

ii) The Canadian atmospheric chemistry program should be expanded by establishing additional monitoring stations especially on the Canadian Shield, by improving access to analyzed data, and by adopting uniform analytical techniques.

Measurements of the chemical loading from the atmosphere can and should be considered a factor of Canadian climate. Major groups of nutrients a) major ions, b) biological nutrients, c) trace nutrients and d) toxic contaminants should be considered with measurement techniques standardized to WMO specifications.

Only 50 stations are in the precipitation chemistry network with very few of these in critical regions of northern Ontario and Quebec and the central Northwest Territories. Moreover, several others are poorly sited and not representative of the regional land use. Results of chemical analyses should be made available in regular publication series.

iii) <u>Year-round environmental data collection platforms should be installed and operated on all large Canadian lakes.</u>

Physically-based prediction models require daily or more frequent meteorological information. Most land stations with a complete monitoring program are located inland away from large lakes. Establishment of a few well-placed observing sites for wind, evaporation, air temperature, humidity, cloudiness, and solar radiation at the lake periphery, on land projectories, on islands, or as monitoring lake buoys should be considered.

iv) <u>Methods of accessing climate data and obtaining information are not well known. A climate data bank featuring direct access and flexible output specified by the user should be possible.</u>

Publications such as the Catalogue of Climatological Data Sources of the Atmospheric Environment Service are especially useful for promoting various information resources of the CCC. Marketing and promotion of the climatological services should be encouraged and be an ongoing program. In-house publications such as the Canada Department of Environment's Contact, brochures, trade magazines etc. are useful vehicles for spreading the word on the existence of a climatological data and information service.

b) <u>Research</u>

i) <u>Operational models for the monitoring of climatic trends and anomalous climatic events such as droughts, floods, temperature fluctuations, and early and sudden ice melts should be developed.</u>

The accurate forwarning of pending climatic events a month or a season in advance would be extremely helpful in designing management strategies for fish and wildlife programs, for fishing operations such as processing and marketing, and for individual decision making such as for the sport fisherman.

ii) <u>Development of new and the documentation of existing physically-based models on the interaction of climate and water quality should be supported.</u>

Understanding the response on lake fish and other biota to such phenomena as storm seiches, radiation loading, water temperature fluctuations, and anoxic conditions requires development of lake/climate interactive models.

Before physically-based prediction models can be developed to the point of being useful for biologists, a comprehensive set of measurements including man-made nutrient loading, climte factors and biological phenomena is needed.

iii) The relationship between climatic fluctuations as manifested in variations in the water environment and fish productivity are not well understood and more research effort is required to uncover the association. Closely aligned to this is a need to develop new water-climate indices to relate to fish productivity.

There is strong evidence that wind strength and solar radiation are major factors controlling the success of year classes for most fish populations. Factors such as the variation in light cycle for spawning, or environmental shock from the sudden melting of a contaminated winter snowpack or the indirect effect caused by temperature changes as a result of the removal of stream side timber are few of the other relationships between climate and fish productivity which require investigation.

iv) Analytical techniques to correct for the underestimation of precipitation in northern latitudes are required.

c) Institutional

i) Greater cooperation between data-supplier agencies and fishery resource agencies should be encouraged.

A first step in establishing better links would be the setting up of representative (near-lake) observing sites and in training fishery personnel in the taking of observations. These project stations should be encouraged to publish their raw climate data in report form.

ii) The Canadian Climate Program should develop a mechanism by which users of climate data can specify their information requirements.

Workshops such as those established to design the Canadian Climate Program, seminars, theme sessions at scientific meetings, roving speakers, exchange programs, visitations, etc. are useful ways to promote the exchange of information and should be formally established to improve the communication lines between fishery biologists, the commercial fishing industry and climatologists.

Attachment

SUMMARY STATEMENTS FROM PARTICIPANTS OF WORKING GROUP 2.4

Climate and Its Impact on Water Quality in Inland Fisheries

G. Burton Ayles
Freshwater Institute, Fisheries and Oceans Canada

Fish cannot be separated from water. Since the water cycle is related to the meteorological elements of climate, a fish's environment is continually subject to changes from temperature, wind, sunshine and precipitation. Daily and seasonal variations in these factors have shaped the evolution of fish to produce species carefully attuned to a particular set of environmental variables. For example, fish respond or are obliged to respond in such ways that:

- they spawn in response to temperature and light changes;
- they feed at different rates, depending on temperature and light;
- they die in face of low oxygen in hot eutrophic waters or acidification due to atmospheric pollution.

The following briefly highlights some of the effects of climate on freshwater fisheries.[1] It is in no way intended to be a definitive statement on the relatonships between climate and fisheries.

A. Glaciation

Fish distribution patterns are strongly influenced by the last ice age. Freshwater fish now occupying Canada survived the last glaciation primarily in four principal refugia: the Bering refugium in Alaska, the Mississippi River area, the Appalachian region ad the Pacific coast around the Columbia River (Lindsey et al. 1970).

B. Temperature

1. Isotherms are frequently useful when describing the northern or southern limits of fish distributions (e.g., Keleher 1956).

2. Spawning of fish is influenced by both light and temperature. Temperatures too high or too low may delay spawning or disrupt it completely (e.g., Hokanson 1977; Bodaly 1980).

3. Fish feed and grow maximally only at certain temperatures. Waters too warm or too cold restrict feeding and growth and too short a summer season will result in poor growth and poor production (e.g., Brett et al. 1969; Casselman 1978).

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1. This statement is to a large part based on an unpublished 1964 review, "Climate Hydrology and Freshwater Fisheries" by Dr. K.H. Doan of the Manitoba Department of Natural Resources.

4. The number of fish surviving in a particular year, or "year class strength", has been shown to be influenced by temperature. For example, eggs and larvae show differential survival at different temperatures and year classes of whitefish in Lake Erie were strong only when suitable temperatures existed (Lawler 1965) and the same may be true for periods (Koonce et al. 1977).

5. Fish catches are also influenced by temperature. Fish movements are greater during periods of optimum temperatures and catches per unit effort tend to be higher (Casselman 1978).

6. Fish mortalities may be caused by both high and low temperatures (Fry 1947). Such mortalities may occur periodically in small shallow lakes in particular.

7. Temperature also has dramatic effects on the development of fish embryos. The effects include altered numbers of vertebrae, fin rays, gill rakers and other characters (e.g., Kwain 1975).

C. Light

The intensity of light and the light cycle dramatically affect fish production. Growth, survival and body morphology may be affected by light (e.g., Kwain 1975; Casselman 1978) as are fish movements (e.g., Ryder 1977). The time of spawning of fish is also controlled by annual changes in day length.

D. Wind

Wind has a direct physical effect on lake waters by causing waves and currents which fish respond to. It also has an indirect effect by causing turbidity, aeration and temperature strata changes.

E. Water Chemistry

The water chemistry is a function of basin type and precipitation. The Canadian prairies are dotted with thousands of small shallow saline lakes which are only marginally suitable for fish habitat because of a lack of flushing.

F. Interactions

Interactions between temperature, precipitation, light and wind also affect fish. For example, in shallow eutrophic prairie lakes during the long cold winter snow cover deceases the light into the lakes and oxygen levels drop to lethal levels for fish. In years of light snowfalls or anearly spring, light penetrates earlier, allowing phytoplankton to start producing oxygen earlier and fish survive (Mathias and Barica 1980).

During the summer the same lakes may suffer a second period of anoxia resulting from the intractions of wind, light and nutrient composition of the water (Papst et al. 1980).

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Climate and the Inland Fishery Resource

D.W. Phillips
Canadian Climate Centre, Environment Canada

The relationship between weather and climate and the quality, abundance, survival, distribution and migration of fish stock has large scale economic and political implications. Water organisms of all types, from plankton to mammals are affected by climate. Fish species involved include food and sport fish, fish caught for fish meal and fertilizer, and fish that are part of the food chain for other fish species.

Research and development programs are needed to enable better management of fisheries resources. Of the greatest concern is whether the fish reproduce successfully or not in any year. Some climatic conditions influence fish populations directly. There is strong evidence that wind strength and solar radiation are major factors controlling success of year classes for most fish populations. Other research endeavours include construction of fish production models under various climatic conditions, the monitoring of episodal events, and the assessment of the impact of climatic fluctuations on fish yield.

These activities are vital to improving the economic viability of the fishery resource. For the commercial fishing industry, especially the fish processing and wholesaling components and for operators and owners of fishing vessels, real-time capability for forecasting wind waves, water temperature and ice formation and dissipation can be used to increase profits. For the fishery management decision makers who establish quotas for fish harvest to prevent overfishing and ensure adequate fish yields in the future, the development of an environmental prediction and operational monitoring system to forewarn of episodal events would be desirable. Knowning that events such as freshets and flood plumes, adverse ice conditions and prolonged warming are pending could alter market strategies and effect transfer or income subsidy adjustments.

Climate as it Relates to Fisheries and Forestry

P. Jablonski, Alberta Forestry Service

In Alberta much of the work of the Alberta Forestry Service involves evaluating the effects of timber harvesting, petroleum exploration and associated road construction on streamflow, sedimentation, water chemistry and their effects on the fishery. Of particular importance to these activities are the effects of precipitation intensity on water quality since the greatest sedimentation occurs during intense storms. An improved flood forecasting system is important in efforts to eliminate wide fluctuations in the year class strength of fish species. Such a scheme would require considerable more snowpack data.

Fish production in most foothill streams may be limited by cold stream temperatures and short summer seasons. Since water temperatures are governed primarily by solar radiation, research into removal of streamside timber may increase water temperatures and aid in improving fish production, that is, if sedimentation due to disturbance can be kept to a minimum.

Winter and spring air temperature and antecedent precipitation governs the amount of flood ice accumulation in streams. Major amounts of aufeis reduce oxygen concentrations and eliminate overwintering habitat for resident fish, e.g. rainbow trout.

Climate conditions during peak tourist periods of July and August cause varying degrees of pressure on the fishery resource. Generally cool and wet weather discourages outdoor recreation resulting in less demand on the fish stock. On the other hand ideal weather for sport fishing may result in overfishing in certain streams. Hot dry periods during the summer reduce the amount of habitat available to stream fish, forcing them to concentrate in pools where they are easily fished out. Low water also leaves spawning beds high and dry reducing the number of young fish for recruitment.

Modelling the Interaction of Climatic and Aquatic Regimes of Large Lakes

D.C.L. Lam and W.M. Schertzer
National Water Research Institute, Canada Department of the Environment

Models of large lakes, over the past decade have demonstrated the capability of predicting such phenomena as lake circulation, storm seiches, wave hindcasting and water levels by using meteorological data such as wind, atmospheric pressure and air temperatures. Recently, the emphasis has shifted towards the development of water quality models which require a comprehensive set of input data based on both climatic and man-made considerations. Not only is the ecological response to these conditions simulated but the interactions between water and air are also explored (see flow chart and diagrams).

Climatic data are used in a vertical turbulent diffusion sub-model which simulates the vertical water temperature profile by considering wind mixing, heat buoyancy effects, convective heat penetration, internal wave interaction, and hypolimnetic turbulence. In addition, climatic data are also used in the primary productivity and biochemical sub-models which simulate the production and decay of phytoplankton and zooplankton as well as the consumption and replenishment of nutrients and oxygen. By incorporating the measured man-made nutrient loadings, the computed water temperature and such factors as sediment oxygen demand in the model, the response of the lake ecosystem to both climatic variations and water management strategies can be simulated.

CLIMATIC INPUTS

- Wind
- Atmospheric pressure
- Air temperature
- Global radiation
- Incoming longwave radiation
- Outgoing longwave radiation
- Reflected longwave radiation
- Latent heat
- Sensible heat
- Net radiation
- Latent heat evaporation
- Dew point temperature
- Saturation vapour pressure
- Ambient vapour pressure
- Sunshine
- Extraterrestial radiation
- Albedo
- Humidity
- Cloudiness factor
- Light extinction coefficient

OTHER INPUTS

- Nutrient loadings
- Water levels
- Sediment inputs
- Outflows
- Water intakes
- Effluent discharges
- Atmospheric deposition
- Industrial loadings

→ LAKE AND RIVER MODELS

- Water quality model
- Hydrodynamic model
- Transport and diffusion model
- Storm seiche model
- Primary production model
- Biochemical model
- Wave hindcasting model
- Toxicant model
- Rain chemistry model
- Ice model

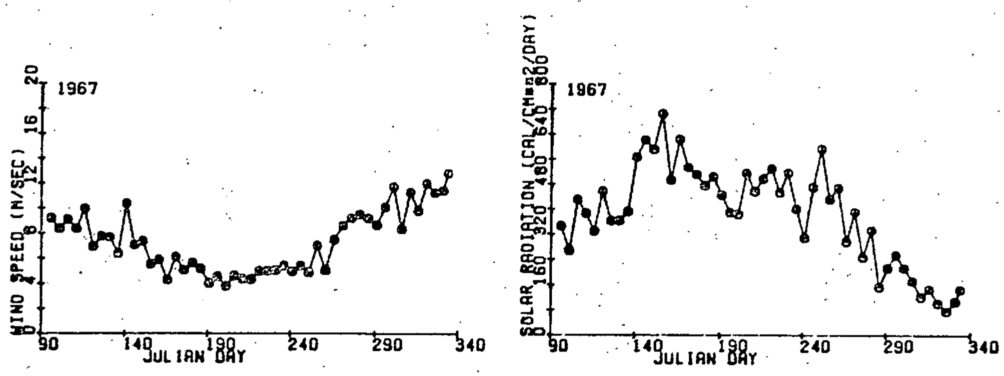
→ ECOLOGICAL RESPONSES

- Transport and dispersion of pollutants
- Waves and storm seiches
- Eutrophication states
- Anoxic conditions
- Biological production rate
- Biological mortality rate
- Nutrient concentrations
- Toxicant levels
- Water quality conditions

↓ FEEDBACK TO CLIMATIC MODELS

- Surface water temperature
- Vertical water temperature profile
- Total heat exchange at air-water interface
- Absorbed and reflected light
- Wind-wave drag coefficient
- Evaporation
- Ice formation

Figure 1: Lake Model Input Data



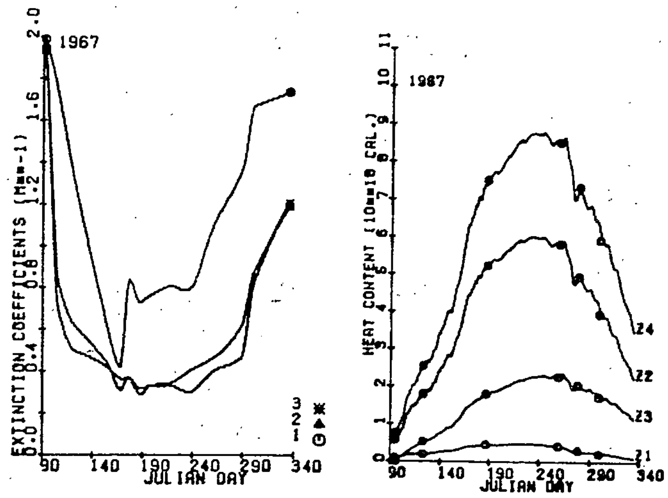
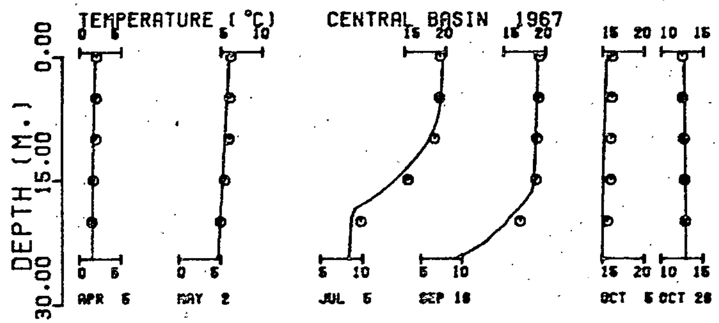
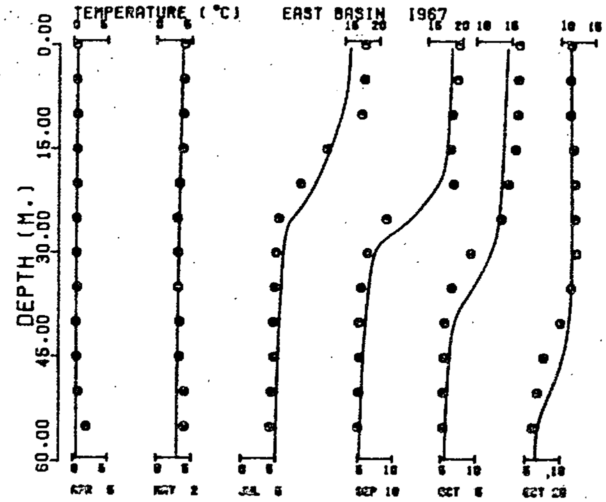


Figure 2 : Computed Vertical Temperature Profiles for Lake Erie Basins —Computed, o Observed





Feedback between model results serves to improve the physical basis on the development of climatic models. For example, by relating the light attenuation to turbidity and biomass, the radiation absorbed and reflected in the water column can be estimated.

The complexities of lake/climate/water quality models is very apparent in the foregoing discussions. Physically-based prediction models require hourly or at least daily meteorological information. Further, the spatial distribution of measurements is of some concern. In the Great Lakes region, most meteorological measurements are too far inland to be of any practical use in lake/climate models. Review of the existing network with an aim toward the establishment of a few well-placed observation sites at the lake periphery is certainly warranted.

The need for atmospheric deposition measurements to inland waters has been emphasized recently as has the changing character of our Canadian northern lakes due to deposition of airborne contaminants. Measurements of the chemical loading from the atmosphere can and should be considered a factor of Canadian climate and the change or potential for change should be documented and modelled. Major groups of materials a) major ions, b) biological nutrients, c) trace metals, and d) toxic contaminants should be considered with measurement techniques standardized to WMO specifications. Analyses of a Canadian atmospheric deposition/water climate must consider wet and dry deposition.

At the present time, the Canadian meteorological network consists of some 2700 precipitation amount stations with a meagre 50 precipitation chemistry stations. In addition, the measurements are most dense in regions of relatively high buffering capacity whereas very few observations are undertaken in the critical regions of northern Ontario and Quebec. Expansion of existing networks to include additional chemical sampling stations would enhance the capability of determining more representative spatial estimates.

Canadian Climate Program - Water Resources Workshop Working Group 3 - Climate Information for the Use of Water in Dry Regions, Including Drought Assessment Strategies and Water Allocation Between Competing Demands

In attendance at the working group session on February 28, 1980:

Chairman:	R. Deeprose	
Rapporteur:	H. Fraser	
Participants:	B. Findlay	C. Betts
	B. Guy	R. Barlow
	D.W. Lawson	L. Winstone
	R.M. Bennett	E. Kerr
	R.K. Lane	D.C. MacKay
	L. McKerness	I.S. Selirio
	D. Liverman	P. Smith
	G.H. MacKay	I. Barnaby
	E.H. Hobbs	P. Cary

1. Introduction

The principal interest of the participants was estimated to be agriculture 4, hydrology 9, meteorology 7; and their involvement were well spread from management and applications through research. A short background note on meteorological studies of drought in Western Canada was presented by B.F. Findlay and is attached.

The recommendations are presented in priority as determined by an objective ranking; this ranking also reflects well the thrusts of the discussions.

2. Recommendations and Notes

It is recommended that the Canadian Climate Program:

i) Develop methods for predicting the onset and ending of drought.

- drought clearly the topic of greatest concern
- "forecasting is the real need"
- two month period mentioned
- interest expressed in long-range predictions via sunspots, volcanoes, astronomical effects, etc

ii) Seek a definition of drought and analyse past droughts.

- definition needed in area, duration and intensity to allow analysis
- analysis of past vital to future probabilities and drought buffering strategies

iii) Develop a real-time drought monitoring system.

- needed for drought mitigation measures
- monitoring parameters need definition

iv) Consider soil moisture as part of its mandate and a) establish a measuring network; b) develop techniques for relating point measurements to aerial values.

- identified as important in drought monitoring, crop estimates, calibration of soil moisture models, river basin modelling (SAAR) and water balance calculations
- problems of aerial variability in both soil type and precipitation variability noted
- serious lack, almost non-existent, of measurements
- instrumental difficulties noted
- AES suggested as operating a network

v) Support the development of AES networks toward WMO standards in drought-prone basins.

- present networks frequently not dense enough to characterize general climate
- areal variability of precipitation a particular problem to agriculture and water management
- precipitation and temperature most pressing needs

vi) Foster the development of automatic stations a) to augment real-time stations, b) to allow researchers to purchase equipment which would produce data acceptable to the AES.

- as an alternative to expanding networks using expensive manned stations
- inexpensive stations needed for research purposes that would be acceptable to AES

vii) Weigh the socio-economic implications of drought in establishing priorities for climatic activities.

- lack of knowledge about socio-economic implications of weather extremes, especially droughts
- decisions of Canadian Climate Program should be based on benefit/cost type of approach

viii) Support the development by the AES and other agencies of high density local networks for specialized or temporary purposes.

- areal variability and topographic effects demand high density networks for research and management
- identified areas include agrometeorology, river basin modelling and land use

ix) Seek improvement in the availability of recent climate data from the AES.

- frequently identified by participants
- disagreement with AES claims of turn-around times; suggestion that climatological data lag is close to two years

x) Endorse the improvement of radiation networks by replacing sunshine recorders with integrated radiation measurements.

- radiation network very sparse
- needed for evaporation calculations, water balance, crop modelling, etc. (and energy research)

xi) Examine the relative implications of climatic trends and climatic variability.

- the two facets have been identified but have not been usefully applied to user problems

xii) Examine the feasibility and implication of weather modification as a drought mitigation procedure.

- efficacy of precipitation enhancement still not defined
- precipitation in mountain areas of importance

xiii) Define the effects of the chinook on snow on the ground and soil moisture.

- chinook removes much of the snow pack normally available for spring runoff
- also causes high evaporation of soil moisture

xiv) Produce a directory of drought programs and agencies and individuals engaged in these programs.

- can possibly be assembled from existing directories

xv) Press for increased amount and quality of hydrometric data.

- may not be within this program

xvi) Press for increased amount and quality of groundwater data.

- may not be within this program

Attachment

Meteorological Studies of Drought in Western Canada

B.F. Findlay

A comprehensive study of the subject of drought implies many physical and socio-economic considerations, as recurrent droughts in a region differ with respect to intensity, extent, duration and effects. The latter depends on the vulnerabilities of social and economic structure, the available technology such as irrigation and conservation measures, and the presence of other weakening agents such as crop disease and insects.

The Atmospheric Environment Service is developing an investigative program to address the type of droughts experienced in the Prairie Provinces and elsewhere in Canada. This is in response to Cabinet directives following the "near-drought" of 1976-77 which was fortunately broken by early summer precipitation. A broad network of cooperation is being established now to ensure service to, and collaboration from, all interested agencies, thus enabling the eventual development of protective and remedial strategies for use by government. The detail of much of the work is pending the formation of such liaison, but basic projects have begun.

Initially, a data base of climatological, agricultural and hydrological information is being established. It is planned to utilize a continuous climatological water balance based on daily data to identify periods of prolonged dry spells affecting agriculture and water supplies in rivers, lakes, and reservoirs. Agricultural and hydrological droughts may vary in location, timing, and recurrence. The water balance is to be applied to a network of grid-points, spaced at about 130 km, over an area extending from 45 degrees latitude to the 60th parallel and west from northern Ontario to within British Columbia. There are several-long term meteorological stations in this region and the analysis is designed to indicate the temporal frequency of droughts of distinguishable severities and durations, as well as their spatial extent.

Canadian Climate Program - Water Resources Workshop
Working Group 4 - Climate and Its Impact on Water Related Wildlife Activity

In attendance at the working session on February 28, 1980:

Chairman:	R.W. Prach	
Rapporteur:	P. Scholefield	
Participants:	J.P. Bruce	V. Schilder
	B. Janz	B. Young
	K. Leggat	

1. Introduction

After a free wheeling discussion on climate and wildlife relationships, an attempt was made to formulate recommendations according to the categories of Services, Research and Institutional. The preliminary discussions will be summarized according to these same categories and these will be followed by the recommendations which have been slightly modified from those presented at the plenary session. The recommendations are actually expressed in terms of needs.

2. Services

A. Discussion

The following service needs were identified:

a) greater use of satellite information in both the visual and infrared bands in monitoring such things as areal snow-cover and polynias.

b) monitor the number of ponds over the Prairies in May and the snowcover further north in June because of the importance of these two climate-related parameters to waterfowl breeding.

c) monitor and predict climatic trends for use in establishing bag limits.

d) More information is required on the characteristics of snow such as depth, crusting and ice layers. Such information would, for example, be useful in understanding the migration patterns of caribou who migrate from areas where ice layers in the snow prevent their access to the underlying vegetation.

B. Recommendations

1. Data - additional data parameters such as ground temperatures and more detail and snow.

   - expanded data networks particularly north of 60 degrees including greater use of remote sensing (e.g. use of satellite information for snow cover mapping and polynia morphology) and automatic stations.

- break-up and freeze-up climatology of water bodies including length of open water season.

- documentation, archiving and greater accessibility of non-standard climatic data.

2. Seasonal prediction of climatic parameters important to wildlife.

3. Utilization of climatic parameters in planning long-term wildlife harvesting.

3. Research

A. Discussion

The study of the impact of climate on polynias would be beneficial to the offshore oil industry as well as wildlife.

It was pointed out that most domestic livestock are breeds that are native to southern, more moderate climates and therefore consideration should be given to the impact of our harsher climate on these animals. Although our native northern species are well adopted to the climate, their production rate is not fast enough for commercial purposes.

Most ecological wildlife studies are conducted during the warmer seasons. There is a need for more winter ecology studies.

The economic value of hunting in Canada needs to be defined as part of a cost-benefit analysis of wildlife and climate.

B. Recommendations

1. Correlation studies between climate, wildlife habitat, and reproduction.

e.g. - effect of cumulative coldness on ungulates
- snowcover and waterfowl (primarily snow geese) breeding
- climate and the number of May ponds (number of standing water bodies in the spring)
- climate, air quality, vegetation relationships including marine and lake vegetation
- ocean climate, currents, polynias and shore leads

2. Cost-benefit studies related to wildlife and the use of climate information.

3. Process studies on representative basin types including the entire hydrological cycle.

4. Implication of climatic change and wildlife to socio-economic and environmental policies.

4. Institutional

A. Discussion

A lack of communication and understanding between physical and biological scientists was acknowledged. Wildlife biologists are generally project oriented and as a result often do not have a broad understanding of climate and its impact on wildlife. They are mainly concerned with operational day to day weather and in many cases do not appreciate the effects of cumulative weather or climate. As biologists' attention turns from descriptive studies to those that are predictive, climate will play an increasingly important role.

B. Recommendations

1. Establish and promote cooperative data collection systems including non-standard data collection (e.g. Polar Continental Shelf Project data collection program, Panarctic, Dome Petroleum).

2. Expand extension services to make the user more aware of data, publications and consultation service.

3. The Canadian Climate Program should ensure that users and involved agencies are aware of the distinction between weather and climate and the advantages of considering climatic factors in planning wildlife activities.

4. Wildlife agencies should actively express their needs for climate information and services through the Canadian Climate Program.

Summary of Recommendations From Working Group Sessions of February 28, 1980

Following the deliberations of the working groups, all the recommendations were tabulated, copied and distributed to each participant for review before the general plenary session on February 29. About 100 specific recommendations were made by the groups.

Working group chairmen also met to prepare a summary of the recommendations according to the three categories of service, research and institutional. These recommendations were presented at the plenary session for review and discussion and were used by the regional working groups, which met on February 29, 1980, as a basis for priorizing regional climatic needs.

Following are the summary recommendations as presented to the plenary session:

Service

1. Enhance the climatological network by the more effective use and standardization of real-time sensing and transmission of hydrometeorological parameters; especially in northern and alpine regions.

2. Improve access to climatological data base by computer to computer linkages, etc.

3. Coordinate, standardize and collect climatological data for Canada in one archive; this should include nearby U.S. stations.

4. Establish specialized short term high density climatological networks to assess fine scale climatic variations impacting on forestry and fisheries sectors and drought-prone regions.

5. Monitor, analyse and display derived climatological fields and anomalies such as soil moisture, snow accumulation/ablation, evaporation, etc.

Research

1. Improve climatic models for prediction and teleconnections, e.g. operation and management of water resources, ocean/climate, polynias.

2. Impact of climate on: dams, large rivers; production of fish; survival of marine mammals; wildlife, forestry; socio-economic activities, ecosystems.

3. Spatial variability of climatic extremes for use in the planning and design of large and small rivers or for example, in the definition of drought and the onset of drought.

4. Effective integration of radar/satellite and airborne remote sensing with ground based measurements for determining areal distribution of climatic variables, such as precipitation, snow water equivalent, soil moisture, lake temperature, lake temperature/evaporation.

5. Improved measurement and estimation of hydrological parameters, especially snow, soil moisture and evaporation.

6. Encourage the collection of all types of proxy data, including the production, calibration and linking of proxy data to the instrumental record in order to extend the historical data base.

Institutional

It is recommended that:

1. There should be better coordination between hydrological and climatological groups for obtaining data and designing and operating networks for training, for the transfer of technology and for the exchange of long range plans.

2. The Canadian Climate Centre takes an active role in assisting in the oganization of regional/provincial climate centres.

3. Consideration be given to the extension of research grants to be compatible with the longer period required to assess climatic variability in water resource projects, e.g. forest management and water supply.

4. There be improved communication between hydrologists, climatologists and other water resource users, e.g. fisheries, wildlife and forestry.

REGIONAL WORKING
GROUP REPORTS

Canadian Climate Program - Water Resources Workshop
Regional Working Group - British Columbia

In attendance at the working group session on February 29, 1980:

Chairman: U. Sporns
Rapporteur: J. Power
Participants: M. Orecklin, N. Lyons, M. Church, L.B. Davies, C.H. Coulson, B. Guy, G. Schaefer, R. Marsh, D. Golding, G.J. Young

1. Discussion

There was a consensus among members of the group that recommendations I1 and I4 were motherhood statements. They felt that these recommendations should be included as a preamble to the final report since they were desirable goals but that they were not required as specific recommendations. Members felt that recommendation R3 was redundant, i.e. that the thrust of it was contained in a number of the other recommendations (I feel that there was insufficient discussion of this point, and my own feeling now is that R3 is not redundant, and should be included with fairly high priority).

Recommendation R2 was extensively rewritten to be both more specific and more concise and now reads, "Special projects to assess the sensitivity of resource projects and ecosystems to climatic fluctuations". Similarly, recommendation S1 was rewritten to read, "Develop representative climatological networks both by increasing conventional observations in data sparse areas, including alpine areas, and by the effective use, archiving and standardization of real-time sensing and transmission of hydrometeorological parameters (DCP's etc).

Group members did not agree with the idea expressed in recommendation S3 that all data necessarily be archived in one place. The recommendation was therefore altered slightly to read, "...collect and/or catalogue all climatological...".

It was agreed to expand recommendation S4 to read, "...impacting on forestry and fisheries sectors, hydro-electric developments, and other water resource management requirements".

Recommendation R1 was subdivided into $R1_A$ and $R1_B$. $R1_A$ covers, "diagnostic climatic models on a regional scale" while $R1_B$, covers "national global scale models". $R1_B$ was then given a much lower priority than $R1_A$ since it was felt that research on the former would proceed in any case, while research on the latter was extremely important for the water sector.

The phrase, "maintain a glacier inventory" was deleted from R6, not because of any feeling that this was not important but because there were many other proxy data programs which were felt to be equally important.

I2 was given a very low priority for B.C. not because it was considered unimportant but because there are already active regional groups.

A new recommendation I5 was added to the list: "Designation of a federal lead agency to coordinate and direct operational activities in the field of remote sensing (especially the use of DCP's) in Canada". There was a lack of consensus on the priority which this recommendation should receive. It was agreed that I5 was closely linked to S1 and they were therefore ranked 1-2 in priority. Some members felt that, by itself, I5 did not rank as the second most important recommendation.

2. Recommendations

Based on the above discussion the final ranking of the recommendations was as follows:

Recommendation	Priority
S1	1
I5	2
$R1_A$	3
S4	4
R4	5
R2	6
R5	7
S5	8
R6	9
S2	10
S3	11
I3	12
$R1_B$	13
I2	14

Canadian Climate Program - Water Resources Workshop
Regional Working Group - Alberta

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1. Discussion and Recommendations

The large number in this group (over 20) precluded reaching a true consensus on each item. The Chairman, therefore suggested a three stage approach which was first to discuss and second to vote on each item with respect to its overall priority - High, Medium or Low in the context of Alberta requirements. Finally, a ranking would be established within the three categories.

Although this final process could not be completed, a realistic stratification was arrived at on the basis of broad priorities.

The results are the following:

High Priority

R.2. Impact of climate on dams, large rivers, fish production, etc.

R.3. Spatial variability of climatic extremes with respect to planning and design.

Discussion: It was suggested that this should include reference to identification of the nature of events which are included in the statistical population for calculation of return periods of droughts and floods.

S.1. Enhance climatological networks by more effective use and appropriate standardization of real-time sensing and transmission of hydrometeorological parameters, especially in northern, alpine and other remote regions.

S.2. Improve access to climatological data by computer to computer linkages.

Discussion: There was reference in discussion to an archive format for non-AES standard climatological data, possibly on a regional basis. It is expected that a national system, which receives a high priority here, may include regional sub-systems which may serve a more limited range of users.

I.1. That there be better coordination between hydrological and climatological groups.

I.2. Encourage the organization of regional climatological committees.

Discussion: This wording was preferred because (a) regional committees must be regionally motivated and (b) the term "centre" implies a form of operational activity and centre of expertise whereas what is intended is a means of coordination and exchange of information.

I.3. Consideration be given to extension of research grants to universities to be compatible with the long periods required in water research projects.

Medium Priority

R.1. Improve climatic models for prediction.

R.4. Develop more effective integration of radar/satellite and airborne remote sensing measurements.

R.5(b) Improved automated hydrometeorological measurement systems for remote applications.

S.4. Establish specialized short term, high density climatological networks to assess climatic features of watershed areas.

Low Priority

R.5(a) Development of improved instruments and point measurement techniques for hydrometeorological parameters.

R.6. Calibration and linking of proxy data to instrumental records in order to extend historical data base.

S.5. Monitor, analyse and display derived climatological fields.

I.4. That there be improved communication between hydrologists, climatologists, and other water resource users.

Discussion: This item could be left out entirely if suitable emphasis is given to I.1 and I.2.

Canadian Climate Program - Water Resources Workshop
Regional Working Group - Central and Arctic Canada - Prairie

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1. Priorization of Recommendations in Each Category

Each individual was asked to priorize separately the 5 Service, 6 Research and the 4 Institutional category recommendations. The results were tallied and displayed in three separate tables. The results for each recommendations were then weighted by multiplying the number of first place rankings by a number corresponding to the total number of recommendations in the category, and the number of second place rankings by a number one less than the total recommendations, etc. and finally the number of last ranking was multiplied by 1. The weighted rankings for each recommendation were then added together and the totals determined the final rankings in each category. The results of this exercise are tabulated as shown in Attachment 1.

2. Discussion of Results

The results in each category were examined and where the priorization results were close, a "hand" vote was taken to assign a consensus priority. During the related discussion, word changes in several recommendations were agreed to as follows (new wording underlined):

Institutional	No. 1	"transfer of technology <u>through extension and training</u>
	No. 2	"regional/<u>provincial</u> climate <u>committees</u>"
	No. 4	"e.g. <u>agriculture</u>
Services	No. 1	"<u>including</u> northern and <u>mountain</u> regions"
	No. 2	"access to existing climatological data"

No. 3 "all climatological data <u>including proxy data</u>"

3. <u>Overall Priorization</u>

A largely unsuccessful attempt was made to priorize all recommendations.

A debate ensued regarding the relative importance of service vs. research and the problem of what constituted "applied" and "pure" research arose. It was agreed that institutional recommendations could not compete with Service and Research recommendations in assigning priorities. Another problem complicating the overall priorization was the fact that the objective priorization results for Research were very close.

Attachment 1

Recommendation	Institutional Rankings (and Weighting Factors)				Weighted Total	Weighted Rank
	I(X3)	II(X2)	III(XI)	IV(XO)		
No. 1	16	8	4	0	68	I
No. 2	5	6	12	5	39	III
No. 3	2	5	7	15	23	IV
No. 4	5	9	6	7	39	II

Recommendation	Service Rankings (and Weighting Factors)					Weighted Total	Weighted Rank
	I(X4)	II(X3)	III(X2)	IV(X1)	V(XO)		
No. 1	8	5	6	7	2	66	II
No. 2	11	4	6	4	3	72	I
No. 3	3	11	4	5	6	58	III
No. 4	4	2	4	7	10	37	V
No. 5	2	4	9	6	6	44	IV

Recommendation	Research Rankings (and Weighting Factors)						Weighted Total	Weighted Rank
	I(X6)	II(X5)	III(X4)	IV(X3)	V(X2)	VI(X1)		
No. 1	6	2	7	5	2	6	99	III
No. 2	4	5	6	7	4	3	105	II
No. 3	7	8	4	2	5	2	116	I
No. 4	4	1	9	5	4	3	91	V
No. 5	2	10	2	6	4	3	99	IV
No. 6	4	1	0	4	9	3	72	VI

Canadian Climate Program - Water Resources Workshop
Regional Working Group - Eastern

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	P.L. Hansen	D.A. Murray
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1. Introduction

The Chairman opened the discussion by noting that Ontario, Quebec, New Brunswick and Nova Scotia were all well represented in the working group. Representation of Newfoundland and Prince Edward Island was restricted to regional personnel of Federal Government Agencies. The possibility of a division of priorities by Ontario - Quebec vs Atlantic Canada was suggested but subsequent discussions showed that difference were dependent on operational vs design considerations rather than on geography.

The process of determining priorities of the individual recommendations involved the following steps:

i) Discussion for purposes of understanding and clarification of the recommendation

ii) Modification where necessary

iii) Discussion on priority

iv) Division of all recommendations into high, medium or low priority categories by vote

v) Determination of priority within the high, medium and low categories.

2. Recommendations

The group's deliberation on the final step was severely curtailed by time constraints. Three recommendations that were considered to have a higher priority than all others were identified before the end of the session. The recommendations rated, according to priorities 1 (highest) to 4 (lowest) are presented in Table 1.

Table 1

Eastern Region Priorities

Priority	
1	Services 1, Research 1, Research 5
2	Institutional 1, Institutional 3, Research 3, Research 4
3	Services 2, Services 4, Services 5, Institutional 2, Research 2
4	Services 3, Institutional 4, Research 6

3. Discussion of Priorities

Brief notes on the discussion of some of the recommendations, follow.

Services #2 - There was widespread variation in perceived priority according to individual user's applications.

Services #4 - It was suggested that this might be more suitable as a research recommendation. A suggestion that this was only of interest to B.C. was strongly refuted by noting that climatic element gradients are very strong in coastal areas so that the high density networks proposed could prove very useful near the Atlantic and Great Lakes. After considerable discussion, the phrase "impacting on forestry and fisheries sectors and drought-prone regions" was deleted. It became apparent during this part of the discussion that several were debating under the misconception that these recommendations were aimed at AES as opposed to an all encompassing national climate program. Concern was also expressed that measurement of non-standard parameters like river ice, soil temperature etc had not been considered in the earlier working groups.

Services #5 - Flow forecasting interests noted that the time of distribution of the monitoring information was critical as far as their priority rating was concerned, i.e. high only if the information were available within a day.

Institutional #2 - This recommendation was reworded to read "That Regional/Provincial Climate Centres be established as an integral part of the CCP with the aid of the Canadian Climate Centre."

Institutional #4 - The word limnology was added to the end of the recommendation. This was considered to be a motherhood statement by many. If specific programs concerning training etc. were meant to be included, it was felt that this could be of high priority. If more committees etc. were meant, the priority would be low. A national newsletter was suggested as a means of improving communication but most considered that improved communication would be a necessary by-product of recommendation Institutional #2 and that the emphasis should be on communication through the Regional/Provincial Centres.

Research #1 - This recommendation was reworded to read "Improve physical basis for global and regional climatic models for prediction and teleconnections -- operations and management of water resources, lake/climate, ocean/climate, polynias." The importance of a Global Climate Model was accepted but the need for further development of smaller scale, regional climate models including provision of feedback mechanisms from large water bodies was also recognized as being highly desirable. It was also pointed out that the real goal should be improved physical knowledge for modelling purposes as opposed to a proliferation of models.

Research #5 - The feeling was expressed that more and more timely data was currently more important than more accurate measurements. It was also pointed out that priority should be given to development of more reliable sensors for use with automatic stations and in remote areas.

Research #6 - The word "collection" was added to the beginning of the recommendation. There was considerable confusion and disagreement over this recommendation dealing with proxy data. The lack of accuracy of synthetic flows based on proxy data was noted and the utility of proxy data was questioned on this basis. It was concluded that the quantitative use of proxy data is currently of little value although the importance of proxy data in adding to a qualitative understanding of climate and climate variability was recognized.

ANNEX 1

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Annex 2

Suggested Points for Discussion by Water Workshop Working Groups

General questions which should be addressed to all working groups include:

Service Requirements

a) General

i) What climatic information does the water sector need?
ii) Why do they need such information?
iii) How do they use such information?
iv) What are the accuracy requirements for climate data for water resources analyses?

b) Existing Data Collection System

i) Adequacy of data collection (parameters and network)
ii) Adequacy of storage and retrieval system
iii) What improvements are required?
iv) Impact of new technology on water resource programs
- quantitative radar for areal precipitation
- satellite imagery
- DCP's

c) Analyses and Interpretation

i) Adequacy of existing analyses
ii) Suggested improvement to existing analyses
iii) New analyses required

Research Requirements

a) Identify the research needs that should be conducted within the CCP - to meet the service requirements identified above, research may be required

b) What are the research priorities that should be identified as thrusts for the CCP?

c) How can technology transfer be best accomplished?

Institutional

a) Is there need for improved communication between agencies (federal, provincial, universities, consultants)?

b) Are there ways to better integrate expertise in different agencies to make work required for the solution of climatic problems in the water sector more efficient and effective?

c) Suggested improvements in communications and co-operation between agencies.

Topics Related to Climatic Problems and Information Needs Specific to Individual Working Groups

WG #1 Planning and Design of Water Resource Projects:

1.1 Climate and Its Impact on Large River Developments

a) For planning and design purposes in all regions of Canada, what are the climatic variables required for analysis? What accuracy in time and space is needed?

- does the current network meet these needs?
- are new analyses required?

b) In frontier or remote regions, climatic networks are sparse and there is often a greater difference between the general climate of a given location and that of the nearest climatological station.

- should the climatic network be expanded in these areas?
- how applicable and valid are interpolation techniques, based, for example, on a combination of climatological data and topographical data?
- what climatic/hydrometeorologic parameters are most important and what is the accuracy for each required for planning and design purposes?

c) Human activities, such as the burning of fossil fuels, may significantly affect our future climate

- what are the likely implications for the planning and design of large water resource projects?
- are possible climatic changes even considered when designing such projects?

d) Environmental impact assessment statements are often required for projects

- what climatic considerations are necessary to assess the effect of climate on the project and the project on the climate?

1.2 Climate and Its Impact on Small Stream Developments

a) For planning and design purposes:

- what are the most important climatic parameters?
- what accuracy in time and space is required?
- does the current "system" meet the needs of the planner/consultant?

b) Can a dollar amount be placed on the value of climate statistics for design purpose?

c) Urban hydrology is an important aspect in hydrologic design. National hydrometeorological networks were established generally for other purposes.

- what are the needs for information by the planner in such regions?
- are those needs currently being met?

1.3 Proxy Climatic Data and Their Implications for Planning and Design

a) To assess long term climatic variability, proxy data have been suggested as one component which should be given more attention.

- what proxy climatic data are available which could aid in assessing long term climatic fluctuations?
- how can these be used in the planning and design of water resource projects?
- how can they be linked with current climatic observations?

b) Proxy data are applicable not only to water resources, but also to other sectors in the climate program.

- what further research activities are required in this field?

WG #2 Operation and Management of Water Resource Projects

2.1 Climate and Its Impact on Large River Developments

a) In the forseeable future, how many weeks or months in advance should it be possible to give outlooks such as "above normal temperature, below normal precipitation"?

- would such outlooks be useful for water resources operations, eg. for operation of hydro projects?

b) Climatological data are reported each month by some 2500 stations in Canada, but it is six months or more before the data become available in published form.

- is this time lag satisfactory or should data be available sooner?
- what are the most important climatic parameters required for operations?
- what time scale is most suitable?
- is there a need for access to climate station data during the month in which they are collected?

c) In some areas there may be many "non-standard" observing sites operated by other agencies.

- should attempts be made to assemble these data from other sources to supplement the standard data and help fill in the gaps for users?
- is there a need for common standards for equipment, observations and siting?

d) Automatic weather stations, DCPs and data retransmission via satellite are going to be an important network component in the 1980's.

- is there a need for standardization of methods for archiving purposes?
- is the accuracy of data different for real-time operations than for subsequent design uses?
- what are the important hydrometeorological parameters which require measurement at remote sites? Are new measurement methods required?

e) What is the dollar value of climate information in a large hydro power operation?

2.2 Climate and Its Impact on Small Stream Developments

a) points a) - d) in 2.1 are applicable

b) Multipurpose reservoir systems are managed to meet the demands of many users, often with different interests. Being smaller systems, the time frame for events may result in needs being closer to "weather" rather than "climate" oriented.

- what are the climate needs for effective operation of multi-purpose systems?

2.3 Climate and Its Impact on Forest Watershed Management

a) How adequate are the current climate network and the parameters monitored for forest watershed management?

b) What are the research needs in the area of climate and forest watershed management?

c) Canada has a strong interest in drought and the social, economic and environmental affects of drought. Conservation of water is one component in any drought analysis. One possible conservation measure includes evaluation of improved management in particular forestry practices, to influence runoff regimes in mountain watersheds and prairie areas - can we yet make such an evaluation or is further research required?

2.4 Climate and Its Impact on Water Quality for Inland Fisheries

a) What are the <u>climatic</u> aspects affecting water quality and inland fisheries?

b) Competing demands for water, particularly in dry regions, may affect both water quality and inland fisheries.

- What types of hydroclimatic studies are necessary to assess such problems?

WG #3 Climate Information for the Use of Water in Dry Regions, Including Drought Assessment Strategies and Water Allocation Between Competing Demands

a) What are the chances of another prairie drought like that of 1961 or a repeat of the climatic conditions of the 1930's? How can users of water resources best prepare for such possibilities (including agriculture, municipal water supply, hydro development)?

b) Competing demands for water in dry regions is a serious problem in areas other than the Prairies, for example, the interior valleys of British Columbia.

- what hydroclimatic analyses are required?
- is the climate network adequate for such impact oriented analyses?

Annex 3

CLIMATE AND WATER RESOURCES

A Selected List of Recent Publications

This bibliography is one of a series of reading lists on applied climatology prepared by the Canadian Climate Centre for the Climate Planning Board. Lists have been compiled for climate and agriculture, building and construction, economics, energy, fisheries, forestry, health and comfort, industry and commerce, tourism and outdoor recreation, transportation and water resources. Although it is not a comprehensive bibliography, it does attempt to provide a representative cross-section of the literature and a guide to some of the more valuable readings published since 1970. Most of the references are available from the AES Library in Downsview, or from university libraries.

DS #12-80 contains bibliographic information for nearly 50 references on applied climatology and water resources and includes topics such as climatic change and water supply, hydrological forecasts, floods and droughts and weather modification.

For further information write to:

Atmospheric Environment Service
Canadian Climate Centre
4905 Dufferin Street
Downsview, Ontario M3H 5T4
Attn: Climatological Services Division

DWP

January 31, 1980

CLIMAT ET RESSOURCES HYDROLOGIQUES

Liste sélectionnée de publications récentes

La présente bibliographie est l'une des listes d'ouvrages de climatologie appliquée qu'a dressées le Centre climatologique canadien pour le Conseil de planification climatologique dans les domaines suivants: climat et agriculture, bâtiment et construction, économie, énergie, pêche, sylviculture, santé et bien-être, industrie et commerce, tourisme et loisirs de plein air, transports et ressources hydrologiques. Quoique la présente bibliographie ne soit pas exhaustive, notre intention est d'offrir un échantillon représentatif de publications parues depuis 1970 ainsi qu'un guide des ouvrages les plus intéressants publiés depuis 1970. Il est possible de se procurer la majorité des publications qui y figurent à la bibliothèque du SEA, à Downsview, ou dans des bibliothèques universitaires.

La circulaire DS #12-80 contient les renseignements bibliographiques d'environ 50 ouvrages de climatologie appliquée et ressources hydrologiques qui touchent notamment à des sujets comme changement climatique et approvisionnement en eau, prévisions hydrologiques, modification du temps relativement aux inondations et aux sécheresses.

Pour de plus amples renseignements, prière d'écrire à l'adresse suivante:

Service de l'Environnement atmosphérique
4905, rue Dufferin
Downsview (Ontario) M3H 5T4
A l'attention de la Division des services climatologiques

DWP

Le 31 janvier 1980

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Annex 4

Inventory of Climate-Related Programs

Questionnaire

1. Description of Climatic Aspects of Your Ongoing Program [over the past year, those which have involved the use or generation of climate information or climate-related information (CO_2 , ice cores, tree rings, crop yields, etc.)].

2. Goals and/or End-Products of the Climate Portion of Your Ongoing Program.

3. Resources (Estimates of person-years and annual non-salary expenses consumed by the climate portion of your ongoing program).

4. Climate Information Used (list type, format, and source for the major pieces of information including consultation services).

5. Can you suggest improvements in climate services from federal or other agencies that would benefit your program?

6. Contact (name, address and phone number of the individual who is principally responsible for the program).

7. Please list the name, phone number, and sector of interest (Agriculture, Energy, Hydrology, Forestry, Wildlife, Lands, Recreation and Tourism, Construction, Transportation, Communication, Climate Research, Oceans, Fisheries, etc.) of any individuals who you think might be interested in participating in one of the planned workshops for users of climatic information.

ANNEX 4

List of Respondents

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INVENTORY OF CLIMATE RELATED PROGRAM
PRELIMINARY ANALYSIS OF WATER SECTOR RESPONSES

Responses to the inventory questionnaire by agency and by region was as follows:

a) Agency

Federal - 20
Provincial - 30
University - 23
Private - 13

b) Region

Atlantic - 6
Quebec - 9
Ontario - 24
Central - 11
Western and Northern - 10
B.C. and Yukon - 20
National Capital Region - 6

TYPES OF WATER PROGRAMS USING CLIMATE DATA

1. Water Resources Engineering and Design

(a) water resource design projects in general
(b) probable maximum precipitation studies for selected watersheds
(c) flood frequency analyses for extreme rainfall runoff events
(d) calibration of storm rainfall intensity and frequency for design of storm sewers
(e) urban hydrology - runoff studies
(f) development of design storm distributions
(g) stochastic modelling of monthly hydrometeorological time series
(h) collection of surrogate records of climate fluctuations to associate with past surface runoff events (use of proxy data)

2. Flow Forecasting

(a) streamflow forecasting/hydrologic modelling
(b) flood forecasting
(c) prediction of rainfall - snowfall - runoff relationships
(d) runoff simulation for the operation of hydro power developments
(e) operation of multi-purpose systems
(f) forecasting of Great Lakes water levels

3. Water Management and Supply

(a) to provide safe and secure water supplies for the Prairie Provinces
(b) agricultural water management and irrigation
(c) modelling of lakes and reservoir levels
(d) general watershed modelling
(e) aquifer recharge and well yield
(f) limnological studies
(g) water resource management

4. Water Quality

(a) assessment of the nutrient budget of lakes and associated causes
(b) water quality monitoring

(c) evaporation from sewage lagoons/settling ponds
(d) water and chemical balance of a saline inland lake
(e) to provide an estimate of the annual loading for lakes

5. Snow/Ice Hydrology

(a) research for improved snowfall - snowpack measurements
(b) snowmelt modelling
(c) avalanche hazard analysis
(d) analysis of lake ice freeze-up and break-up
(e) role of glaciers and glacier melt contributions over a long term periods
(f) ice core extraction and use as proxy data for climatic change analysis

6. General Hydrometeorology

(a) water balance studies
(b) long term climatic trends (including paleoclimatology)
(c) development of methods to compute precipitation from GOES imagery

7. Environmental Impact Studies

(a) man's impact on climate
(b) water resource evaluation of proposed mining/industrial activities
(c) change in lake level caused by man's intervention

CLIMATE INFORMATION USED - WATER

Information Source	Sector			
	Federal	Provincial	University	Private
1. AES Current and Historical Climate Data Periodicals	10	12	12	11
2. AES Statistical and Special Data Publications	10	14	7	6
3. AES Archive Tapes	4	3	1	2
4. AES Abstracts and Tabulations	2	5	2	3
5. Original Observing Forms and Charts	3	0	3	1
6. Real-Time Observations	7	8	4	2
7. Satellite Imagery	1	2	0	1
8. Synoptic Weather Maps (Historical)	0	0	0	1
9. Sea Ice maps	1	0	0	2
10. AES Weather Forecast	3	0	0	0
11. Climate Data Not Collected by AES	2	11	5	0

SUGGESTED IMPROVEMENTS IN CLIMATE SERVICE FROM FEDERAL OR OTHER AGENCIES

No suggestions for improvement or satisified with current service:

Federal - 6
Provincial - 4
University - 9
Consultant - 3

1. Climate Station Network

   a) establishment of more high elevation stations in mountainous regions, especially British Columbia (repeatedly identified by users in all four sectors)

   b) expansion of network stations into data sparse but economically important (eg. hydro electric or agricultural potential) regions using automatic weather stations

   c) expansion of observation network for selected parameters, including

      i) evaporation
      ii) snow depth, snow course, especially in mountain regions
      iii) freshwater lake ice network
      iv) snow cover on lake ice
      v) chemical monitoring

   d) use of radar to provide areally averaged estimates of precipitation, in conjunction with satellite and ground based observations

   e) observations over large water bodies

   f) establishment of temporary local networks in order to assess the spatial and temporal variability of parameters

2. Data Analyses

   a) provision of areal (watershed) estimates of precipitation rather than point values

   b) development of techniques to provide areal rainfall, snowmelt - runoff, and evaporation loss predictions

   c) storm studies in regions above the 53rd parallel

   d) regionalized intensity-duration-frequency curves for use in hydrologic runoff models

   e) measurement and modelling of snowpack ablation in transition zones

   f) use of proxy data to extend historical data to gain an indication of climatic variability

g) synthesize data records to provide a long summary of climate records where the station site has been moved. This would best be a centrally directed activity since the degrees of judgement involved about comparability of data could best be developed in a group that had this activity as a primary task.

3. Data Services

a) direct access to the computer archive from remote (private) terminals (i.e. on-line access to data or at least to a listing of data available)

b) data on archive tapes should be in a readable format

c) precipitation data must be made available to users more quickly

d) more rapid publication of AES data summaries

e) increase the number (types) of computer utility programs for climatological data analyses and the computing services at AES, Downsview

f) establishment of regional data banks

g) ability to update previously purchased data tapes at minimal cost

h) make radar imagery and analyses available to users

i) archive data collected on an irregular basis using non-standard equipment, particularly in data sparse regions

4. Forecasting

a) improved five-day forecasts

b) improved and expanded weather radar systems for accurate precipitation measurement

5. Co-operation

a) better co-ordination and joint planning of data collection programs

b) better communication betweem researchers and improved co-ordination between agencies

c) provision of consistent and reliable scientific support (personnel and instruments) in co-operation or collaboration with other departments