

RECOLLECTIONS OF HYDROMETEOROLOGY
IN
CANADA'S METEOROLOGICAL SERVICE

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INTRODUCTION AND ACKNOWLEDGEMENTS

This informal paper is a contribution to the archives of the Meteorological Service of Canada (MSC). It is not intended for publication, but may be of particular interest to those who worked in the Hydrometeorological components of the Service. Some portions of the text will be "stating the obvious" for that group but are included for other readers not so familiar with hydrometeorology.

Mal Berry (2002) wrote a comprehensive paper entitled "The Rise and Fall of Climate Applications: The History of a Meteorological Service Program". The present paper could well have a similar title.

In the latter half of the 20th century the current MSC (Meteorological Service of Canada) went through several name changes and resided in 3 different federal departments (*Figure 1*). When the term "the Service" is used in the following text it should be understood as referring to this agency in its various manifestations. Also the capitalized word "Hydrometeorology" refers to the variously-named components of this science in the Service organization charts.

While the technical/scientific facts presented here are believed to be accurate, the paper reflects the author's personal views and emphasizes the years he worked in Hydrometeorology (1966-1976). The paper also focuses on the research and applications carried out during the International Hydrological Decade (IHD, 1965-1974) and the IHD studies published for several years after 1974.

In general, no attempt is made to explore research results in depth - there are simply too many of them for a brief overview. However, an extensive bibliography is included for those who seek more information. The bibliography is a somewhat arbitrary sampling of the many papers published by Hydrometeorology authors. Publications in refereed journals were given added weight in this selection and, as stated above, IHD work is emphasized. The bibliography also illustrates the great diversity of hydrometeorological projects.

Andrew Thomson*	(1946)- 1959	Controller Director	Meteorological Division Meteorological Branch (1956)	Transport Transport
P.D.McTaggart- Cowan*	1959-1964	Director	Meteorological Branch	Transport
Reg Noble*	1964-1976	Director Administrator ADM**	Meteorological Branch Canadian Meteorological Service (1970) Atmospheric Environment Service (AES) (1971)	Transport Fisheries & Forestry (1970) Environment (1971)
Arthur E.Collin	1977-1980	ADM	AES	Environment
James P.Bruce*	1980-1985	ADM	AES	Environment
Howard L.Ferguson*	1986-1989	ADM	AES	Environment
Elizabeth Dowdeswell	1989-1994	ADM	AES	Environment
Gordon A.McBean*	1994-2000	ADM	AES Meteorological Service of Canada (MSC,1999)	Environment Environment
Marc Denis Everell	2000-	ADM	MSC	Environment

Figure 1. Service Heads, Service Names and Departments 1950 - 2000

* Professional meteorologist

** Assistant Deputy-Minister

Obviously, Hydrometeorology in the Service operated within the framework of overall government and departmental priorities, policies and organizations. A "Backgrounder" Chapter 1 is included to provide context. Chapter 2 is a short summary of the wide variety of hydrometeorological processes and problems and their economic significance.

In the interest of brevity the extensive and valuable participation of Hydrometeorology staff in the activities of WMO and other international organizations is, with a few exceptions, not included here. This is admittedly unfortunate, since such work often goes unrecognized by award-granting institutions in Canada.

This paper benefited greatly from the inputs of many colleagues. In particular, Morley Thomas, the MSC Historian, provided information and support and the loan of several documents; Jim Bruce contributed a detailed account of activities leading up to the establishment of a Hydrometeorology Section in 1959 and Don Storr provided extensive notes describing his prolific work in Alberta. Other colleagues were generous with their time in providing information and answering questions. They included Paul Louie, Bill Pugsley, Bill Hogg, Jim McCulloch, Dick Stoddart, Des O'Neill and Ian Rutherford. MSC Librarians Heather Bennett and Roberta Mc Carthy were very helpful in searching out MSC archival data. The author also wishes to thank his grandsons, Adam and Jon Ferguson, for their assistance with the Figures and the final printing.

Any errors or omissions in the text are solely the fault of the author.

CHAPTER 1

THE METEOROLOGICAL SERVICE IN THE LAST HALF OF THE TWENTIETH CENTURY

In order to appreciate the growth and decline of Hydrometeorology it is useful to consider the bigger picture of the evolution of the service over the same period. Morley Thomas (1991, 1996, and 2001) has written 3 books on the history of the meteorological service, covering the period from its beginning in 1871 until the late 1940's. It is noteworthy that the Service had resided in the Department of Marine until shifting to the newly formed Department of Transport in 1936. This heralded the growth of services to aviation, which accelerated remarkably after the start of the Second World War.

The explosive growth in budgets and person-years between 1940 and 1943 was largely attributable to the British Commonwealth Air Training Plan, one of Canada's major contributions to the war effort. The hiring and training of wartime weather forecasters or "metmen" began in 1940. Their numbers rose to about 230 in 1943 and subsided to just over 50 in 1946, with most returning to their peacetime jobs. Meanwhile the total budget for the Service rose from about \$800,000 in 1940 to \$2,700,000 in 1945 before subsiding to about \$1,900,000 in 1946 (Thomas, 2001).

Figure 2 shows the evolution of Service budgets and person-years from 1950 to 2000. Clearly the Service prospered from the 1950's through the 1980's before experiencing a decline in resources in the 1990's. *Figures 3 and 4* show the remarkable changes in the organization of the Service between 1973 and 1999. The 1999 Service bore little resemblance to the Service in 1973, at least in nomenclature. (There have also been very significant changes since 1999.)

Thomas (1971) wrote a comprehensive account of the Service's first hundred years. Here we list (the author's choice of) a few highlights of the 1950-2000 period.

The 1950's

The core activity of the Service was, and remains, the provision of weather forecasts and warnings. This is an obvious federal responsibility because of the life saving and property protection nature of the products, which are based on national observing networks and which serve the entire country. The weather does not recognize provincial boundaries. Hydrometeorological research and applications are similar in the sense of contributing to the protection of Canadian citizens and their property from the effects of large and costly floods.

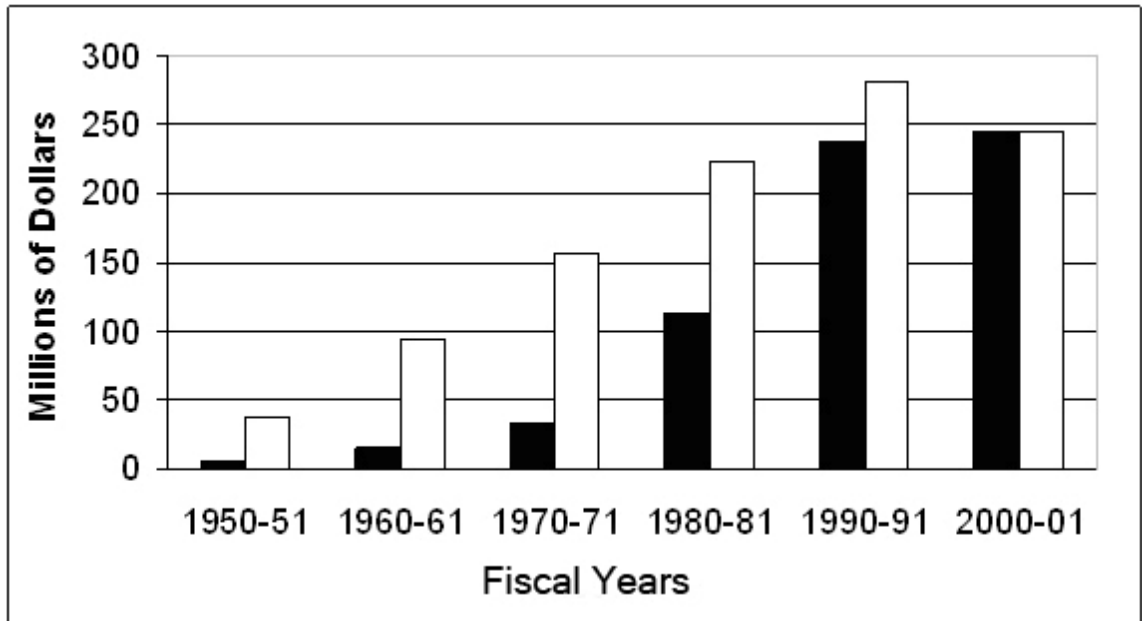


Figure 2a. Service Budgets for selected Fiscal Years in millions of dollars (black columns) and in millions of year 2000 dollars (white columns)

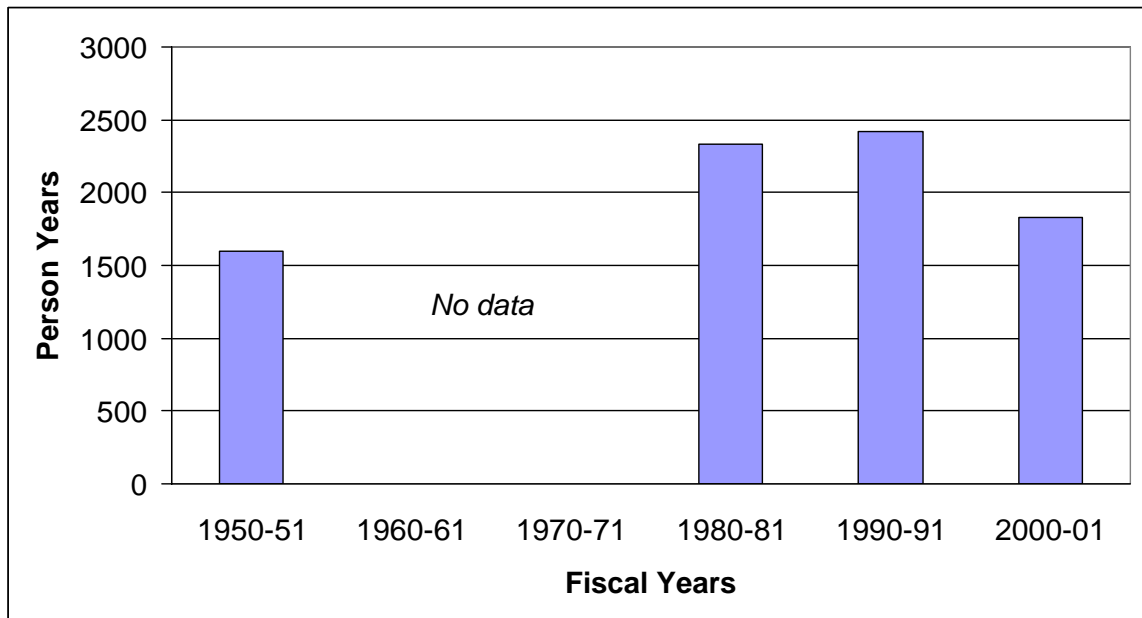


Figure 2b. Service Person-Years for the same period.

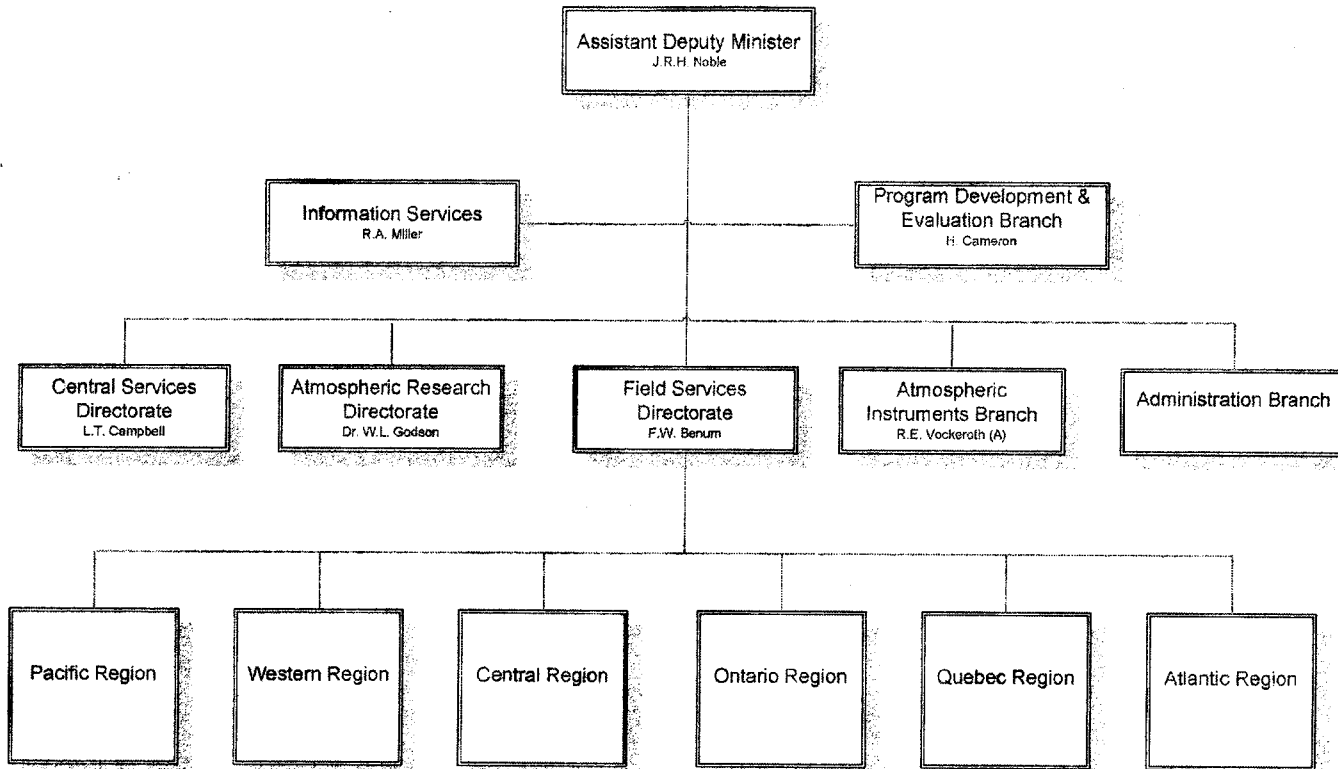


Figure 3. Service Organization Chart 1973-1974

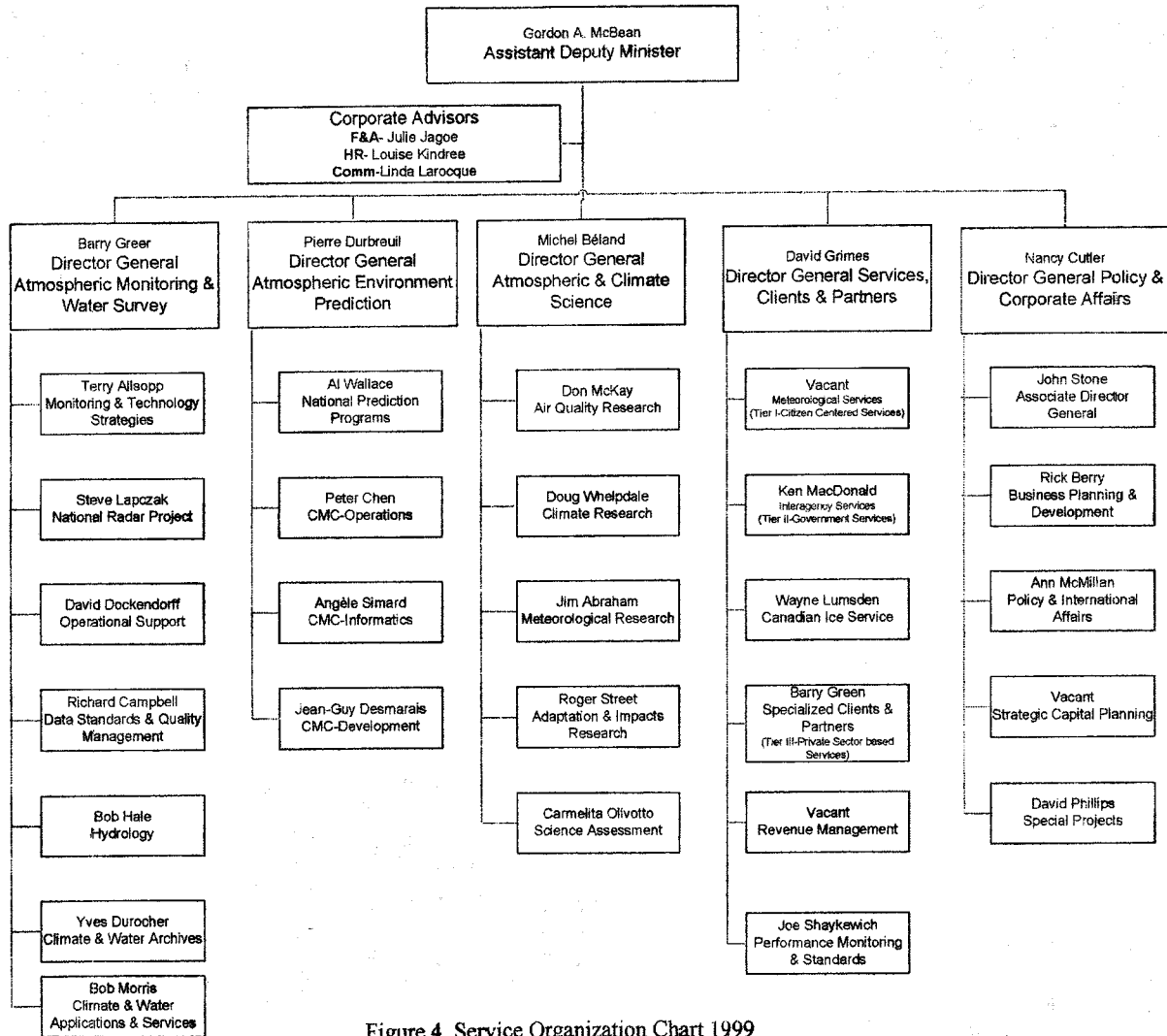


Figure 4. Service Organization Chart 1999

In 1950 a Central Analysis Office (CAO) was established in Montreal and was transmitting surface and upper-air analyses and prognostic maps to the Toronto Headquarters and 6 regional centres by facsimile. Map analyses were carried out using the recently- developed Canadian Three Front Model devised by Al Crocker, Clarence Penner and Warren Godson. The model was based in turn on the Norwegian (or Bergen) School of air mass and frontal analysis. Canadian weather map analysts employed the three-front model over the ensuing decades. One feature was the "trowal", a distinctly Canadian invention and abbreviation for "trough of warm air aloft".

(The name of the CAO was changed in 1973 to the Canadian Meteorological Centre or CMC. It is rumoured that the new name raised a few eyebrows among the Headquarters staff in Toronto who considered themselves to be at the centre of national meteorology. Outsiders might identify this as a typical Toronto attitude.)

While service to commercial aviation was expanding, increasing attention was also being paid to public and marine forecasts. Meteorologist Percy Saltzman "opened" the first CBC telecast in Toronto in 1952 and immediately became a TV star. He was the predominant national TV weathercaster until he retired in 1982.

Hurricane Hazel in 1954 was the most devastating extreme weather event in Canada during the decade.

A feature of the early 50's was the secondment of several Service meteorologists to other agencies in recognition of a need for close day-to-day interdisciplinary working relationships. It marked an emerging public and political realization of the economic importance of meteorological and climatological applications to a variety of disciplines. Prominent among the seconded staff were Les McHattie (Forestry), Don Boyd (NRC Building Section) and George Robertson (Agriculture). Their salaries continued to be paid by the Service. Berry (2002) provides a comprehensive list of such secondments.

Gord McKay was seconded in 1959 to the Prairie Farm Rehabilitation Authority where he carried out many hydrometeorological studies over the following 8 years.

The nature of weather forecasting demands the continuous exchange of meteorological observations among countries. An international agency responsible for standard codes and communication arrangements is essential. The International Meteorological Organization (IMO) handled this responsibility until 1950. In that year the creation of the United Nations resulted in the birth of the UN's World Meteorological Organization (WMO), which replaced the IMO. The WMO became increasingly involved in various other applications of meteorology, including its links to hydrology. WMO created a Commission for Hydrology in 1956. The name was later changed to the Commission for Hydrometeorology. The Service is a strong supporter of WMO, including its hydrometeorological activities.

The 1960's

Employee satisfaction in the Service was generally very high, due to several factors:

1. All staff took pride in the unique aspects of this vital federal service, which issued essential information across the country every day, including weekends and holidays. The Service was the only credible Canadian source of this information. It was also distinctive in being one of the few federal government organizations with headquarters outside of Ottawa.
2. It was science-based, which provided intellectual discipline and common interests among professional staff and well-trained technicians.
3. It was an organization with a long tradition and high visibility, much appreciated by the public (most of the time!).
4. It was the prototypical paternalistic organization, which promoted from within.
5. There was an almost militaristic esprit de corps, which had been nurtured during the war years. Meteorologists who had worked through those years were now becoming the senior managers of the Service, ensuring that this esprit de corps would be long-lasting.

The first earth-orbiting weather satellite, TIROS 1, was launched in 1960. A short time later the first geostationary weather satellite, ATS, was put in space. Continually-transmitted images of cloud cover over North America and the adjacent oceans were soon available to the Service and were a boon to weather forecasters and researchers. The program evolved into a series of more advanced NIMBUS satellites.

The publication of Rachel Carson's *Silent Spring* (1962) marked a "sea change" in the public's awareness of global environmental degradation problems. Ensuing critiques and large numbers of related follow-up publications ensured the continued dramatic growth in public disquiet. Canada and the United States were becoming increasingly concerned about contaminants entering the Great Lakes, particularly phosphates. It was recognized that many other contaminants were entering the lakes through atmospheric deposition.

The Canadian Branch of the Royal Meteorological Society became the Canadian Meteorological Society (CMS), the "Learned Society" for Canadian Meteorology.

The 1970's

After 33 years in Transport (*Figure 1*) the Service was transferred in 1970 to the Department of Fisheries and Forestry (known among bureaucrats as "Fish and Chips"). Its new title was the Canadian Meteorological Service, but it was sometimes referred to as the Canadian Weather Service. The sojourn in Fish and Chips turned out to be a very

short stopgap measure. The government had more important fish to fry; it moved dramatically in 1971 to address environmental problems, which had become its highest priority in response to public demands. It created a new Department of the Environment, including the Atmospheric Environment Service. The Head of the Service, Reg Noble, was raised in status to the level of Assistant Deputy Minister. The new organization was met with approval and even enthusiasm by most Service staff.

The Service Headquarters now came together in a new building at 4905 Dufferin St., Downsview, after occupying the old Headquarters at 315 Bloor St. West and about 5 other locations in the city for many years. A prominent new feature of the Service was an Air Quality and Inter-Environmental Research Branch with a Division working on atmospheric chemistry. The Branch also included a new Boundary Layer Research Division and a Hydrometeorology and Environmental Impacts Research Division. The new Branch was located in the Atmospheric Research Directorate. A hydro-meteorological and Marine Applications Division remained in the Central Services Directorate.

Prime Minister Trudeau and President Nixon signed a Great Lakes Water Quality Agreement (GLWQA) in 1972. This was a natural "great-grandchild" of the bilateral Boundary Waters Treaty of 1909. The International Joint Commission, (IJC), which had been formed at that time to monitor and make recommendations on trans-boundary pollution disputes, now focused much of its attention on Great Lakes problems. It formed a bilateral Great Lakes Water Quality Board and a Great Lakes Research Board to carry out the work.

A major Great Lakes problem arose with the leaching of toxic chemicals from a dumpsite at Love Canal. The Hooker Chemical Company had dumped upwards of 20,000 tons of toxic waste at the site between 1942 and 1953. Later a residential community was built around the site. In 1978 this material began to leach into basements and the waterway and thence to the Niagara River and Lake Ontario. The US Environmental Protection Agency eventually identified 82 toxic chemicals in water, soil and air. As a result the whole community was abandoned. Many former residents suffered serious health effects including a high number of miscarriages and birth defects.¹

Through the efforts of Art Collin, Morley Thomas and Barney Boville the Canadian Climate Centre (CCC) was established in 1978. This was quickly recognized as the leading Canadian "Centre of Excellence" on Climate Change. It provided a national focus and the obvious contact point for co-operating international agencies interested in the Canadian Climate Program.

¹ In the early 80's the author, as Ontario Regional Director General of Environment Canada, escorted Ministers John Roberts and Charles Caccia (separately of course!) on visits to the site.

When Reg Noble retired Dr Arthur Collin had been appointed ADM to replace him. This broke the century-old tradition of having a professional meteorologist as Head of the Service. However, it was recognized that Dr Collin was a professional oceanographer and the two sciences share many common elements, scientific principles and interests (witness the Canadian Meteorological and Oceanographic Society (CMOS), which evolved from the CMS in 1977).

Acid rain was becoming a major bilateral issue. It was clearly of interest to both meteorologists and hydrologists and thus fell into the domain of hydrometeorology. The increased loading of chemical contaminants in precipitation was resulting in harmful changes to the chemistry of lakes in eastern Canada. A large proportion of these contaminants originated from US industry, especially fossil fuel-fired power plants.

The 1980's

Following a Memorandum of Intent between Canada and the United States concerning the Long Range Transport of Atmospheric Pollutants, several Working Groups were formed and their reports led to a formal bilateral agreement. Throughout the decade there was a rapid growth in national and international concerns about anthropogenic Global Warming associated with Climate Change.

The government was becoming more aware of the national debt problem. In the late 1980s some modest attempts were made to keep annual deficits in check, with few noteworthy results.

In April 1986 a massive nuclear accident took place at Chernobyl in the USSR. This engendered worldwide anxiety. A nuclear cloud spread over northern Europe. Thirty people died immediately and untold numbers more eventually died from radiation sickness. Chernobyl village was immediately abandoned². In the region more than 135,000 people were evacuated. The Service was able to apply its long-range transport model to advise the government on the predicted path of the plume. Environmental managers were concerned about fallout into reservoirs, other water bodies and soil as well as the immediate effects of air pollution.

After his "retirement" in 1985, the "father" of Hydrometeorology in the Service, Jim Bruce, spent several years with WMO in Geneva, including a stint as Acting Deputy Secretary General.

² The author (accompanied by his courageous wife) visited the ghost town of Chernobyl, as a member of WMO's Executive Committee, in 1988.

In 1986 the author, as ADM of AES, accompanied by Neil Trivett, Mike Balshaw and Dennis Stoessel officially opened the world's northernmost Air Quality Observatory/Laboratory at Alert, NWT. This was met with enthusiasm by the international scientific community interested in the monitoring of greenhouse gases and toxics in the atmosphere as well as the impact on arctic snowcover. (This observatory was still in operation in 2006 and is still highly valued by other nations and the UN.)

In 1987 the Service was the lead agency and host of a major international Conference on "The Changing Atmosphere : Implications for Global Security". This was the first international conference to bring together expert stake-holders from a wide range of disciplines (including hydrologists and water resource managers) and countries, and the first to formally propose a specific target for the reduction of greenhouse gases. This target was adopted by the City of Toronto and soon by several other jurisdictions around the world. (Regarding global security, a statement signed by 100 Nobel Prize winners including John Polanyi and Mikhael Gorbachev appeared in the Toronto Star on December 7, 2001. It expressed concern about "the world's dispossessed" and that global warming would "affect their fragile ecosystems most".)

The Intergovernmental Panel on Climate Change (IPCC) held its first operational meeting in Nairobi in June 1989. It was sponsored by WMO and UNEP and attended by all interested countries. The author led the Canadian delegation.

The 1990s

The word hydrometeorology disappeared from the Service's organization charts at the beginning of the nineties, although vestiges of the work continued in the Water Resources and Marine Applications Division.

Government priorities shifted dramatically to the elimination of annual deficits and the pay down of the national debt. These were issues generally supported by Canadians. (Chantal Hebert, writing in the Toronto Star (2006) had this to say: "In the nineties the crusade against deficits turned finance ministers at every level into the white knights of their governments. Over that period, the bottom line replaced policy as the first measure of the performance of entire governments".)

Later in the 90's the government also began to implement policies of decentralization (major offices of some federal agencies were moved out of Ottawa) and the provision of added financial support to universities and the private sector. These moves were probably supported in principle by most citizens, but had a serious impact on many government in-house programs. The funding and manpower previously allocated to them were now being reduced (*Figure 2*).

The environment was still on the list of public priorities, but was now reportedly well down the list (in spite of the continuing concerns about climate change).The government

appeared to be moving toward the "U.S. Model" in regard to the increased "farming out" of weather forecasting and meteorological research activities.

The shift in government priorities placed considerable stress on the senior managers of the Service, now required to abandon or reduce programs. Some reorganization was unavoidable. Reduced staff were called upon to "do more" in the name of improved efficiency (although some might already have been quite efficient). Many staff members saw their jobs disappear or change significantly. Staff morale understandably sagged.

The Canadian Climate Centre, which was the national "Centre of Excellence" on climate and climate change, was disbanded and decentralized in 1994. International organizations now direct enquiries on Canadian climate and climate change activities to several different addresses.

The reporting relationship of AES Regional Directors was changed. Administratively they now reported to the department's Regional Directors General, who in turn reported to the Deputy Minister. Previously the RDs had reported to AES Headquarters. (They continued to do so, on technical matters.) The change, in effect, was mostly cosmetic, and was intended to strengthen the RDGs' role and the Department's visibility in the regions. However, the optics suggested a loosening of the "stand alone" cohesiveness of the Service, which characterizes most national weather services of the world.

In 1999 the name of the Service was changed from the Atmospheric Environment Service to the Meteorological Service of Canada. For the majority of staff, engaged in the core activity of weather observing, analysis and forecasting, this change probably elicited little reaction. Some may have approved. For employees and former employees who had worked in the many applications of meteorology and climatology to economic sectors such as forestry, agriculture and water resource management, as well as major international environment issues, this renaming was seen by many as the official (and sad) end of an era, signaling the much-reduced involvement of the Service in interdisciplinary environmental research and applications.

CHAPTER 2

HYDROMETEOROLOGY AND ITS ECONOMIC BENEFITS

Hydrometeorology has been defined as the application of meteorology to hydrological problems. This covers a great variety of processes. From the early days of the Service, when timely forecasts of precipitation became available to water resource managers, the information was applied locally in the first crude attempts at flood forecasting. After a few decades of data collection, climatological information could also be applied to this problem, as well as the engineering design of control structures on rivers, lakes, reservoirs, sewers, culverts etc.

Meteorologists are particularly focused on atmospheric water in all its states: water vapour, cloud and fog droplets and the various forms of precipitation and how they are transported through the atmosphere. Hydrologists concern themselves with water quantity, storage on or below the land surface (including water bodies) and the movement of water at and below the surface. Hydrometeorologists focus on the exchange of water between the atmosphere and the earth's surface.

A basic equation linking meteorology to hydrology is the basin water balance equation (assuming net groundwater inflow or outflow to be negligible):

$$P - E - \Delta S = R$$

Where P = Precipitation, E = Evaporation and/or Evapotranspiration
 ΔS = Storage Change and R = Runoff

Much of the work in hydrometeorology is devoted to point measurements and areal estimates of the meteorological elements in water balance equations for hydrologic basins, other catchment areas and water bodies, on time scales ranging from individual storms and their related streamflows to long-term climatological estimates of probable maximum precipitation for flood prediction. Climatological records are also used in the engineering of control structures designed to prevent destructive flooding.

There are many publications by Hydrometeorology staff describing relevant techniques. In Canada the estimates of the storage change element in winter often involves measurements of basin snowpack depth and water equivalent.

Almost 8% of Canada is covered by lakes. Canada has more lakes, probably surpassing a million, than any other country. The Great Lakes contain almost 20% of the total volume of the world's lakes (RCGS, 2006).

Because Canada is richly endowed with lakes, Canadian hydrometeorologists have a particular interest in the water balances of lakes and reservoirs. Another focus of lakes research is the relationship between winds and waves. Coastal inundations may result in property destruction and shoreline erosion. The wind-wave data can also be used for shoreline control structure design. These data are useful along sea coasts as well as inland water bodies. Technically speaking, offshore oceanic studies are not in the realm of hydrometeorology.

Since the 1970s both hydrologists and meteorologists have become increasingly concerned with water quality and the potential impacts of climate change on regional and local water quality as well as water balances. Bruce (1981) noted that the atmosphere was the main source of lead, PCBs, nitrogen and mercury inputs to the Great Lakes.

Canada dumps more than one trillion litres of untreated sewage into waterways every year. One study noted that "typical municipal water contains some 200 synthetic chemicals". In a land blessed with an abundance of freshwater the consumption of bottled water rose from 18 to 47 litres per person per year between 1995 and 2003. One gram of PCBs is enough to make one billion litres of water unfit for freshwater life (RCGS, 2006).

Other, less obvious applications of hydrometeorology include predictions of risks of avalanches and massive mudslides, the freeze-up and break-up of lakes and irrigation and drought studies. Meteorologists are also interested in the effects of large water bodies on the surrounding overland weather (as in snow belts, lake and land breezes) and climate.

It is difficult to assign economic values to Canadian hydrometeorological research and applications. A paper by Jim Bruce (1981), aided by Paul Louie, provided cost estimates for a few selected items of hydrological interest, as shown in *Figure 5*. Equivalent values in year 2005 dollars can be found by multiplying the Figure costs by a factor of 2.16, based on the standard Statistics Canada CPI conversion factors. These equivalent dollar numbers provide only a very rough indication of the potential financial benefits of hydrometeorological work in 2005. There have been significant changes in the economy and water resource management since 1981.

A listing of major floods in Canada (Atlas of Canada, 1999) contains 58 items for the period 1980 to 1999. Eleven of these caused property damages of at least 10 million dollars. Those costs do not include response costs, which are sometimes higher than the damage costs. Canada's most costly flood occurred in the Saguenay Region of Quebec in 1996. Total damage was 1.5 billion dollars (1.8 billion in 2005 dollars). This disaster was the result of 290mm of rain within 36 hours, combined with the insufficient storage capacity of local dams.

ITEM

COST IN DOLLARS (1981)

Average Annual Total Flood Damage in Canada (to 1981)	More than 100 million
Shorline Damage from General Lakes High Water Levels and Wind Action (Canadian Side Only)	28 million
One to Two percent of GDP Invested in Water Structures	4 billion
Hydropower Production at Sault Ste Marie, Niagra, Cornwall, and Beauharnois, per year	1 billion
Replacement of all Electric Power by Water Generation Using Thermal Plants	5.4 billion
Prairie Drought 1980	2 billion
Human Health Impacts of Water Pollution and Climate Change	Unknown

Figure 5 - Some Economic factors to be considered in evaluating the benefits of hydrometeorological research and applications (after Bruce, 1981). For equivalent costs in year 2000 dollars, multiply by 2.16.

Even marginal improvements in hydrometeorological applications would obviously have large economic benefits. If past and current financial allocations by governments to hydrometeorological work in-house and in universities and the private sector were available, it might be possible to estimate some benefit/cost ratios, taking account of the financial data presented above and in *Figure 5*. Chances are they would be very high.

CHAPTER 3

PRECURSORS OF A FORMAL ORGANIZATION

Mariners have always had a keen interest in the weather. This is particularly true of those who work at sea or on *large* inland lakes. The Service recognized this special interest early on. By the end of the nineteenth century, several observing stations had been established at lighthouses and shoreline points on the Great Lakes and storm warnings were being hoisted at some locations.

With the advent of radio communications, weather forecasts and warnings could be transmitted "in real time" and ships could return general reports on weather conditions. Property owners on the lakes were also interested in storm warnings because onshore gales and storm surges could threaten lives and cause extensive property damage.

F.Graham Millar entered the Service in 1934 and was put in charge of marine observations. He was also expected to study evaporation on the Great Lakes (Millar, 1992). One of his initiatives was to obtain water temperatures from thermographs in the engine room water intakes of vessels. Results of his research on evaporation and on water temperatures were published (Millar, 1935, 1953). Millar was also designated to represent Canada on the International Meteorological Organization (IMO) Commissions on Hydrology and on Maritime Meteorology.

Stream flow and flood forecasting were no doubt carried out in some areas of the country in the late 1800s and early 1900s, but there seems to be little information available on these rudimentary activities. They do not appear to have been well-organized on a national, or even provincial, scale.

The seminal event for the establishment of a hydrometeorological component in the Service was Hurricane Hazel. It had actually been downgraded to a tropical storm when it crossed Toronto on October 15-16, 1954. Because of the extreme rainfall and inadequate control structures it caused 81 deaths and 24 million dollars (182 million in 2005 dollars) in property damage.

The following paragraphs are based on information provided by Jim Bruce.

Hazel prompted the Conservation Authorities Branch of Ontario to consult with the Service with a view to the secondment, for 6 months, of a meteorologist to help develop flood warning techniques. Jim Bruce won the subsequent competition and, as it turned

out, the 6-month assignment turned into 3 years. Methods pioneered in the United States were used to produce 100-year flood estimates for the designation and zoning of flood

plain lands. Estimates of probable maximum floods were then used for designing new control structures. These studies were published (Bruce, 1957b; 1959).

Several other publications of interest during this period included a study of the accuracy of precipitation measurements (Bruce and Potter, 1957) and a paper on the applications of hydrometeorology in Ontario (Bruce, 1957a).

In 1958, Dr G. Ross Lord³, the Chair of the Toronto Region Conservation Authority and also of the Department of Mechanical Engineering at the University of Toronto, arranged for a hydro-meteorologist to provide the first term of a graduate course in Hydrology.

³ By coincidence the Conservation Authority eventually established a park named after him, immediately south of the (then) Service headquarters building on Dufferin St in Downsview

CHAPTER 4

ACTIVITIES OF THE HYDROMETEOROLOGY SECTION 1959-1971

In the next three chapters we examine some of the more significant activities and publications of the Hydrometeorology Divisions. The publications cited are only a sampling of those produced and no doubt reflect the author's bias. This sampling is limited to the work of the *Headquarters* Hydrometeorology components and is intended to illustrate the diversity of projects and the interdisciplinary, interagency and international aspects of the work. The bibliography emphasizes publications in refereed journals and *projects of the International Hydrological Decade* (for which Canada, in an unusual step, issued a postage stamp in 1968).

A much more exhaustive list of publications is available in "Publications in Hydrometeorology and Marine Applications" from 1954 to mid-1976 (Atmospheric Environment Service, 1977). About 50 of the 484 publications listed were written by seconded meteorologists, including Gord McKay and Don McMullen, and Service Regional staff including Syd Buckler and Howard Cork working in the Prairie Hydrometeorological Office in Regina. About 230 other papers on the list could be characterized as meteorological studies of some hydrometeorological interest written by Service personnel not on the staff of Headquarters Hydrometeorological components

The remaining 200 or so publications listed were authored or co-authored by Headquarters Hydrometeorology staff. Most of the references in the present paper are included in that AES document. Of course, the large majority of Hydrometeorology staff papers listed appeared in the Proceedings of conferences of many different international organizations such as the International Association for Great Lakes Research (IAGLR), the Western Snow Conference, the Eastern Snow Conference and the International Association of Scientific Hydrology (IASH). These were invaluable venues for the exchange of current research results and new applications.

The staff of the new Hydrometeorology Section of the Climatology Division in 1959-1960 consisted of Jim Bruce, Eli Mukammal, Uly Sporns and Eileen Veinot. Jim Bruce (2002) notes that this group was known locally as Eli, Uly, Eily and Jim.

Meanwhile, an important development was taking place in the realm of Great Lakes hydrometeorological research. Through the efforts of Service Director Pat McTaggart-Cowan, Jim Bruce and the University of Toronto, a naval vessel, the *Porte Dauphine*, was obtained on loan for research on the Great Lakes. This enabled the regular monitoring of

water chemistry and other properties, water and air temperatures, currents and winds. The U of T took the opportunity to establish a Great Lakes Institute for related studies.

The Porte Dauphine operated out of the Douglas Point-Baie du Dore area of Lake Huron for many productive years.(The Porte Dauphine was returned to the Navy in 1974. In 1978 she was based in Victoria B.C. serving as a Naval Reserve training ship. She was declared surplus in 1997 and was purchased by GNC Fisheries. As of 2001 she was still at work on the Pacific Coast under the pseudonym MV Salmon Transporter.)

In 1966 Jim Bruce and Bob Clark published the highly-regarded textbook "Introduction to Hydrometeorology" intended for use at the university undergraduate level.

MANAGEMENT PERSONNEL

Lloyd Richards joined in 1961 to head up a new Lakes Unit and this marked the beginning of substantial growth in the Hydrometeorology Section. Jim Bruce now had the title of Superintendent. In 1966 the author won the newly-created position of Head of the Special Projects Unit, set up to carry out research under the IHD program. In 1967 Jim Bruce left the Service⁴ to take up a position in the Inland Waters Branch and 2 years later he was appointed Director of the new Canada Centre for Inland Waters (CCIW). Lloyd Richards replaced him as Superintendent. Jim McCulloch arrived part time, changing to full time in 1968, to take charge of the Lakes Unit.

RESEARCH ACTIVITIES

Precipitation

The Section continued to focus on precipitation studies for Ontario basins, gradually expanding to the rest of Canada. Bruce (1959) published a paper on storm rainfall transposition and maximization. The use of precipitable water obtained from radiosonde observations (Ferguson, 1962) for estimating precipitation was investigated by Bruce (1963).McCulloch and Booth (1970) described the estimation of basin precipitation by regression equation.

Evaporation

Several papers were published on evaporation studies including work by Mukammal and Bruce (1960). For many years Eli Mukammal operated a large weighing lysimeter at a climatological station in the northwestern suburbs of Toronto. Eventually urbanization disrupted the long-term relevance of the site in terms of its ability to represent stable conditions and the operation was closed down. Ferguson, O'Neill and Cork (1970) published a paper on "Mean Evaporation over Canada" in Water Resources Research, the first of several publications of this kind leading to maps published in the Atlas of Canada and the Hydrological Atlas of Canada.

⁴ On the day that Jim Bruce left in 1967, the author asked him whether he had any parting words of wisdom. The reply was "Illegitimus nil carborundum" This advice proved quite useful, even after the author retired from the Service in 1989.

Water Balance

Bruce and Rodgers (1962) described the water balance of the Great Lakes system. Several papers of a general nature discussing applications of hydrometeorology included those by Bruce (1966; 1967).

Remote Sensing

In the realm of remote sensing the Lakes Unit did pioneering work on the application of Airborne Infra-red Thermometry (ART) to observations of lake water temperatures (Richards, 1966; Irbe, 1968). George Irbe, Don Massey and Tom Cutler were the technicians most involved in the surveys. Applications of satellite photographs to hydrology were also studied (Ferguson, Cork and O'Neill, 1969).

THE IHD

The International Hydrological Decade (1965-1974) was established by Unesco with the close cooperation of other international agencies, including WMO. About 30 countries participated. Canada's IHD program was among the largest national contributions. This country's program was run by the Canadian National Committee for the IHD (CNC-IHD). The Committee was chaired by retired Major General H.A.Young and the first Secretary was R.H.Clark. He was replaced early in the program by Dr Ira Brown, assisted by his deputy Dick Stoddart.

The main thrust of the Program was Basin Research. About 60 research basins were established in three different categories: Benchmark, Representative and Experimental Basins. Service Hydrometeorology technicians as well as Regional staff did outstanding work in identifying sites, installing and servicing meteorological equipment and data processing. Individual basin projects were mostly run by universities and provincial agencies. Literally hundreds of university students were employed in these projects during the summers - a splendid adjunct to their education.

The Service participated in the interdisciplinary research carried out in about 15 of these basins, notably those included under the Eastern Rockies Watershed Research Program (ERWRP) in Alberta. That program had actually started in 1962 in the Marmot Creek Basin. Deer Creek and Streeter Basins were subsequently added and all were included in the IHD Program. Many provincial and federal agencies were involved.

The purpose of the ERWRP was to manipulate ground cover in these basins to increase runoff and thus stream flow to the prairies (Storr, 2002). Marmot Creek's cover was fir-spruce. Deer Creek was covered by lodgepole pine, while Streeter was in a rangeland environment.

Don Storr had published a number of papers on one-day rainfall frequencies in western Canada (for example see Storr, 1963). In 1965 he won a position as Hydrometeorologist with the ERWRP, but continued to report to the Service's Western Region. General papers on meteorological studies at Marmot Creek soon followed (Munn and Storr, 1967, Storr, 1969).

A paper on precipitation variations (Storr, 1967) was presented at the Western Snow Conference (WSC) meeting. It was one of many papers delivered by Storr at WSC meetings over the years. Eventually his contributions were recognized when he was awarded a Life Membership in the WSC. Papers relating to basin evaporation estimates were also published (Storr, Ferguson and Cork, 1970; Storr, 1971).

Other IHD projects included studies of anchor ice in the Niagara River (Ferguson, 1968), the Mountain Transects Project in B.C. and the Perch Lake Evaporation Study. Lengthier descriptions are provided in the next chapter.

The Canadian IHD program included more than 300 projects and expenditures over the ten years totaled about \$42 million. Of this, AES expenditures were in the range of \$4 to \$5 million.

CHAPTER 5

ACTIVITIES OF THE HYDROMETEOROLOGY DIVISIONS 1971-1976

The year 1971 was a momentous one in Service history. The move to the new headquarters building in mid-1971 was followed by a large reorganization, which was completed the following year. Hydrometeorology was now elevated to 2 divisions. The Hydrometeorology and Marine Applications Division was located in the new Central Services Directorate (CSD). The Hydrometeorology and Environmental Impacts Research Division (ARQH) was located in the new Atmospheric Research Directorate (ARD). A list of personnel in these two divisions is shown in *Figure 6* (summer students and temporaries are not included).

During the 6 years 1971-1976 inclusive, Hydrometeorology staff authored or co-authored 92 publications, of which 17, or 18.5%, appeared in refereed journals (Atmospheric Environment Service, 1977). This was also the period when Hydrometeorology staff numbers reached a peak.

In this chapter emphasis is placed on the IHD, and in particular the work of the Hydrometeorology and Environmental Impacts Research Division.

MANAGEMENT PERSONNEL

Lloyd Richards remained as Chief of the Hydrometeorology Division in CSD. The author was appointed Chief of ARQH. Jim McCulloch was named Regional Director, Atlantic Region, and left Hydrometeorology in 1975.

THE IHD

The data collection phase of the IHD ended in 1974 but the data analysis and publications of the research results continued to 1976 and beyond. Basin studies remained the main element of the Canadian program. In 1971 the IHD Steering Committee appointed a 3-man group to report on progress in Experimental and Representative Basins across the country. This group consisted of Dr Don Gray of the University of Saskatchewan, Mr Michel Slivitzky of Quebec (later Chairman of Unesco's Committee for the International Hydrological Programme) and the author. The group visited 10 basins from New Brunswick to British Columbia and the Northwest Territories and submitted a report covering the adequacy of the hydrological and meteorological instrumentation and progress toward the research objectives for each basin.

HYDROMETEOROLOGY AND MARINE APPLICATIONS DIVISION

Chief: Lloyd Richards

Hydromet Services Section

Dave Pollock
 Dave Carr
 Ken Devine
 Bill Hogg
 Paul Louie
 Neil McPhail
 Rich Poersch
 Jack Powers
 Jim Young

Lakes and Marine Applications Section

Jim McCulloch
 Joan Atkinson
 Tom Cutler
 George Irbe
 Don Massey
 John Metcalfe
 Dave Phillips
 Val Swail
 Mike Webb
 Eileen Veinot

HYDROMETEOROLOGY AND ENVIRONMENTAL IMPACTS RESEARCH DIVISION

Chief: Howard Ferguson

Secretary: Pat Terry

Hydromet Research Section

Howard Cork
 Bob Chapil
 Gerry Den Hartog
 John Hebgen
 Neil Trivett
 Steve Lapczak
 Mike Malone
 Des O'Neill
 John Reid
 Gary Schaefer

Calgary Office

Don Storr
 Steve Belseck
 Harold Bredo

Biometeorology Research Section

Eli Mukammal
 Harold Neumann
 Gary Teeter
 Denis Walsh

Figure 6. Staff of the Hydrometeorology Divisions, 1971-1972. Figures 6, 7 and 8 are staffing "snapshots". Many other staff members worked in Hydrometeorology, but not on these snapshot dates, including for example Dave Sparrow and Tom Dane. Apologies to any members who have been overlooked.

IFYGL (IHD)

The International Field Year on the Great Lakes turned out to be something of a misnomer. In hindsight it might more accurately have been referred to as the Bilateral Field Year-and-a-Third on Lake Ontario! It was a major collection of inter-related projects carried out by leading Canadian and American hydrometeorological experts. Detailed planning began in August, 1966, at the first meeting of the IFYGL Steering Committee, co-chaired by Lloyd Richards and W.J. Drescher of the U.S. Geological Survey. Jim Bruce, as Director of the Canada Centre for Inland Waters, was a member of the Steering Committee.

More detailed planning was carried out by 11 Advisory Working Groups and Scientific Panels. Lloyd Richards, Jim McCulloch and the author each served on 3 of these bodies while other Hydrometeorology staff members, including Dave Phillips, George Irbe, Dave Pollock and Bill Hogg, were also involved. The data collection period began on April 1, 1970 and ended in June, 1971.

Studies published over the ensuing few years included those on Lake Ontario basin evapotranspiration (Ferguson and Hogg, 1974), basin temperature and precipitation (Phillips and McCulloch, 1974), precipitation estimates by radar (Hogg and Pollock, 1975), the evaporation program (McCulloch, 1975), and atmospheric water balance (Sullivan, Rasmusson and Ferguson, 1975). A comprehensive book on the IFYGL was published much later (Aubert and Richards, 1981).

The IFYGL was an outstanding example of Canada-U.S. cooperation in a very large and unprecedented scientific project.

Marmot Creek (IHD)

Marmot Creek was the most densely-instrumented basin in the Canadian IHD Basin Program. Cooperating agencies included the Water Survey of Canada, the Canadian Forestry Service and the Alberta Forest Conservation Board. Two students from the University of Alberta and the University of Calgary were hired each summer to assist in taking readings from instruments.

From 1971 to 1976 several studies using Marmot Creek data were published. These included precipitation network design (Ferguson, 1971), estimating net basin radiation, energy and water balances and wind-snow relationships (Storr, 1971, 1972, 1973) and Bowen Ratios over freezing and melting surfaces (Storr and Ferguson, 1974).

Don Storr and his staff of 2 technicians were located in Water Survey offices in Calgary and reported to the author at ARQH in Toronto.

In the Toronto Office a 3-dimensional scale model of Marmot Creek Basin, in Plaster of Paris, was constructed on a plywood "Lazy Susan". A vertically-moveable arc lamp was mounted on a fixed post a few feet from the model. A camera was suspended on a stationary support several feet above the centre of the model. The whole apparatus was located in a darkroom. Photos were then taken, with the arc lamp as a "point source" of light representing the sun. A clear-sky solar insolation factor could then be simulated for any elevation and azimuth of the sun for any calendar date and time. (At low solar elevations the basin topography resulted in shadowing over parts of the basin.) Several hundred photos were useful in estimating net incoming solar radiation and basin energy balances.

The first results of tree cutting along the tributary streams were mixed. Initially the runoff increased, but then counter-balancing siltation also began to increase. In later experiments the tree cuttings were carried out on circular areas of 40 to 60 ft. diameter away from the tributary streams. This had the desired effect of increasing the basin outflow without increasing the sedimentation.

Niagara River Ice (IHD)

Legend has it that on March 30th, 1848, ice blocked the lower end of Lake Erie so completely that the Niagara River dried up. Since the river began producing electrical power (and in the 1970s it was the greatest single power source in the world) problems due to icing have cut heavily into power output, which in 1968 in Canada alone was valued at \$5000 an hour.

By international treaty a minimum flow of 50,000 cubic feet per second must go over Niagara Falls for the scenic enjoyment of tourists. On very cold winter nights crystalline "frazil ice" forms in the turbulent, fast-flowing, super-cooled river water and begins to adhere to the river bottom as "anchor ice" which can reduce the flow by as much as 30,000 cubic feet per second.

Ontario Hydro operates a control structure crossing the river just above the falls. The flow of water over the falls can be increased or decreased depending on ambient conditions. Under anchor ice damming effects it may be necessary to reduce the amount of water which would ordinarily be diverted for power generation so that the minimum flow over the falls is maintained. This may result in a drastic reduction in power generation for a short period.

In 1967-68 instrumentation was installed along the control structure in order to compute the energy balance of the river on winter nights. A preliminary estimate of the ice season energy budget (Ferguson, 1968) was followed by the development of regression equations relating river flow retardation to meteorological variables (Ferguson and Cork, 1971).

Mountain Transects Project (IHD)

In mountainous areas of the world snowmelt from higher elevations contributes to the Spring freshet, often causing major floods. The problem is that massive amounts of snow may accumulate at high elevations but snowfall and snowpack measurements may be impossible due to the remoteness and inaccessibility of sites, to say nothing of the costs.

Many experiments have been carried out by hydrometeorologists, particularly in the U.S.A., using temporary specially-instrumented remote sites over selected mountain ranges. The objective is to estimate snowfall and snow accumulation over a mountain "transect" using the meteorological data from lower permanent observing sites. From these estimates the Spring runoff can be predicted with more confidence.

The Beaufort Range on Vancouver Island has elevations ranging from about 1000 ft. to over 4500 ft. above sea level. The IHD project, in cooperation with B.C. water resources and forestry agencies, commenced in 1967. Lower elevation sites were accessible in summer, and sometimes in winter, by logging roads. Higher sites were similarly accessible in summer but in winter had to be serviced by helicopters operating out of Comox.

Two transects of 5 stations each were instrumented. Because of expected maximum snow depths, instruments at around the 2500 ft. level were mounted on 10-foot towers while those near the 4500 ft. level were mounted on 20-foot towers. The project was described by Ferguson, Hunter and Schaefer (1975).

Perch Lake Evaporation Study (IHD)

Perch Lake is a circular pond with a diameter of about 2000 ft. It is located about 1 mile southwest of the Atomic Energy of Canada Limited (AECL) plant at Chalk River, Ontario. Its drainage basin includes the plant's disposal areas and the lake therefore contains tritiated water. This presented a unique opportunity to compare standard techniques for estimating evaporation with measurements of the flux of tritiated water vapour from the lake surface. The project was initiated in 1965. In addition to the AECL, cooperating agencies included the Inland Waters Directorate of Environment Canada and the Department of Fisheries and Forestry.

Meteorological instrumentation included three Class A evaporation pans. Two were located on the shore on opposite sides of the lake. The third pan was operated in 1971 and 1972. It was partially submerged in the lake and surrounded by a boom to dampen wave action.

Other comprehensive instrumentation enabled calculations of evaporation using Mass Transfer, Penman Combination, Energy Balance and Priestley-Taylor equations.

Results were published by Ferguson and Den Hartog (1975).

Airborne Remote Sensing of Snow Cover (IHD)

The earth emits natural gamma radiation. This varies depending on the nature of the surface. The intensity of the gamma rays is attenuated by water in its various phases.

In the winter of 1972-73 four gamma-ray spectrometer surveys, each 1850 km long, were flown over Southern Ontario at an altitude of 150 m, using a sodium iodide detector system. The data were used to calculate snowpack water-equivalent for 16 km sections along each flight line. The results were compared to data from 10 snow courses along the flight lines. Soil moisture corrections were based on measurements at selected sites.

For several years the Geological Survey of Canada (GSC) had been mapping surface concentrations of potassium, uranium and thorium using the spectrometer. "Ground truth" data were available from snow-free periods. The measurement technique had been used in the U.S.S.R., Norway and the U.S.A.

In addition to the GSC and AES, the Environmental Management Service of Environment Canada was a cooperating agency. Results were published by Grasty, Loijens and Ferguson (1973).

Other Remote Sensing Applications

Several studies applied surface, airborne or satellite remote sensing to estimate hydrometeorological elements. Hogg and Pollock (1975) used radar observations to estimate precipitation. Ferguson and Cork (1972) described the use of satellite photographs to determine the times of freeze-up and break-up of Canadian lakes.

The Water Balance and Its Components

Maps of surface water cover over all of Canada were derived (Hare, Ferguson, Anderson and Schwartz, 1974) and were printed in the Atlas of Canada (1974). A related publication dealt with national maps of precipitation as well as evapotranspiration (den Hartog and Ferguson, 1975). As previously mentioned evaporation maps for Canada were printed in the Atlas of Canada and in the Hydrometeorological Atlas of Canada. The water balance and its applications were described by Ferguson and Hare (1975).

CHAPTER 6

HYDROMETEOROLOGY ACTIVITIES 1977-2000

In the late 1970s there were still numerous publications based on data collected during the IHD. Many basin studies established during the IHD, including Benchmark Basin work, continued after the Decade (Louie, Goodison and Perks, 1988).

Hydrometeorology staff numbers declined; compare *Figures 7 and 8* with *Figure 6*. In 1991 the word "Hydrometeorology" disappeared from Service Organization Charts.

The reader may note that the name Eileen Veinot was mentioned on page 20 as one of the "original four" in 1959, and also appears on *Figures 6, 7, and 8*. As the longest-serving staff member Eileen had an excellent career.

After 1991 some of the traditional hydrometeorological work was continued in the new Water Resources and Marine Adaptation Division. This was largely in the area of wind-wave climatology studies. Much of this work, as well as studies of ice accretion on structures, was directed to the oceans off both the east and west coasts.

The Atmospheric Environment Service (1993) produced a list of publications in hydrometeorology and water resources applications from 1980 to 1993. There were 150 entries, of which 71 were authored by Hydrometeorology/Water Resources staff members. Of these, only 4, or 5.6%, were published in refereed journals. Also, between 1985 and 1993, 25 of the publications were written by contractors, representing a new emphasis on contracting-out.

Acid rain became a major issue in the 1980's. Climate Change was a growing issue in the 1980's and 1990's. The implications for regional and local water balance elements are of great significance. Hydrometeorologists and water resource managers became very interested in this issue and in the work of the Intergovernmental Panel on Climate Change (IPCC).

In 1999 the name of the Service was changed to the Meteorological Service of Canada (MSC).

Chief: Bill Pugsley
Secretary: Lou-Ann Hotz

Services	Lakes	Projects
Bill Hogg	Andrej Saulesleja	Shig Ishida
Dave Carr	George Irbe	Barry Goodison
Andy Hansen	Don Massey	Kirk Johnstone
Ain Niitsoo	Val Swail	Paul Louie
Vijaya Polavarapu	Eileen Veinot	Leo Mapanao
		John Metcalfe

Figure 7. Hydrometeorology Staff 1981-1982

Chief: Dave Colwell

Services	Lakes	Projects	Research
Dave Carr	George Irbe	Brad Bass	Barry Goodison
Andy Hanssen	Linda Mortsch	Ross Brown	John Metcalfe
Bill Hogg	Andrej Saulesleja	Shig Ishida	
Hao Le	Val Swail	Paul Louie	
Ain Niitsoo	Eileen Veinot		
Brian Routledge			

Figure 8. Hydrometeorology Staff 1990

MANAGEMENT PERSONNEL

With the gradual fading-out of IHD research and another reorganization of Hydrometeorology on the horizon, the author applied for and won the position of Chief of the Applications and Consultation Division in CSD, commencing in 1977. For a short period Gordon McBean, Chief of the Boundary Layer Research Division in ARD, was also Acting Chief of the Hydrometeorology and Environmental Impacts Research Division. Reorganization eliminated ARQH, with most of the staff returning to the one remaining Hydrometeorology component, in CSD. Lloyd Richards retired in 1977. He was succeeded by Bill Pugsley as Chief of the Hydrometeorology and Marine Applications Division, a position he held until 1982 when he left and Bill Hogg became Acting Chief. In 1990 (Figure 8) Dave Colwell was Chief and from 1991 to 1994 Paul Louie served as Chief of the renamed Water Resources and Marine Adaptation Division.

Water Balance of Large Lakes and Reservoirs (IHP)

During the IHD, the Coordinating Council of Unesco began planning for less intensive but longer term projects in an “International Hydrological Programme” starting in 1975. The Council identified the water balance to be one of the most important areas in the field of hydrology. After conducting a survey of 27 countries it was decided that a manual on the Water Balance of Large Lakes and Reservoirs would be produced. The author was appointed Chairman of a four-man international Working Group to carry out this task, which was expected to take several years to complete.

The work was carried out intermittently over the period 1978 to 1982. The task of authoring Volume I of the manual was shared among the four WG members. It was noted that the water balances of lakes and reservoirs are used for solving the following practical problems: quantitative and qualitative assessment of water resources; planning and control of electricity production at hydroelectric power stations; planning and implementation of irrigation and soil improvement; planning and implementation of fishery management; management of water resources, runoff transport and redistribution; planning and security of water transport and the protection of water resources.

(Among the countries of the world Canada has the largest total lake area, amounting to 780 thousand square kilometers, or 7.9% of the total area of the country.)

Volume I of the manual described methodology and was published by Unesco (Ferguson and Znamensky, 1981). This was followed by a volume of case studies (Ferguson et al., 1982) which included a chapter on computing the balance of natural substances and pollutants in water bodies.

Remote Sensing

Several papers were written on the applications of remote sensing, including flood prediction from satellite data (Ferguson, Deutsch and Kruus, 1979) and rainfall-rate estimates using radar (King, Hogg and Arkin, 1995).

Evaporation and Precipitation Studies

Phillips (1977) published a comparison of mass transfer estimates of evaporation from Lake Ontario during IFYGL. Extreme value estimates of snowmelt were described by Louie and Hogg (1980). In 1981 Don Gray and D.H.Male of the University of Saskatchewan edited a 776-page Handbook of Snow. Many Service researchers contributed to this publication. One lengthy chapter dealt with measurement and data analysis (Goodison, Ferguson and McKay, 1981). Estimating basin precipitation over the upper Great Lakes was the subject of a paper by Saulesleja and Louie (1983). Canadian methods for precipitation measurement and correction were published (Goodison and Louie, 1985).

Acidification

An acidic snowmelt shock-potential model for basin studies was produced (Louie, Johnstone and Barrie, 1984). An acidic shock study in south-central Ontario followed (Goodison, Louie and Metcalfe, 1986).

Climate Change

In 1987 a comprehensive book on the influence of climate change and climate variability on the hydrologic regime and water resources was published (Solomon, Beran and Hogg 1987). Socioeconomic implications of climate change were described by Mortsch and Louie (1992) and a related risk assessment approach was developed (Bass, 1993).

Flood Forecasting

Pugsley (1977) described meteorological support for flood forecasting and later produced a flood hydrology guide for Canada focusing on hydrometeorological design techniques (Pugsley, 1981).

EPILOGUE

Disraeli (1867) said "Change is inevitable. In a progressive country change is constant". This is certainly true for the Canadian Public Service. New (and existing) governments bring with them changes in priorities, programs and financial and person-year allocations, and reorganizations soon follow. At the level of smaller programs, adjustments often need to be made in response to public demands for action on new issues.

In 1970 Alvin Toffler coined the term Future Shock. He foresaw the now-obvious acceleration of change, which affects many aspects of our lives. This is most apparent in the communications sector. The rapid advances in miniaturized communications devices are astounding. This year's hot item may be obsolete next year. Of course these rapid changes are a normal part of life for younger people. On the other hand one might question the value of some modern communications innovations. For example voice mail ("your call is important to us.....") may well be a boon to those responding to requests for information. But there are still older Luddites among us who prefer to speak immediately to a real person rather than being subjected to long and frustrating waiting times. Voice mail represents a noteworthy decrease in the quality of service to the unfortunate "customer". Change, while inevitable, is not always for the best for all people.

Those staff members who are seriously affected when programs, or even Departments, are eliminated will be understandably upset. Those who contributed many years to successful programs are sad to see them wind down.

Some measure of the success achieved by the relatively small Hydrometeorological programs in the MSC from 1959 to 1990 is reflected in the many new economically valuable applications techniques and research publications produced. A measure of the scientific and management skills nurtured in Hydrometeorology could be found in the subsequent careers of senior managers and scientists who worked in Hydrometeorology over the years. This brings to mind a parallel.

In 1980 ADM Art Collin jokingly coined the term "Gander Mafia", noting that many of the senior managers and senior scientists in the current and past Service had "done time" as weather forecasters in Gander:

Pat McTaggart-Cowan, Reg Noble (and later, the author) became Heads of the Service. McTaggart-Cowan and Noble were awarded the Patterson Medal, the most prestigious prize for "distinguished service to meteorology in Canada". Ted Munn and Gordon McKay also won this award. McTaggart-Cowan was honoured with an MBE.

One could as easily refer to a more modern “Hydrometeorology Mafia”: Three Hydrometeorology staffers - Jim Bruce, the author and Gordon McBean- eventually became ADM's of the Service. Bruce and McBean were awarded the Patterson Medal. Dave Phillips and Des O'Neill were also winners. Bruce and Phillips were awarded the Order of Canada. Jim Bruce was only the third Canadian (after Warren Godson and Ken Hare) to win the IMO Prize, the most prestigious recognition for contributions to international meteorology (among many other honours, including honorary doctorates).

Other staff members had very successful careers in the MSC and some were recognized with other awards and honours, including a few (perhaps not enough!) from the CMS/CMOS.

By all standards the Hydrometeorology program was highly successful. Its phasing-out was largely a result of significant changes in government priorities and policies.

Momentous changes in the Service structure have continued since 2000. For example, the Headquarters of the Service, and the main office of its Head, had been located in the Toronto area from the time the Service originated in 1871. In 2006, as a cost-cutting measure, the Downsview office of the ADM was closed and the building was downgraded to Environment Canada's Ontario Region Office.

The Departmental Organization Chart for 2006 lists an Associate Deputy Minister and 8 Assistant Deputy Ministers, at least 3 of whom (in addition to the ADM of MSC) have significant responsibilities in meteorology and climate. Perhaps this dispersion of responsibility reflects an increased and wider interest in climate change.

BIBLIOGRAPHY

- Agnew, T.A., and V.R.Swail , 1985. Proceedings, International Workshop on Offshore Winds and Icing. Atmospheric Environment Service, CCC, 407pp.
- Atmospheric Environment Service, 1977. Publications in Hydrometeorology and Marine Applications. Environment Canada DS#8-77.
- Atmospheric Environment Service, 1993. Publications by the Water Resources and Marine Applications Division. (Includes publications by the Hydrometeorological Projects Section and the Lakes and Marine Section Of the former Hydrometeorology Division). Internal Report.
- Aubert, E.J. and T.L.Richards, eds., 1981. IFYGL - The International Field Year for the Great Lakes. National Oceanic and Atmospheric Administration Dept. of Commerce, Ann Arbor Michigan 410pp.
- Bass, B., 1993. Water Resources under Climate Change : A Risk Assessment Approach. AES Internal Water Resources and Marine Adaptation Division Report.
- Berry, M.O., 2002. The Rise and Fall of Climate Applications : The History of a Meteorological Service Program. Unpublished Report, 69pp..
- Bruce, J.P., 1957. Hydrometeorology and its Applications in Ontario Transactions of the Royal Society of Canada, Series 3, Vol LI Section 4 pp63-70.
- Bruce, J.P.,1957. Preliminary Estimates of Probable Maximum Precipitation Over Southern Ontario. Engineering Journal, Vol 40 No 7 pp978-984
- Bruce, J.P., and J.G.Potter, 1957. The Accuracy of Precipitation Measurements Proceedings, Third National Meeting, Royal Meteorological Society, Canadian Branch, Toronto 8(1) pp1-15.
- Bruce, J.P., 1959. Storm Rainfall Transposition and Maximization. Proceedings First Canadian Hydrology Symposium. NRC Ottawa pp162-171.
- Bruce, J.P., and G.K.Rodgers, 1962. Water Balance of the Great Lakes System American Association for the Advancement of Science Publication #71.
- Bruce, J.P., 1963. Relationship Between Precipitation and Precipitable Water on the Canadian Prairie. IASH, IUGG General Assembly Berkely California, Publication #63 pp181-188.
- Bruce, J.P., 1966. Weather and Water. Canadian Geographical Journal Vol LXXII(1) pp23-31.
- Bruce, J.P., and R.H.Clark, 1966. Introduction to Hydrometeorology. Pergamon Press, Oxford 319pp.
- Bruce, J.P., 1967. Meteorology and Water Resources. In Water Resources in Canada University of Toronto Press, C.E.Dolman, editor.
- Bruce, J.P., 1981. Hydrometeorology in Canada. Keynote Address, Canadian Meteorological and Oceanographic Society Congress, Saskatoon 22pp.
- Bruce, J.P., 2002. Personal communication.

- Carson, R., 1962 *Silent Spring*. Houghton Mifflin Co.
- Cork, H.F., and R.G.Chapil, 1967. Instrumentation for the Study of Ice Formation on the Niagara River. Meteorological Branch CIR 4496 TEC 627, Dept of Transport.
- Den Hartog, G. and H.L.Ferguson, 1975. National Water Balance Maps of Evapotranspiration and Precipitation. Proceedings Canadian Hydrology Symposium pp511-525.
- Disraeli, B., 1867. Speech, Edinburgh, 29 October.
- Ferguson, H.L., 1962. A Tephigram Overlay for Computing Precipitable Water. Meteorological Branch, Dept of Transport, CIR-3653, TEC-409.
- Ferguson, H.L., 1968. A Preliminary Estimate of the Ice Season Energy Budget for the Niagara River. IASH Bulletin, Vol.13, pp 41-58.
- Ferguson, H.L., H.F.Cork and A.D.J.O'Neill, 1969. Applications of Satellite Photographs to Hydrology in Canada. Proceedings, NRC Hydrology Symposium No 7, Victoria, pp311-343.
- Ferguson, H.L., A.D.J.O'Neill and H.F.Cork, 1970. Mean Evaporation over Canada. *Water Resources Research* 6(6) pp1618-1633.
- Ferguson, H.L., and H.F.Cork, 1971. Regression Equation Relating Ice Conditions in The Upper Niagara River to Meteorological Variables. Proceedings, WMO-4 Symposium on Measurement and Forecasting. Banff, 13pp.
- Ferguson, H.L., and H.F.Cork, 1972. The Use of Satellite Photographs to Determine The Time of Freeze-up and Break-up of Canadian Lakes. Proceedings, First Canadian Symposium on Remote Sensing, Ottawa pp269-280.
- Ferguson, H.L., 1973. Precipitation Network Design for Large Mountainous Regions. Proceedings, WMO Symposium, Geilo, Norway.
- Ferguson, H.L., and W.D.Hogg, 1974. Monthly Evapotranspiration Estimates for the Canadian Land Portion of the Lake Ontario Basin during IFYGL. Proceedings IAGLR 17th Conference on Great Lakes Research pp269-287.
- Ferguson, H.L., H.I.Hunter and D.G.Schaefer, 1975. The IHD Mountain Transects Project- Instrumentation Problems and Data Record. Atmospheric Environment Service, CMRR - 1/75.
- Ferguson, H.L., and F.K.Hare, 1975. The Water Balance and its Applications. Proceedings, Canadian Hydrology Symposium pp417-434.
- Ferguson, H.L., and G.denHartog, 1975. Meteorological Studies of Evaporation at Perch Lake, Ontario. AECL-5041/1, Chalk River Nuclear Laboratories, pp418-447.
- Ferguson, H.L., M.Deutsch and J.Kruus, 1979. Applications to Floods of Remote Sensing from Satellites. Proceedings COSPAR Twenty-Second Plenary Meeting, Bangalore, India.

- Ferguson, H.L., and V.A.Znamensky, eds., 1981. Methods of Computation of the Water Balance of Large Lakes and Reservoirs. Vol I Methodology. Unesco Studies and Reports in Hydrology No 31 120pp.
- Ferguson H.L., V.A.Znamensky, B.E.Goodison, T.P.Gronskaya, P.Y.T.Louie and M.N. Moskvina, 1982. Methods of Computation of the Water Balance of Large Lakes and Reservoirs. Vol II , Case Studies, Unesco Studies and Reports in Hydrology No 31 75pp.
- Goodison, B.E., H.L.Ferguson and G.A.McKay, 1981. Measurement and Data Analysis, pp191-274 in Handbook of Snow, D.M.Gray and D.H.Male eds., Pergamon Press Canada Ltd., 776pp.
- Goodison, B.E. and P.Y.T.Louie, 1985. Canadian Methods for Precipitation Measurement and Correction. Proceedings, WMO Workshop on the Correction of Precipitation Measurement, Zurich, pp141-145.
- Goodison. B.E., P.Y.T.Louie and J.R.Metcalf, 1986. Snowmelt Acidic Shock Study In South-Central Ontario. Water,Air and Soil Pollution Vol 31 pp131-138.
- Grasty, G.H., H.S.Loijens and H.L.Ferguson, 1973. An Experimental Gamma Ray Spectrometer Snow Survey over Southern Ontario. Proceedings, US/IHD Interdisciplinary Symposium on Advanced Concepts and Techniques in the Study of Snow And Ice Resources, Monterey, Cal., pp579-593.
- Hare, F.K., H.L.Ferguson, J.C.Anderson and J.Schwartz, 1974. Mean Evapotranspiration Over Canada, Part 1, Cover and Land Form. Atmospheric Environment Service Climatological Series, Environment Canada. (See also Atlas of Canada 1974, Maps pp7-8 and 39-40).
- Hogg, W.D., and D.M.Pollock, 1975. Precipitation Estimates by Radar during IFYGL. Proceedings, Canadian Hydrology Symposium pp51-64.
- Hogg, W.D., D.A.Carr and B.Routledge, 1985. Rainfall Intensity-Duration Frequency Values for Canadian Locations. AES CLI -1-85 18pp.
- Hogg, W.D., 1993. Integration of Satellite,Radar and Rain Guage Data. Proceedings CGU Meeting, Banff.
- Hogg, W.D., 2006. Personal Communication.
- Irbe, G., 1969. Some Unusual Surface Water Temperature Patterns in the Great Lakes As Detected by Airborne Radiation Thermometer Surveys. Proceedings IAGLR 12th Conference on Great Lakes Research, pp583-607.
- Irbe, G., 1992. Great Lakes Surface Water Temperature Climatology. AES Climatological Studies No 43, 215pp.
- Johnstone, K., and P.Y.T.Louie, 1983. Water Balance Tabulations for Canadian Climate Stations. Atmospheric Environment Service, DS-#8-83, 16pp.
- King, P.W.S., W.D.Hogg and P.A.Arkin, 1995. The role of Visible Data in Improving Satellite Rain-rate Estimates. Journal of Applied Meteorology Vol 34, No 7, pp1608-1621.

- Louie, P.Y.T., 1979. Lake Evaporation Estimates in Northern Latitudes. Proceedings, Canadian Hydrology Symposium pp490-501.
- Louie, P.Y.T., and W.D.Hogg, 1980. Extreme Value Estimates of Snowmelt. Proceedings, Canadian Hydrology Symposium pp64-76.
- Louie, P.Y.T., K.Johnstone and L.A.Barrie, 1984. Acidic Snowmelt Shock Potential Model for Basin Studies. Proceedings, Canadian Hydrology Symposium
- Louie, P.Y.T., B.E.Goodison and A.R.Perks, 1988. Canada's Benchmark Basin Program. Proceedings, Canadian Hydrology Symposium, pp13-19.
- Louie, P.Y.T., 2006. Personal Communication.
- McBean, G.A., and R.D.Paterson, 1975. Variations of the Turbulent Fluxes of Momentum, Heat, and Moisture over Lake Ontario. Journal of Physical Oceanography, Vol 5, pp523-531.
- McCulloch, J.A.W., and V.S.Derco, 1968. Great Lakes Wind-Wave Study Meteorological Branch, DOT, Tech. Memoranda No 1 Tec-696.
- McCulloch, J.A.W., and M.Booth, 1970. Estimation of Basin Precipitation by Regression Equation. Water Resources Research, Vol.6 No.6.
- McCulloch, J.A.W., 1973. The International Field Year for the Great Lakes. Hydrological Sciences Bulletin XVII , 4, pp367-373.
- McCulloch, J.A.W., 1975. The IFYGL Evaporation Program. Proceedings, Canadian Hydrology Symposium pp137-146.
- McCulloch, J.A.W., 2006. Personal Communication.
- Millar, F.G., 1936. Wind Tunnel Experiments on Evaporation. Canadian Meteorological Memorandum #2.
- Millar, F.G., 1953. Surface Temperatures of the Great Lakes. Journal, Fisheries Research Board of Canada. Vol 9 pp239-376.
- Millar, F.G., 1992. My Years in the Meteorological Service. Unpublished Paper.
- Mortsch, L.D., and P.Y.T.Louie, 1992. The Socioeconomic Implications of Climate Change in the Great Lakes - St.Lawrence Basin. Proceedings AWRA Conference, Reno, Nevada. Pp397-406.
- Mukammal, E.I., and J.P.Bruce, 1960. Evaporation Measurements by Pan and Atmometer. Meteorological Branch, Dept. of Transport CIR 3300 TEC 315
- Munn, R.E., and D.Storr, 1967. Meteorological Studies in the Marmot Creek Watershed Alberta, Canada. Water Resources Research, 3(3), pp713-722.
- O'Neill, A.D.J. and H.L.Ferguson, 1971. A Spectral Investigation of Horizontal Moisture Flux in the Troposphere (IFYGL Feasibility Study SP-2). Journal of Applied Meteorology 10(1) pp14-22.
- O'Neill, A.D.J., and D.M.Gray, 1971. Energy Balance and Melt Theories. NRC 8th Hydrology Symposium, Quebec City.
- Phillips, D.W., and J.A.W.McCulloch, 1974. Monthly Means and Deviations From Normal of Temperature and Precipitation in the Lake Ontario Basin During IFYGL. Atmospheric Environment Service. Environment Canada TEC 815

- Phillips, D.W., 1977. A Comparison of Mass Transfer Estimates of Evaporation from Lake Ontario during IFYGL. AES Tec 828 12pp.
- Pugsley, W.I., 1977. Meteorological Support for Flood Forecasting in Canada. Proceedings, Canadian Hydrology Symposium, Edmonton.
- Pugsley, W.I., 1980. Role of AES in Hydrometeorology and Marine Applications. Unpublished paper.
- Pugsley, W.I., 1981. Flood Hydrology Guide for Canada : Hydrometeorological Design Techniques. CLI-3-81 Atmospheric Environment Service, 102pp.
- Pugsley, W.I., 2002 Personal Communication.
- Richards, T.L., 1966. Great Lakes Water Temperatures by Aerial Survey Proceedings, IASH Symposium on Hydrology of Lakes and Reservoirs, Garda Italy, Publication #70 Vol 1 pp406-419.
- Richards, T.L., 1971. Hydrometeorology. In Encyclopedic Dictionary of Physics Supplementary Vol 4, Pergamon Press 6pp.
- Richards, T.L., 1973. Hydrometeorology in the Atmospheric Environment Service. Atmosphere, Vol. 11, No.4.
- RCGS (Royal Canadian Geographical Society), 2006. Brochure, September.
- Saulesleja, A. and P.Y.T.Louie, 1983. An Evaluation of the Real-Time Observing Network for Estimating Basin Precipitation over the Upper Great Lakes. Proceedings, Fifth AMS Symposium on Meteorological Observations and Instrumentation, pp384-386.
- Solomon, S.I., M.Beran and W.D.Hogg, Eds., 1987. The Influence of Climate Change and Climate Variability on the Hydrologic Regime and Water Resources. IAHS Publication No 1689, 640pp.
- Storr, D., 1963. Maximum One-Day Rainfall Frequencies in Alberta . Cir 3796 Tec 451. Meteorological Branch Dept. of Transport.
- Storr, D., 1967. Precipitation Variations in a Small Watershed. Proceedings, Western Snow Conference, Boise, Idaho.
- Storr, D., 1969. Meteorology in Watershed Research in Alberta. Atmosphere, Vol 7 No 2.
- Storr, D., H.L.Ferguson and H.F.Cork, 1970. A Graphical Aid for Bowen Ratio Applications. Journal of Applied Meteorology 9(6) pp940-942.
- Storr, D., 1971. Estimating Effective Net Radiation for a Mountainous Watershed. Boundary Layer Meteorology 3 pp3-14.
- Storr, D., 1973. Wind-Snow Relations at Marmot Creek Alberta. Canadian Journal of Forest Research, Vol 3.
- Storr, D., and H.L.Ferguson, 1974. On the Ambiguity of Bowen Ratios over Freezing and Melting Surfaces. Journal of Applied Meteorology Vol 13 No 4 pp509-511.
- Sullivan J., E.M.Rasmusson and H.L.Ferguson, 1975. Atmospheric Water Balance Over Lake Ontario, October 30 - November 14, 1972 (IFYGL) Proceedings, 18th Conference on Great Lakes Research.
- Swail, V.R. and A.Saulesleja, 1981. Geostrophic Wind Climatology of the Northwest Atlantic Region. Proceedings, Canadian Meteorological

And Oceanographic Society Congress, Saskatoon.

- Thomas, M.K., 1991. *The Beginnings of Canadian Meteorology*.
ECW Press.
- Thomas, M.K., 1996. *Forecasts for Flying : Meteorology in Canada 1918-1939*.
ECW Press.
- Thomas, M.K., 2001. *Metmen in Wartime : Meteorology in Canada 1939-1945*.
ECW Press
- Thomas, M.K., 2002. Personal communication.
- Thomas, M.K., 2006. Personal communication.
- Toffler, A., 1970. *Future Shock*. Random House
- Webb, M.S., and D.W.Phillips, 1973. An Estimate of the Role of Lake Snowstorms in the Hydrology of the Lake Erie Basin. *Water Resources Research* Vol 9 No 1, pp103-172.