Inquiry on Federal Water Policy
Research Paper #2

THE IMPACT OF HUMAN ACTIVITIES ON WATER IN CANADA

by

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THE INQUIRY ON FEDERAL WATER POLICY

The Inquiry on Federal Water Policy was appointed by the federal Minister of the Environment in January of 1984 under the authority of the Canada Water Act. The members were Peter H. Pearse, chairman; Françoise Bertrand, member; and James W. MacLaren, member. The Inquiry was required by its terms of reference to review matters of water policy and management within federal jurisdiction and to make recommendations.

This document is one of a series of research papers commissioned by the Inquiry to advance its investigation. The views and conclusions expressed in the research papers are those of the authors. Copies of research papers and information on the series may be obtained by writing to the Enquiry Centre, Environment Canada, Ottawa, Ontario K1A 0H3.

Frank Quinn
Director of Research

Abstract

The paper offers an overview of the impact of the human economy on water quantity and quality. The pristine environment had intact forest or prairie cover, with low sediment and nutrient burdens in streams and lakes (though prairie sloughs were often clouded). Forest cutting has denuded slopes, thereby encouraging soil losses. Agricultural development has also led to increased sediment and nutrient loading of streams. Urban and industrial development has upset local drainage, and added a large roster of toxic pollutants. The Great Lakes-St. Lawrence system has seen recent reductions of phosphorus loading, and a reduction in algal blooms: but toxic substances in sediemtns remain a problem. Acid deposition has also affected water quality. Future climatic change associated with carbon dioxide build-up will add to water demand, and reduce supply in many areas. Great Lakes outflow is expected to decrease over the next half-century because of increased evaporation and increased consumptive withdrawals, especially by the U.S. Good water science--already available--is one of the keys to remedial action.

Résumé

Cette recherche présente un sommaire de l'impact qu'a eu l'économie humaine sur la qualité et la quantité des resources en eau. L'environnement primitif était recouvert de forêts intactes ou de prairies et la charge en sédiments et en nutrients dans les lacs et les cours d'eau était peu élevée (bien que les eaux de marécages des prairies aient été souvent troubles).

La coupe forestière a dénudé les pentes et de ce fait accentué les pertes en sol. Le développement de l'agriculture a aussi contribué à l'augmentation de la charge en sédiments et en nutrients des cours d'eau. Le développement urbain et industriel a dérangé le drainage local et ajouté une longue liste de polluants toxiques.

Le système des grands lacs et du St-Laurent a connu récemment une réduction de sa charge en phosphore et en algues mais les substances toxiques et les sédiments demeurent un problème. Les dépôts acides ont aussi affecté la qualité de l'eau. Les modifications climatiques futures associées à l'augmentation de la concentration en CO_2 dans l'atmosphère vont faire augmenter la demande en eau et réduire l'approvisionnement dans plusieurs régions. La quantité d'eau quittant les grands lacs pourrait diminuer au cours du prochain demi-siècle en raison de l'évaporation accrue et de l'augmentation des prélevèments pour consommation spéciallement par les États-Unis. L'utilisation de principes scientifiques reconnus et déjà applicables est une partie de la solution à ces problèmes.

Acknowledgement

In preparing this paper I was helped by many generous people. Those whose works I have cited are acknowledged in the text. In a few cases my helpers declined to be identified, either because of modesty or of the sensitivity of their jobs. A partial list of those to whom I am grateful includes T.R. Oke, G. Wall, D. Coleman, H. Hill (and his PFRA colleagues), K.D. Harvey, R.H. Swanson, W.I. Pugsley, E.D. Ongley, J.P. Bruce, A. Lachance, D. Lennox, R. Pentland, Keith Rodgers, F. Elder, J. Barica, J. Lawrence, A. Laycock, A.P. Grima, J. Marsalek and S. Ommanney. E.D. Ongley in particular subjected an early draft to intensive and most helpful criticism. To all of them, and to their institutions, go my warmest thanks. The staff of the International Joint Commission were also most helpful in providing documentation.

I profited from reading several early drafts of Environment Canada's <u>State of the Environment</u>, not yet directly quotable. D.J. Rapport and P.M. Bird are thanked for their courtesy in allowing me to abstract certain diagrams and data.

I could not have completed this essay within the announced time frame without the help of my Executive Assistant, Mrs. M.C. Grisdale. The text was word processed by another good friend, Kartini Rivers.

Finally my apologies to any I have overlooked, and my thanks to the Inquiry for the chance to contribute to its important work.

F.K.H.

List of Contents

Figures

Tables

The Impact of Human Activities on Water in Canada

F. Kenneth Hare
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1. Preamble

The Inquiry has asked me to write a broadly philosophical introduction to the human impact on water in Canada, deliberate and inadvertent. Statistics, tables and graphs, it was hinted, would be much less useful than a flowing text full of ideas. In any case, someone else would provide the hard numbers.

This is a formidable challenge, because I am a natural scientist used to dealing in firm quantities. Numbers are easier to come by than words or ideas. Description is simpler than analysis, and measurements are easier than speculation--at least if the latter is to mean anything. I conclude that the Inquiry has thrown me a fast ball.

What I have done is to write one person's perception of a complex question that defies simple analysis. I have cited many authorities from a variety of fields, mostly the various sciences that have a bearing on the hydrologic cycle, and on human interference in the way it works. I have written as a friendly outsider. I apologize to those who have spent their lives on water research and management. Many of them could have done this job far better than I could. Only when I am writing about climate am I on my own ground.

I confess that here and there numbers, tables and graphs have crept into my account--and I have no doubt that they will invade the Inquiry's own report. One major difference is that my numbers are not often preceded by the dollar sign. I have written in the currency of science.

2. The Apparent Abundance

Canadians have put their national life together in the presence of superabundant water. Parliament looks down on the turbulent Ottawa River. The Heights of Abraham command superb views across the St. Lawrence, surely one of the world's great waterways. The enormous Fraser delta lies behind Vancouver. The country was first linked from coast to coast, not by the CPR, but by the fur brigades of the North West Company, who used the Great-Lakes system, and the Hudson's Bay drainage, to get their access to the west. Far away to the north-west lay an even greater river, the Mackenzie, still close to its pristine state. Water has thus been part of our legend and will remain so.

The superabundance is legendary, but not mythical. The mean annual discharge of Canadian rivers to the Pacific, Arctic and Atlantic Oceans is near 100,000 cubic metres per second, $m^3\ s^{-1}$. This amounts to an annual transfer to the oceans of 3,150 billion (10^9) cubic metres. A cubic metre of water weighs a metric tonne, so that no-one can dispute that this is a huge output of water, only a small part (of order 2 per cent) of which will have been withdrawn and used by people on its route to the sea (see Appendix I).

All these figures refer to throughput, to annually recharged supply--which, incidentally, is more than double that of the contiguous US. In addition, Canada has huge lakes, which hold immense amounts of water in storage. Smaller amounts are stored as glacial ice. Even greater storage lies below the surface, as groundwater. All this is ultimately derived from the annual surface run-off, but the existence of such reservoirs in the throughput system is a great asset, because it stabilizes streamflow. Lake

Superior's volume is such that its storage is equivalent to about two centuries of outflow through the St. Mary's River (Figures 1-3).

Why are we so richly endowed? Because of abundant rainfall and snowfall, together called precipitation. In an average year Canada gets the equivalent of about 600 millimetres depth of rainfall, averaged over her 9,900,000 square kilometres (km^2) of territory. The national input thus equals about 6,000 x 10^9 cubic metres, or metric tonnes, of water. About 2,850 x 10^9 cubic metres are lost by evaporation. The rest is the annual streamflow that provides us with our major sources of water.

Most people cannot grasp such huge numbers. Hence the ordinary Canadian has little feeling for our water situation. He or she is vulnerable to bad advice, because the intuition works poorly if there is no assured base of information to start from. A helpful yardstick is to recall that each Canadian, among the largest of water users, needs about 7 cubic metres per day to help run the national life and economy. This amounts to 64 x 10^9 m^3 per annum for the whole population. The annual discharge to the ocean of our rivers is thus about fifty times as great as our withdrawals of water. Clearly we still have more than enough for all our purposes. The abundance is real.

Yet problems have arisen, or this Inquiry would not be sitting. Canadians insist on living in cities, creating the need for large, local concentrations of supply. The habits of urban life, together with industrialization, create pollution problems. Water quality has been drastically altered. The forest industries have stripped the vegetation off much of southern Canada's surface, altering the flow pattern, sediment-load and nutrient balance of the lakes and rivers. Agriculture has had similar impacts. Navigation and power development have led to the damming and regulation of streams and estuaries. And there are large regional inequalities of supply, so that the Prairies go short while British Columbia's coastline is drenched with surperfluous rainfall.

It will be my conclusion that the shortage now threatening in some areas arises from human failures and false expectations--from institutional weakness, postponed decisions and the view that water is locally inexhaustible, which is certainly untrue. It is also the case that many future images of economic expansion, especially in the energy sector, are quite unrealistic in their assumptions about available water.

In a striking exposé of these problems, Foster and Sewell (1981) spoke of an emerging crisis in the nation's access to water. Two areas, in particular, are potentially water-deficient--much of the Prairies, and the parts of Southern Ontario that fringe Lakes Huron, Erie and Ontario. The first of these is a region of naturally low rainfall and streamflow. The second, however, has abundant natural supply--whose adequacy is nonetheless threatened by future economic development. Both areas will be looked at in detail in the following account.

Having grown up in a densely-populated European country where denser population and more intensive industry are well-served by supply less abundant than that of Southern Ontario, I remain unrepentantly of the opinion that Canada's water problems arise from human misuse, not from poverty in the resource. In the same vein, the problems are soluble if good water science is combined with sound political understanding.

3. The Hydrologic Cycle

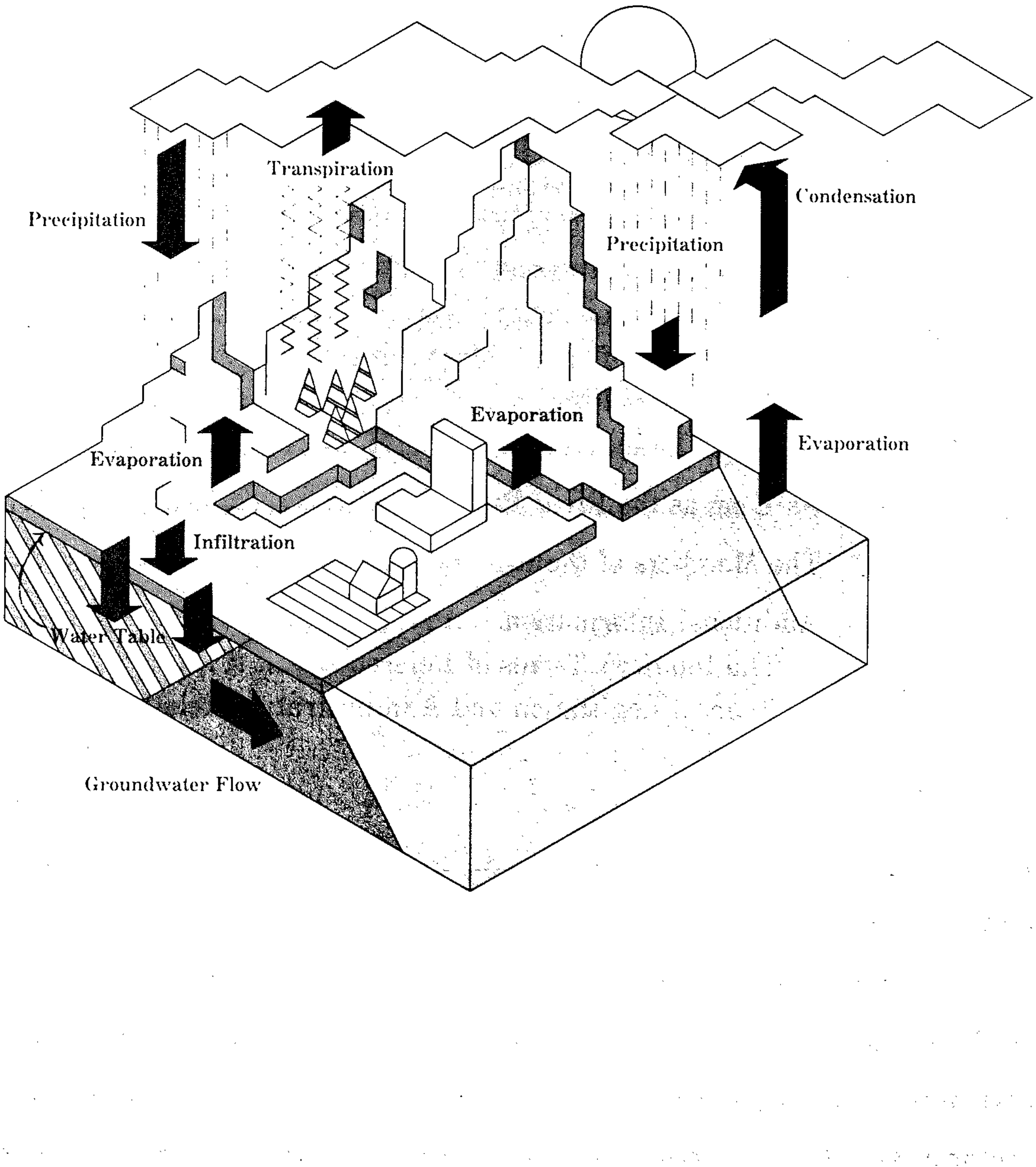
Figure 1 is a sketch of the hydrologic cycle, the system whereby water is stocked in certain reservoirs, and transferred between them by processes often subject to human influence (see also Figures 2-3).

Precipitation--rainfall and snowfall--starts the cycle off. The water vapour in the air (humidity) is condensed as cloud, and precipitated in the storm systems familiar to all Canadians. The humidity of the atmosphere is maintained by evaporation from the oceans and wet continental surfaces (including transpiration from vegetation). On the average, Canada gains 600 mm per annum (600 kilogrammes per square metre) from precipitation, and loses a little under half this by evaporation or transpiration.

The surplus precipitation becomes run-off--the discharge of water from the land-surface into streams--and then becomes streamflow. Part of such run-off, especially during heavy downpours or during snowmelt, goes directly downslope, as surface or very shallow flows. But most of it infiltrates the soil (which may hold in storage, available to plants, up to about 200 mm of rainfall). Some reaches the level of saturation in the rock below, the watertable, which is the upper surface of the groundwater that occupies the fractures and porespaces of the subsoil and bedrock. A slow flow of groundwater down the watertable slope may return the infiltrated water to the stream systems as springflow.

All these processes are the objects of detailed scientific analyses by hydrologists, climatologists, geomorphologists, groundwater geologists, soil scientists, agricultural scientists, foresters, hydraulic engineers, and ecologists. Water science is highly interdisciplinary. Hence its study in

Figure 1 The Water Cycle



the universities is badly fragmented. In the public service many departments have a legitimate interest. To overcome this fragmentation Canada has created a number of broadly-based research centres across the country--for example, the Canada Centre for Inland Waters at Burlington, Ontario. Nevertheless, there is still scope for further integration, especially in the universities.

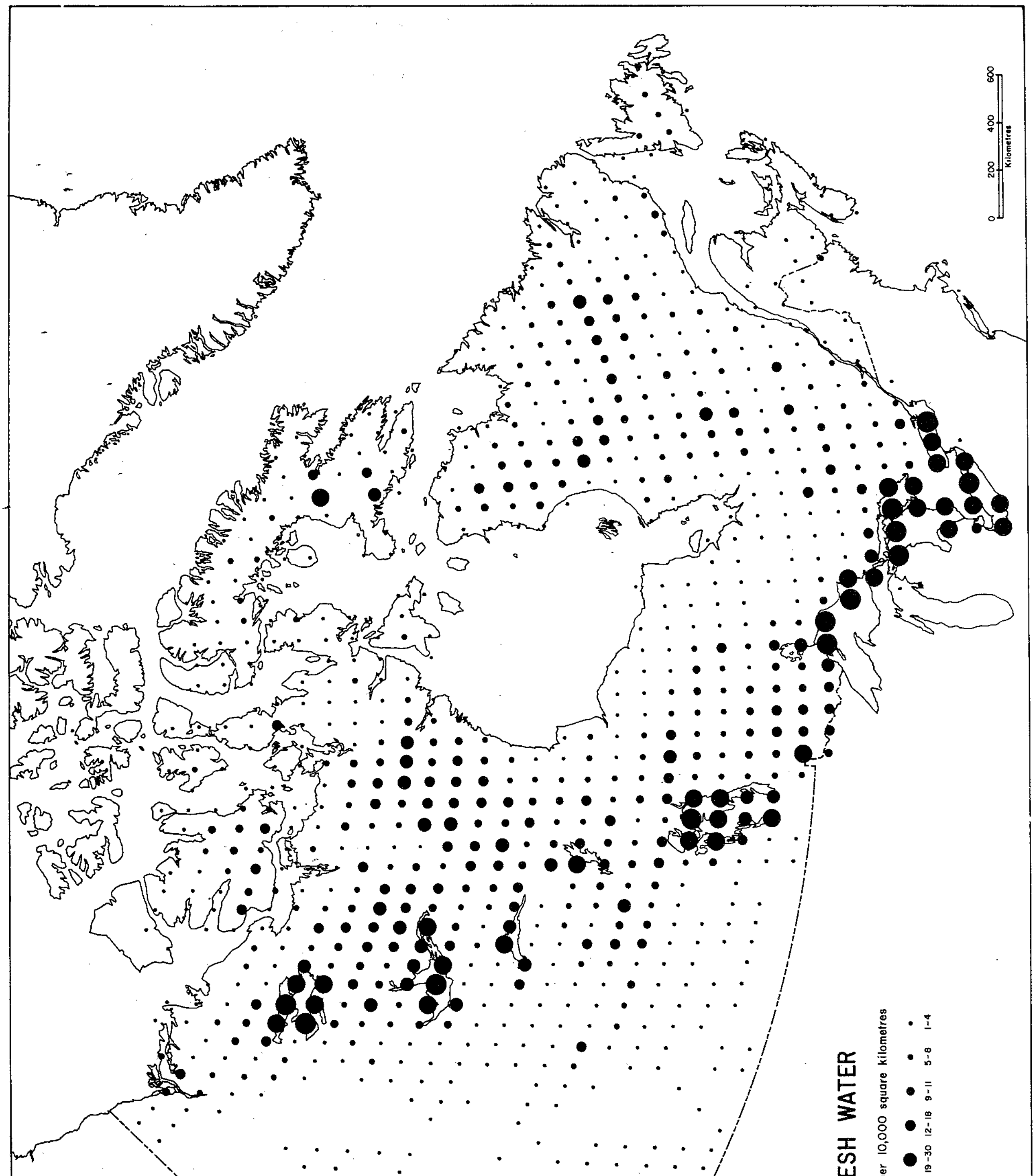
The economic activities of mankind have greatly disturbed the hydrologic cycle, in two chief ways:

(i) rates of run-off and streamflow have been affected, so that flood incidence, high and low water levels and rates of erosion or deposition have also changed. These are questions of water quantity. They depend primarily on altered timing and magnitude of events, rather than on actual change of annual discharge. The activities leading to these effects include:

- deforestation, or altered soil and vegetation, due to the forest industries;
- agricultural land use, both arable and pastoral, where the largest effects may be due to the deliberate withdrawal and consumptive use (evaporation) of streamflow for irrigation and stock watering;
- stream channel alteration for navigation or flood-control;
- streamflow regulation, including damming, for hydroelectric development;
- urbanization, involving widespread building of impervious surfaces and storm sewers, both of which drastically alter streamflow.

Figure 2. Distribution of fresh water lakes, as percentages of total area within 10,000 square kilometre squares. Total water volume is not reliably known.

Source: These and comparable figures were prepared under contract to the Atmospheric Environment Service, and are reproduced by permission of H.W. Ferguson, Director-General, Canadian Climate Centre, John C. Anderson, J. Schwartz and others did most of the original estimation.


FRESH WATER
Percentage per 10,000 square kilometres
61-100 31-60 19-30 12-18 9-11 5-8 1-4
0 200 400 600
Kilometres

(ii) water quality has been affected by altered sediment and nutrient loading of streams, releases of untreated sewage, farm and forest wastes, and industrial residues, chiefly arising from:

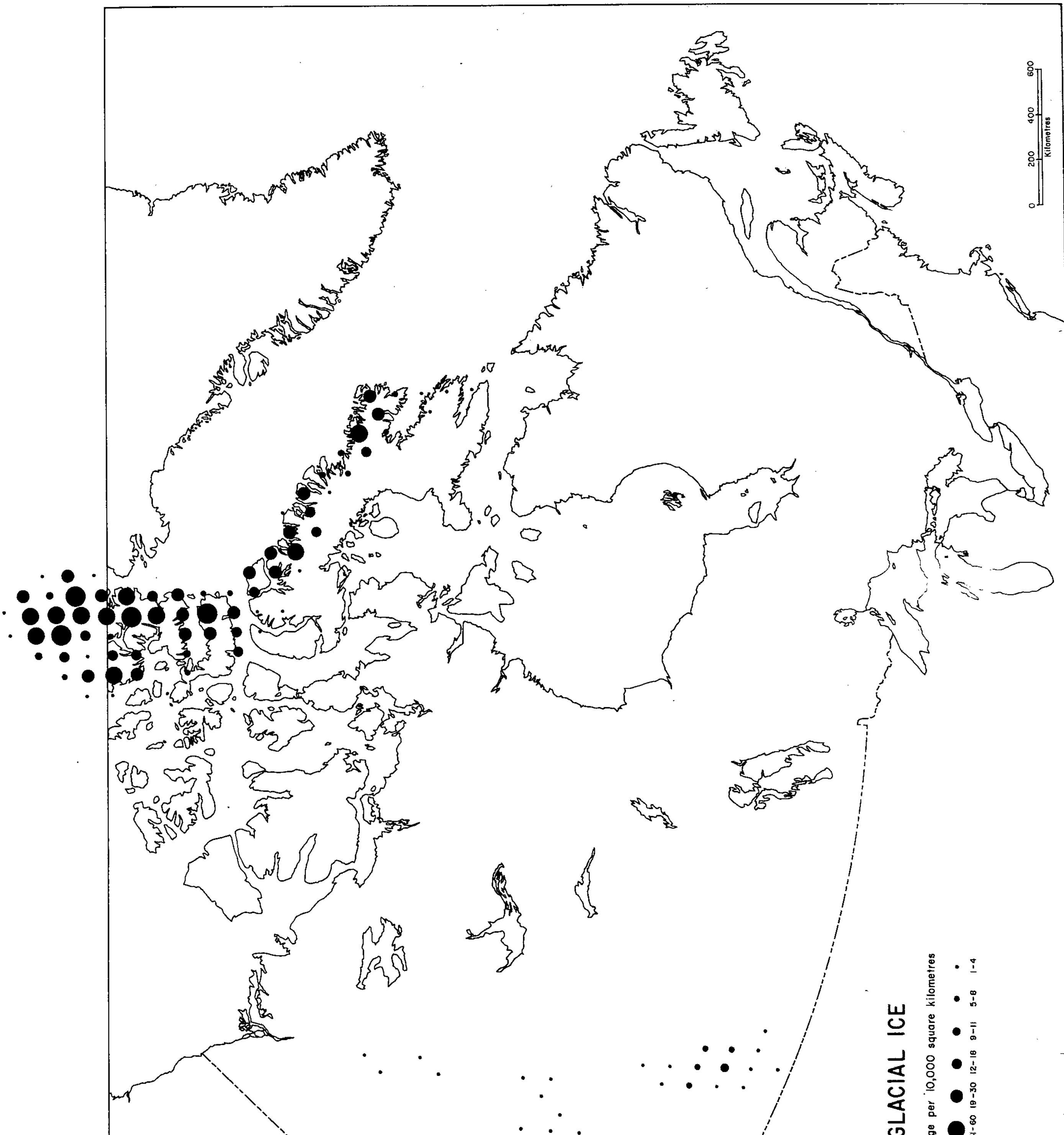
- leaching from agricultural land of natural materials, including carbon, and added fertilizers, herbicides and pesticides;
- sewage overspills, often in association with inadequate storm sewers, with consequent release of microbial contaminants into streams and lakes;
- industrial waste products, notably toxic organic substances (PCB's, dioxins, etc.), heavy metals (mercury, lead, cadmium, etc.) and other unwanted by-products of industrial processes or resource exploitation deliberately discharged into water bodies;
- changes induced by use of water as a coolant in processing in the energy industry (e.g. water-cooled thermal or nuclear power stations, present and future oil sands development);
- atmospheric inputs, such as acid-forming pollutants (especially sulphur and nitrogen oxides), radionuclides and a wide variety of toxic or noxious substances chiefly originating in urban areas.

Underlying this classification of human impacts on the hydrologic cycle lie two major historic processes. The first is the colonization of the Canadian land surface, and its gradual conversion over two centuries to the evolved condition we know today. Land use change has been a key to Canada'a economic evolution. The second process has been the shift in the past century from a predominantly rural society to a highly industrialized, largely city-dwelling nation.

The hydrologic cycle of today is controlled by a climate that has varied little since the nation's beginnings. The rainfall and snowfall that

Figure 3. Distribution of glacial ice on land, as percentages of total area within 10,000 square kilometre squares. Though important for local streamflow, these glaciers store little water by comparison with lakes and groundwater.

Source: see Figure 2


GLACIAL ICE
Percentage per 10,000 square kilometres
61-100 31-60 19-30 12-18 9-11 5-8 1-4
Kilometres
0 200 400 600

dominate present water supply come in amounts and at dates quite similar to those of the past. But now Canada faces the probability that the next century will bring an altered climate, due largely to human interference. Because of rising carbon dioxide concentrations, and of certain other atmospheric changes, it is likely that temperatures will rise significantly. The rise may, indeed, have begun already. The warming will significantly alter the rain/snow ratio in our annual precipitation, and also change the freeze-thaw cycle. Beyond this, there may well be changes in the total precipitation, and in evaporation. Hence the entire hydrologic cycle will be altered. These changes, too, may already be in progress.

4. The Pristine Environment

We have no precise records of the condition of Canada's streams and lakes before European colonization. The native societies, Inuit and Indian, were too scattered and too small in numbers to have had much impact on water quantity and quality. The environment was almost untouched by mankind. It was pristine.

No water body is left to which we can wholeheartedly apply this adjective. Human interference has touched the whole planet, thanks to the spread of pollutants by ocean and atmosphere. The lichen carpet, and hence the mammals, of Canada's sub-arctic and arctic contain traces of radioactive strontium and cesium released by Soviet and Chinese testing of nuclear weapons. The acidity of precipitation has been changed by sulphur dioxide and nitrogen oxide production, at least in the east. The chemistry of all our water bodies must show traces of these and other airborne insults.

Yet we still have lakes and rivers that are close to the pristine state. It is still possible to infer their pre-colonization condition. Among the major rivers the Mackenzie stands out, though its major headstream, the Peace, has now been altered, as has Lake Athabasca. The Mackenzie is not pristine, but it still has much of its original quality. It is our greatest river, and with its immense lakes is the superior of the St. Lawrence as an aquatic system. It is urgent to look closely at it before it, too, is changed fundamentally.

World-wide surveys of the chemistry and ecology of the major rivers and lakes have been carried out in the past decade, chiefly in the context of the so-called biogeochemical cycles--the flows of carbon, nitrogen, phosphorus, sulphur and other nutrients through the major ecosystems. These efforts, sequential to the International Biological Programme, have been co-ordinated by the International Council of Scientific Unions, through its Scientific Committee on Problems of the Environment (SCOPE).

These efforts have confirmed an opinion derived from our knowledge of ecosystem behaviour: that mature, undisturbed ecosystems effectively conserve their own land surfaces and waters. Nothing preserves water quality better than nature's own choice for protective cover.

This conclusion is well illustrated by the extraordinary contrast between the Rhine and the Amazon drainage (Kempe, 1984). The European river puts only 1 per cent of the discharge of the Amazon into the oceans. Yet the Rhine carries almost half as much nitrate and phosphate as does the Amazon. The rivers of France export almost as much nitrate and phosphate as the Amazon, which is by far the world's largest river. The European streams are heavily influenced by industrial and agricultural pollution, whereas the Amazon is still, in spite of recent forest clearance, reasonably near the pristine state (Meybeck, 1982; Salati and Vose, 1984).

This notion, that pristine streams transport low volumes of dissolved nutrients, arises from the observed fact that natural ecosystems, especially grasslands and forests, recycle the various elements. In forests, especially those of the tropics, much of the available supply is likely to be locked up in the living vegetation. When the latter dies, rapid processes of decomposition and soil chemistry enable the nutrients to be quickly taken back into the plant cover.

Figure 4, modified from Kempe (1984), compares the concentrations of nitrogen and phosphorus in various major river systems. The Mackenzie, and other major northern rivers, seem to be phosphorus-deficient, whereas tropical

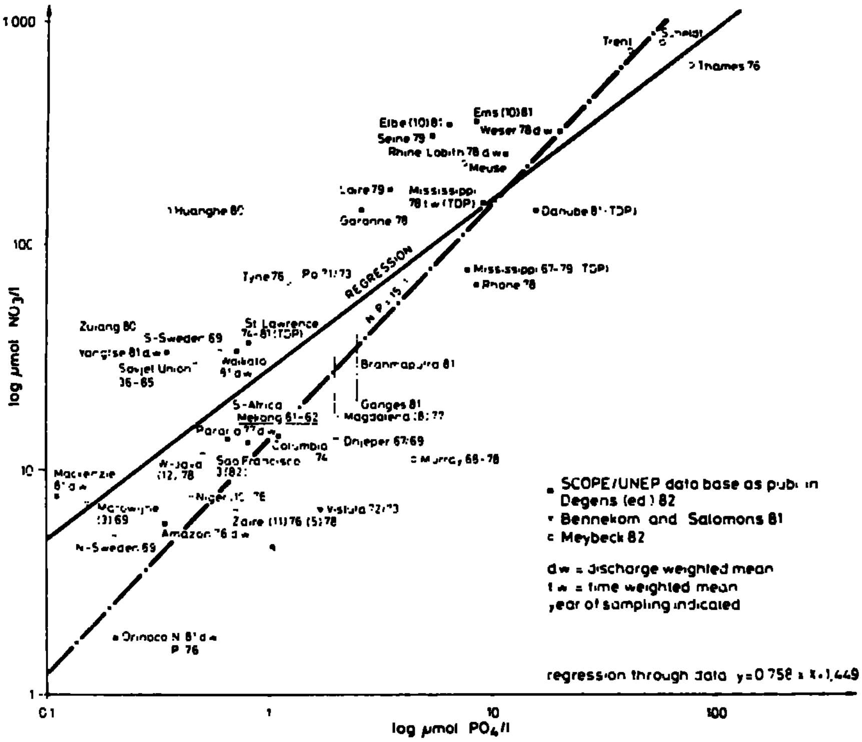


Figure 4. Mean nitrate (vertical scale) versus phosphate (horizontal scale) concentrations for selected rivers. Units are micromoles per litre, on logarithmic scales. Dot-dash line indicates normal 15 to 1 ratio for nitrogen to phosphorus in organic materials. Regression line shows actual relationship in the world's streams. The Mackenzie has very low concentrations of both nutrients, and is especially low in phosphate.

TDP, total dissolved phosphate; TDN, total dissolved nitrogen (inorganic).

Source: Kempe (1984)

pristine streams lack nitrogen (relative to the biologically normal 15 to 1 ratio for nitrogen to phosphorus). Absolute loading of the Mackenzie is far below that of the streams of the industrialized and agricultural basins of Europe. The Great Lakes tend to reduce the loading of the St. Lawrence. The lesson is not merely that pristine streams tend to carry low nutrient concentrations, but also that their nutrient balance may not favour high biological productivity within their own waters. It is worth noting (E.D. Ongley, personal communication) that "pristine" does not mean clear and clean. Heavy algal growth was typical of prairie sloughs long before settlement. The turbid brown waters of many Canadian Shield lakes are also quite normal, and useful in an ecosystem sense. Clear water may owe its attractiveness to the death of useful organic content, for example in very acid conditions.

The same principle applies to erosion and sediment load. An intact vegetation cover tends to protect soils, and distribute storm run-off over fairly long periods, thereby reducing erosive power. Forest vegetation is especially effective in this respect. On steep slopes it is widely held to create, via its root system, channels within the soil to expedite sub-surface downslope flow, the surface flow being retarded by litter, ground vegetation (often water retentive, as in the case of *Sphagnum* and the feather-mosses), and a high soil organic content. Moreover the intact forest maximizes evapotranspiration, which in turn reduces the run-off or infiltration (Swanson, 1984).

How much of Canada is protected in these ways? Essentially those stream basins that have escaped the effects of major deforestation, or conversion to agriculture. This means the basins of the Yukon, the Mackenzie system, the other Arctic rivers, the Hudson's Bay drainage (but not including the

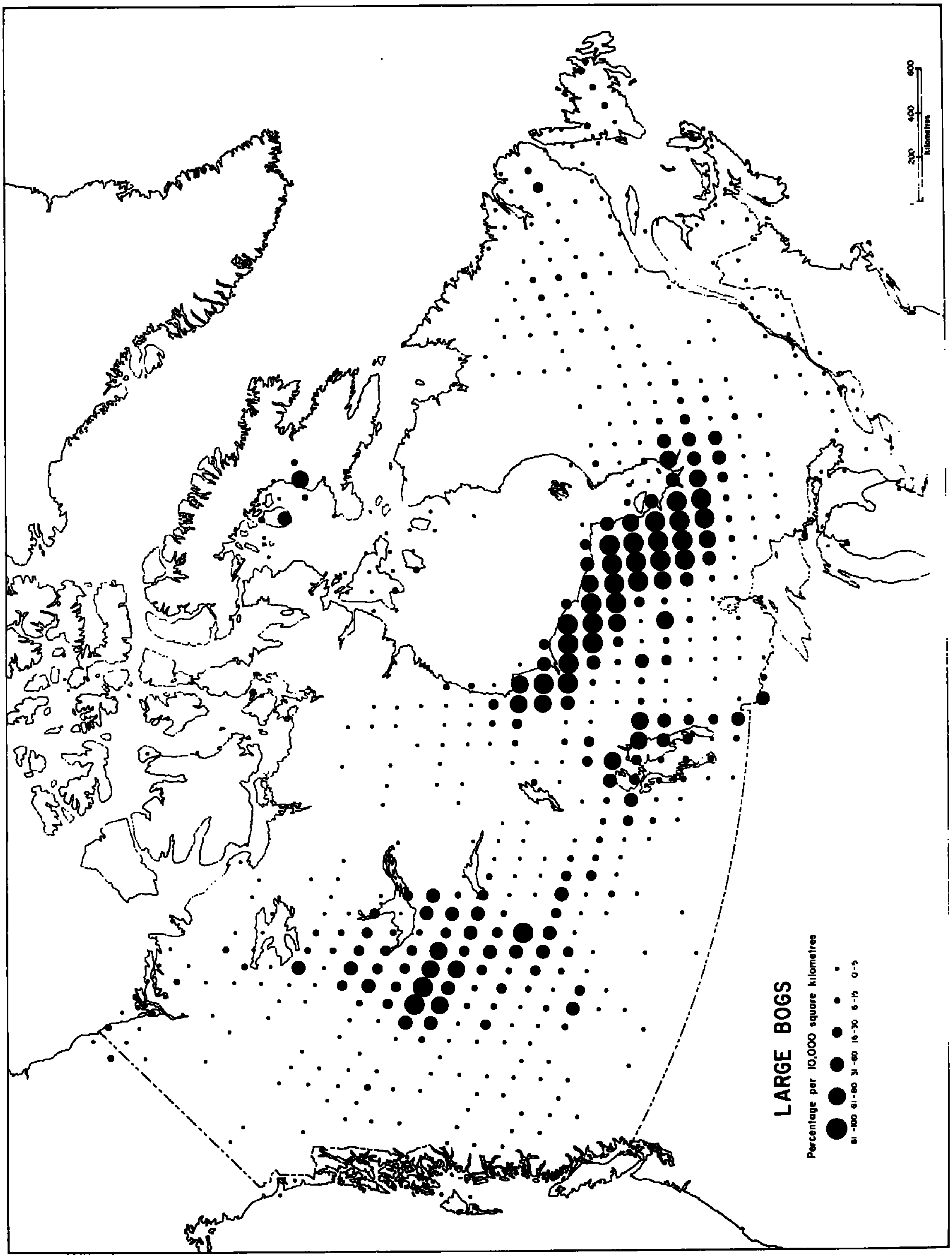
Nelson, which inherits the much modified Saskatchewan and Red Rivers), and the Atlantic drainage of the Labrador peninsula. In addition many basins in Newfoundland, New Brunswick, Nova Scotia and southern Québec have either been little affected, or have partially returned to forest cover as the result of farm abandonment.

As noted above, eastern rivers and lakes show the impact of acid deposition from industrial air pollution. In the pristine state surface waters have acidities and alkalinities that reflect (i) the acidity of precipitation, usually mildly acid; (ii) the composition of the soils, especially the presence of substances capable of buffering acid deposition, such as calcium compounds; and (iii) the effect of organic substances carried into streams and lakes as products of the decomposition of dead vegetation. The streams of western Canada east of the Coast Range tend to have low acidities, because in dry climates calcium carbonate is often abundant in soils. Those of the Boreal forest and southern tundra regions will generally be heavily influenced by the huge amount of only partially-decomposed plant material lying in the soils, bogs and lake bottoms of the Canadian Shield; in general they should tend towards acidity (see Figure 5). Those of eastern Canada receive large loadings of sulphate and nitrate ions in falling rain and snow, and over large areas the acidifying effect of these ions has substantially increased acidity. Hence the pristine state has already gone, even in watersheds not yet penetrated by settlement or deforestation.

The surface waters of the rest of Canada have been subjected to major modification by human activities. The Fraser, Columbia, Saskatchewan, the Great Lakes--St. Lawrence system and the Saint John have all undergone extensive changes--regulation of their channels, consumptive or instream use of their waters, damming and other highly visible mechancial interventions. Even if they had not, the changes in land use since European colonization would have--and indeed <u>have</u>--altered the quality of the waters. Their pristine state has been heavily modified.

Figure 5. Distribution of large bogs, as percentages of total area within 10,000 square kilometre squares. Bogs and other wetland types are best developed in the Boreal Forest zone. They store substantial water, and are vital wildlife areas. Many are moderately acidic.

Source: see Figure 2



LARGE BOGS
Percentage per 10,000 square kilometres
81-100 61-80 31-60 16-30 6-15 0-5
200 400 600
Kilometres

The changes that colonization has brought can be summarized in the words of Kempe (1984):

1. Deforestation and the spread of large-scale mechanized agriculture increases soil erosion and loss of humic soil-material to rivers.
2. Waste waters introduce labile organic substance into lakes and streams, thus stimulating respiratory activity that raises CO_2 [carbon dioxide] pressure and acidifies the water while depriving it of its oxygen.
3. The leaching of nitrates from agriculture and the sewage inputs of ammonia, nitrite, nitrate, and phosphate can cause vigorous phytoplankton blooms in lakes and reservoirs. The water becomes more alkaline, and inorganic carbon is transferred to organic carbon. The excess organic carbon is either buried in lake sediments or respired when washed out into free running rivers.

Kempe's analysis is global, and these three processes are world-wide in scale. Yet they are fully applicable to Canada. They will be examined in the context of our use of forests, our agriculture, and the phenomena of urbanization and industrialization.

5. Effects of Forest Exploitation

To the European invaders Canada appeared as a land of rich but difficult forests, cloaking lowland and upland alike. Only the highest land rose above the treeline, except in the western mountains. To the British, Irish and French in particular, with their memories of bare moorland and windswept summits, the look of the land was especially strange. The legendary figures of early Canada were the coureurs des bois and the bûcherons, who learned how to traverse the forest by water, and to cut its trees for the benefit of the settlers. The pristine streams and lakes were the means by which they achieved these ends. Only on the Prairies did the circumstances and the means of penetration change.

Today, much of the productive forest is exploited by the forest industries, which achieve annual sales exceeding $20 billion. Table I shows the distribution of forest and agricultural land by province or territory.

Though forests cover 43 per cent of Canada's land surface, the proportion is higher in the southern half of the country (see Figure 6, from Hare and Thomas, 1979). Most of the stream basins of interest to the Commission are extensively forested, in some cases to the extent of 80 or 90 per cent of the land surface (see Figure 7).

Forest hydrology is becoming a well developed art in Canada. It has directed attention to the ways in which the exploitation of forests alters the water system. The early history of cutting was generally destructive, since little attention was paid to the consequences, whether for the forest itself, the soils that nurtured it, or the lakes and rivers that gave access, and ensured prompt removal of surplus waters. Today impending shortages of trees in most parts of the country are forcing a new era of intensive management on

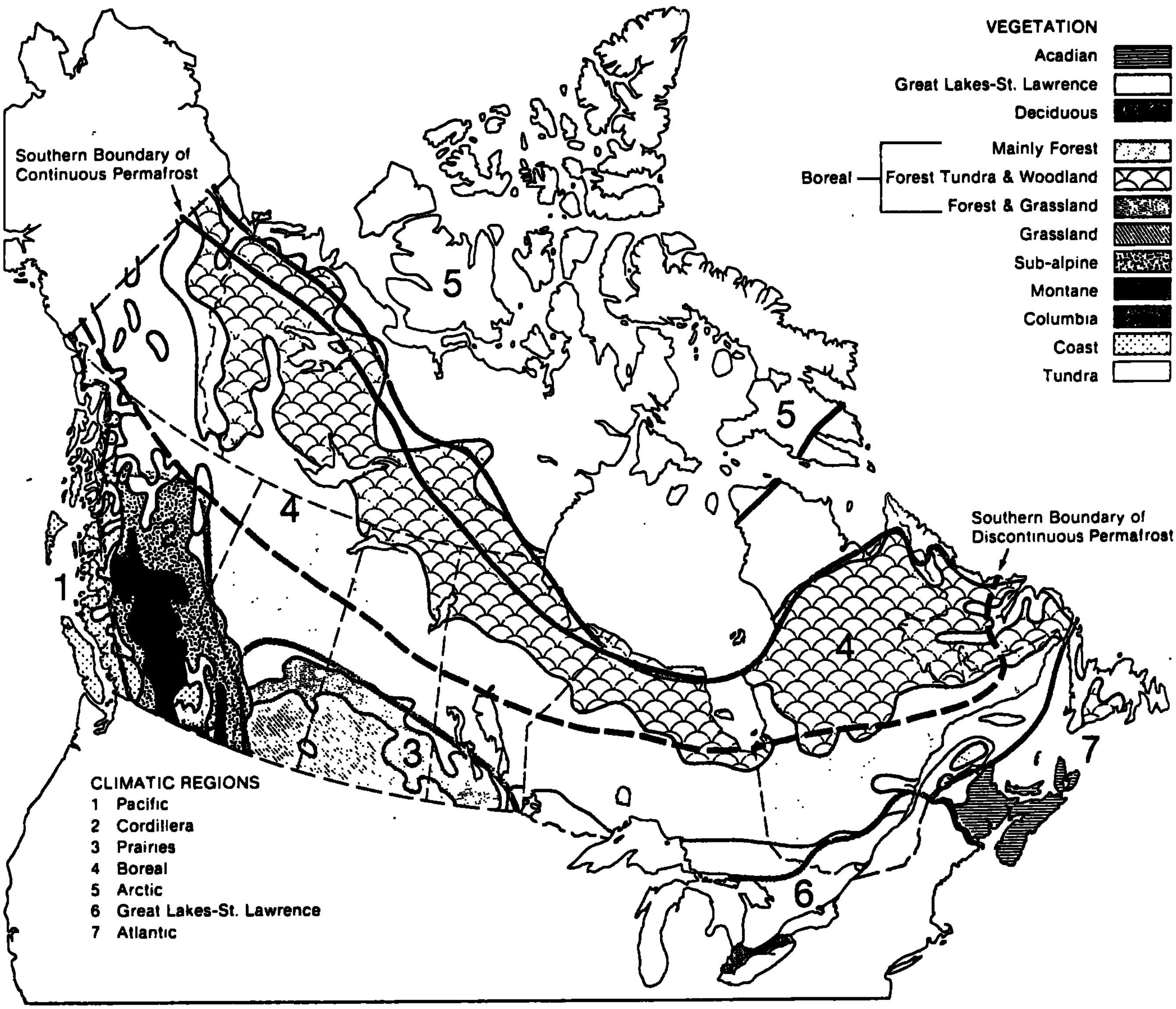


Figure 6. Climatic regions (numbered), vegetation divisions and permafrost limits.

Source: Hare & Thomas, 1979. Reproduced with the permission of J. Wiley & Sons (Canada) Ltd.

TABLE I

AREA CLASSIFICATION CANADA - 1981

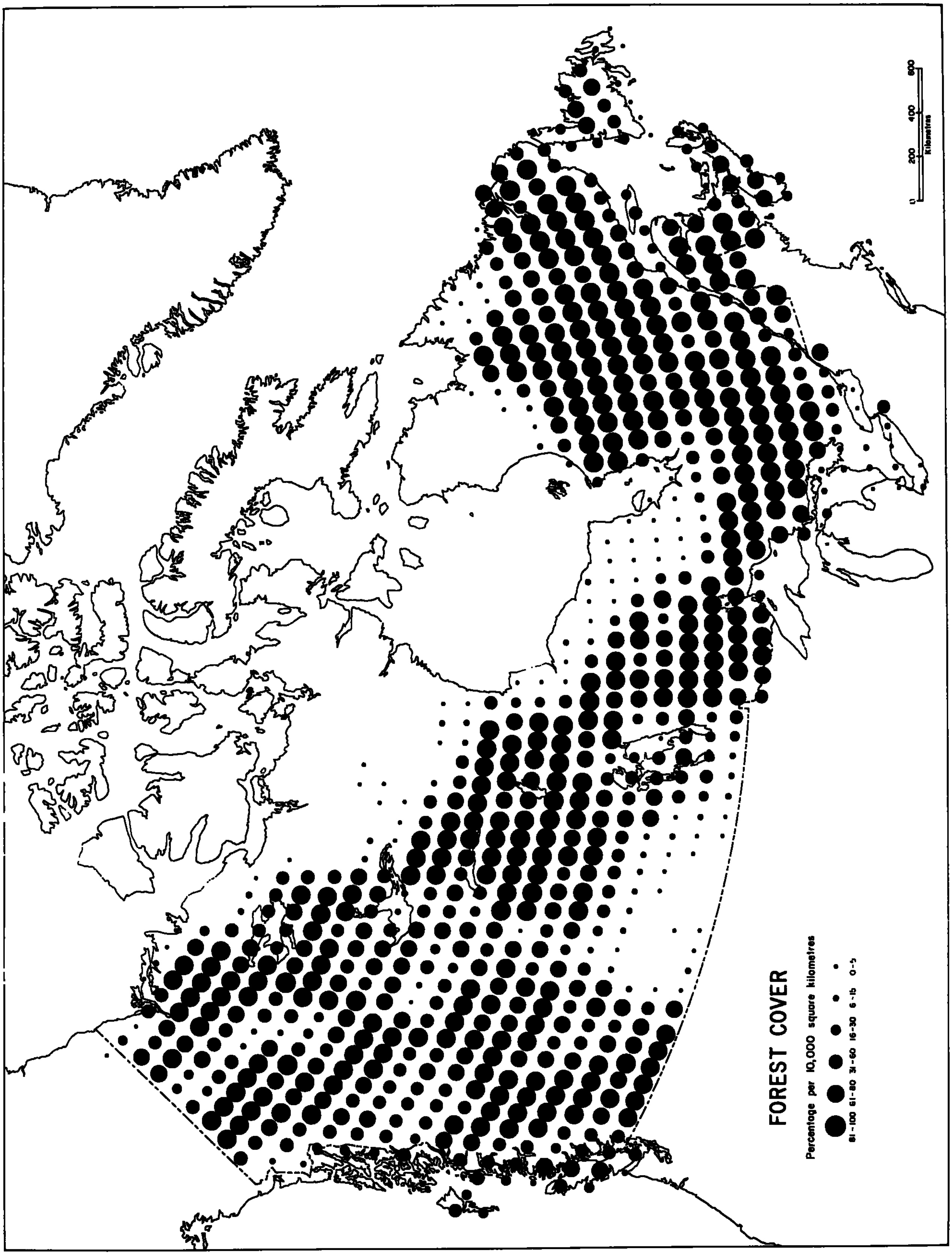
Area class	NFLD.	P.E.I.	N.S.	N.B.	QUE.	ONT.	MAN.	SASK.	ALTA.	B.C.	Y.T.	N.W.T.	CAN.
							(1 000 km^2)						
Forest land													
Inventoried													
Productive	85	3	29	62	533	377	140	89	216	458	67	143	2 202
Unproductive	57	-	12	3	91	55	100	34	115	108	175	472	1 223
Subtotal	**142**	**3**	**41**	**65**	**624**	**432**	**240**	**123**	**331**	**566**	**242**	**615**	**3 425**
Not inventoried	-	-	-	-	316	375	109	55	18	67	-	-	940
Total forest land	**142**	**3**	**41**	**65**	**940**	**807**	**349**	**178**	**349**	**633**	**242**	**615**	**4 364**
Agricultural land	-	3	5	4	38	60	76	260	191	22	-	-	659
Other land	229	-	7	3	379	24	123	132	104	276	236	2 631	4 144
Total land	371	6	53	72	1 357	891	548	570	644	931	478	3 246	9 167
Water	34	-	3	2	184	177	102	82	17	18	4	133	755
Total area	**405**	**6**	**55**	**73**	**1 541**	**1 069**	**650**	**652**	**661**	**949**	**482**	**3 380**	**9 922**

Figures may not add due to rounding.

Source: Bonnor, G.M., Canada's Forest Inventory 1981, Forestry Statistics and Systems Branch, Canadian Forestry Service, Environment Canada.

Figure 7. Present-day distribution of forest and woodland, as percentages of total area within 10,000 square kilometer squares. In southern areas much of this is cut-over land that has reverted to forest.

Source: see Figure 2.


FOREST COVER
Percentage per 10,000 square kilometres
81-100 61-80 31-60 16-30 6-15 0-5
0 200 400 600
Kilometres

an industry that has been slow to learn the hydrological and ecological implications of careless methods. Forest hydrology will play a significant rôle in this new and more acceptable stage in the industry's history.

Cutting of forests tends to alter streamflow and hence erosion. Several basic processes are involved. One is evapotranspiration. A tree-covered area contains innumerable pumps, since the physiology of trees requires that they transport water from the soil to their green tissues, where it is evaporated to the atmosphere. This process is effective during the growing season, chiefly in daylight. The leaves, branches and boles of trees intercept falling rain and snow, some of which is evaporated before it can reach the soil. A leaf canopy also shades the forest floor, reducing surface evaporation, and delaying the spring melt of accumulated snow. These processes differ as between evergreen coniferous and deciduous broadleaved forests. The latter are widespread only in the Great Lakes-St. Lawrence basin.

A recent review from the Northern Forest Research Centre (Swanson, 1984) suggests that the removal of forests increases streamflow by about one quarter. Reforestation, whether by natural regeneration or by deliberate planting, reduces streamflow progressively. The effective process in the increase due to cutting appears to be the reduction of evapotranspiration because of the loss of trees. Cutting forests also exposes the snowcover to direct solar radiation, and altered energy exchanges, usually so as to accelerate spring melting. This affects the date and magnitude of the run-off peak.

On the other hand there is evidence from western Canada (Cheng, Black and Willington, 1975) that logging a forested hillside actually retards storm run-off. They infer that this may be so because on forested slopes most downhill flow takes place within the soil along root channels. These are disrupted by logging operations and the decay of root systems.

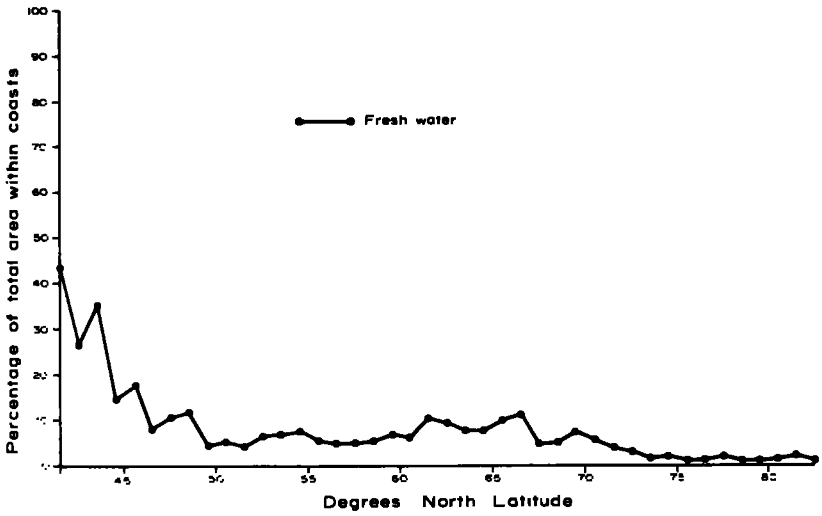
These and other results in forest hydrology suggest that a tightly managed forest offers opportunities for control or manipulation of streamflow. For example, it may be possible, by reduction of forest cover, to increase streamflow deliberately, and accelerate spring snow melt. In water-hungry areas this may be a beneficial side-effect of logging. Commercial clearcutting at Hinton, Alberta (Swanson and Hillman, 1977) appears to have increased water yield by 27 per cent by comparison with nearby uncut areas. A review of several experimental or commercial cuts led Swanson (1984) to suggest that . . . . "forest clearing can produce sizeable increases in the amount of water yield from a forested area." He added, however, that he knew of no case where this concept had been used in actual stream management.

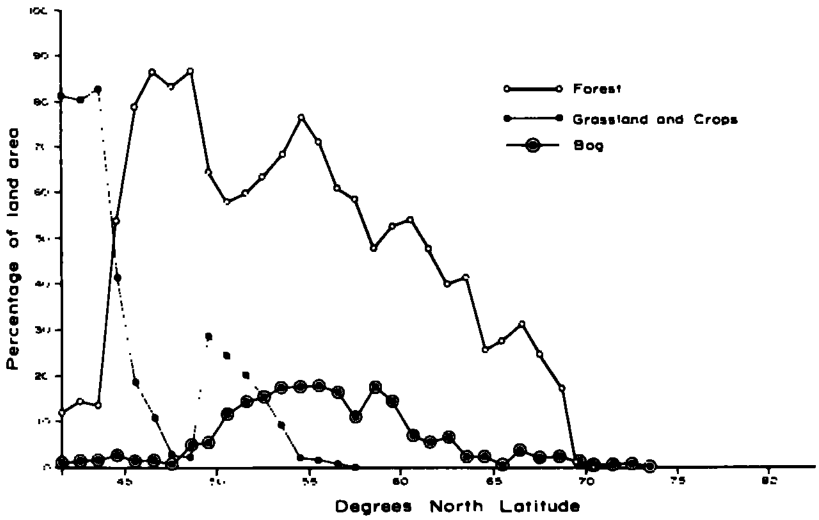
The general perception of the effects of deforestation is much less optimistic. The qualitative view is that widespread forest cutting accelerates hillside and streambank erosion, as regards both suspended sediment and nutrient removal.

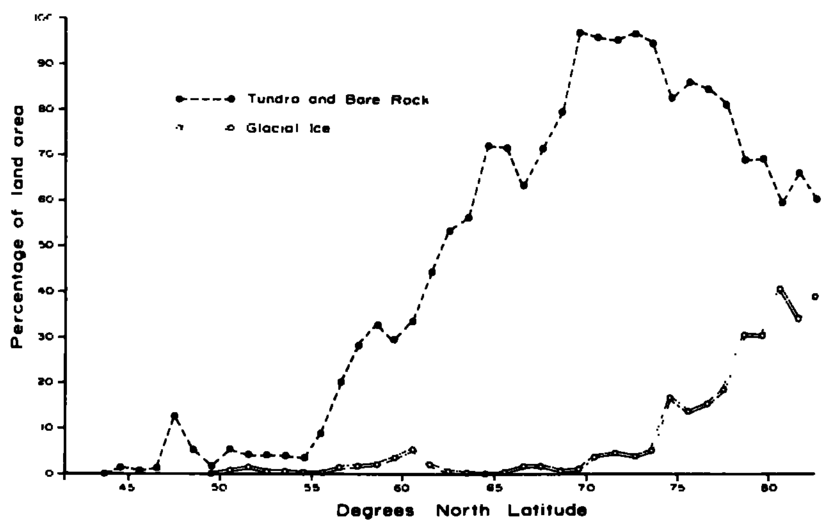
I am unaware of any overall synthesis of what the exploitation of Canada's forests has done to the major stream systems. The Fraser, for example, is an undammed, tumultuous river draining a huge basin that has been heavily logged for most of this century. Its sediment-laden waters make an extraordinary contrast with the clear sea-water of the Straits of Georgia. Its delta shows that the deposition of alluvial material is an ancient process that far outdates forest cutting, or even human presence. In recent decades there has been severe flooding and channel alteration during the early summer

Figure 8. Latitudinal distribution (as percentage of total area--for fresh water--or of land area, for other categories) of open water (top curve), forest and woodland, grassland and crops, bog, tundra and bare rock, and glacial ice on land.

Source: see Figure 2


Fresh water
Percentage of total area within coasts
Degrees North Latitude


Forest
Grassland and Crops
Bog
Percentage of land area
Degrees North Latitude


Tundra and Bare Rock
Glacial Ice
Percentage of land area
Degrees North Latitude

peak streamflow. Extensive work has had to be done to control these problems. Hence it is easy to assume that forest removal has exaggerated the river's natural behaviour. But I have no firm long-term evidence that this is so. Nor have I such evidence for other streams. We have yet to take overall stock of what Canada's most spatially-extensive industry has done to our rivers and lakes.

It is probably the case, moreover, that the major impact of the entire forest-based industry has lain in the domain of water quality rather than quantity. The industry has discharged a great deal of unpleasant material into our streams and lakes. Suspended organic solids, a variety of organic compounds in solution and phenolic preservatives are cases in point. The most notorious instance has been the residual effects of mercury pollution. In many cases the present generation finds itself coping with the aftermath of technologies no longer in use. And if one looks for a symbol of the careless use of resources--trees and water alike--it is the melancholy sight of thousands of stranded logs lining the banks of forest streams, or half-buried in the beach sands of the British Columbian coast.

6. The Impact of Agriculture

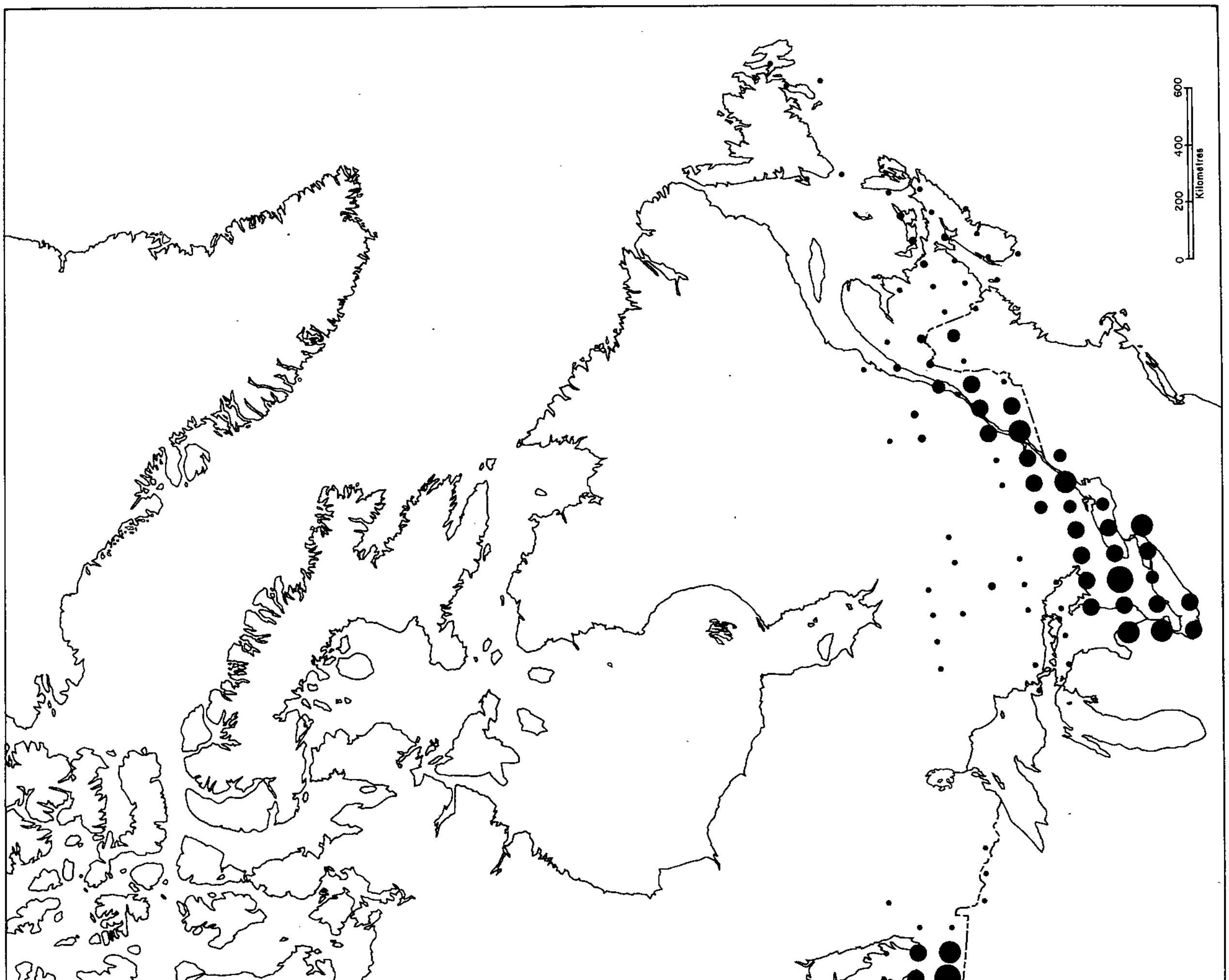
The data given in Table I emphasize that Canada's agriculture is concentrated on only 7 per cent of her land surface, which is very small by comparison with the forest area. But Canadians live close to the farming areas, through which the rivers of importance to water supply flow. The main areas of concern are the Fraser, Thompson and Okanagan valleys of British Columbia, the Prairie farming belt of Alberta, Saskatchewan and Manitoba, and the Great Lakes-St. Lawrence basin, especially southwestern Ontario (see Figure 9).

A major consequence of the clearance of virgin land for agriculture has been, for the world as a whole, the loss of much topsoil, especially during the first century of development. This loss has included nutrients and humus as well as silt, sand and clay. There are many who see this loss as the world's most serious environmental problem. These lost materials in turn affect streams and lakes. Agricultural practice touches run-off too, and may drastically increase the flood hazard, notably through accelerated field drainage. Fertilizers and pesticides pose a comparable threat to the health of the water system--even to the groundwater.

These effects have been long visible, for example, in the Mississippi, North America's greatest river. At its mouth the river discharges 270 million tonnes of suspended material per annum--most of it topsoil or organic material in origin. Yet Iowa alone loses 240 million tonnes of soil per annum to erosion (Brown, 1981), and comparable losses must be in progress from the rest of the huge basin. Clearly the extra sediment is collecting in the channels and on the floodplain of the Mississippi and its tributaries.

Figure 9. Distribution of grassland and crops, as percentages of total area within 10,000 square kilometre squares, showing restricted non-forested surfaces in southern Canada.

Source: see Figure 2


GRASSLAND
Percentage per 10,000 square kilometres
81-100 61-80 31-60 16-30 6-15 0-5
0 200 400 600
Kilometres

The west bank tributaries (including the Milk and Frenchman Rivers of Alberta and Saskatchewan, which drain to the Missouri) derive most of or all their flows from snowmelt in the Rockies or the Cypress and Black Hills, and as they flow eastwards across the Plains their channels become wide, braided strips of sand and gravel that move only when spring flood waters (or sometimes winds) dislodge them. Widespread damming of these streams, plus the consumptive use of the water for irrigation, has removed much of the flow and tamed the summer floods that might otherwise move the sediments. Agricultural practice, that is to say, increases the supply of sediments to the stream systems, but decreases their capacity to carry the material away. Hence North America's lost topsoil is accumulating, not so much on the seafloor, as on floodplains and in lake and reservoir bottoms.*

The Saskatchewan and Red River basins (including the Assiniboine, Souris and Qu'Appelle Rivers) are affected by similar changes. The Diefenbaker Dam, the various diversions of water, and the widespread irrigation of Alberta and Saskatchewan, have all influenced the capacity of streams to transport their loads--which were certainly increasing. A recent estimate is that the Prairies lose 160 million tonnes per annum of soil by wind erosion, and a further 117 million tonnes by water erosion (PFRA, 1983). By the 1930's organic matter and nitrogen in Prairie soils had been reduced by 20 to 25 per cent and it is now believed that losses of organic material amount to about 45 per cent. In post-war years there has been a huge increase in the application of nitrogen and phosphorus fertilizers. Figure 10, after C.F. Bentley (1982), sketches why this need has arisen.*

In the drier parts of the Prairies these lost soils and nutrients do not quickly reach the stream systems. Instead they mostly accumulate in the

*see Note 1, Appendix II, for an amplification of these points.

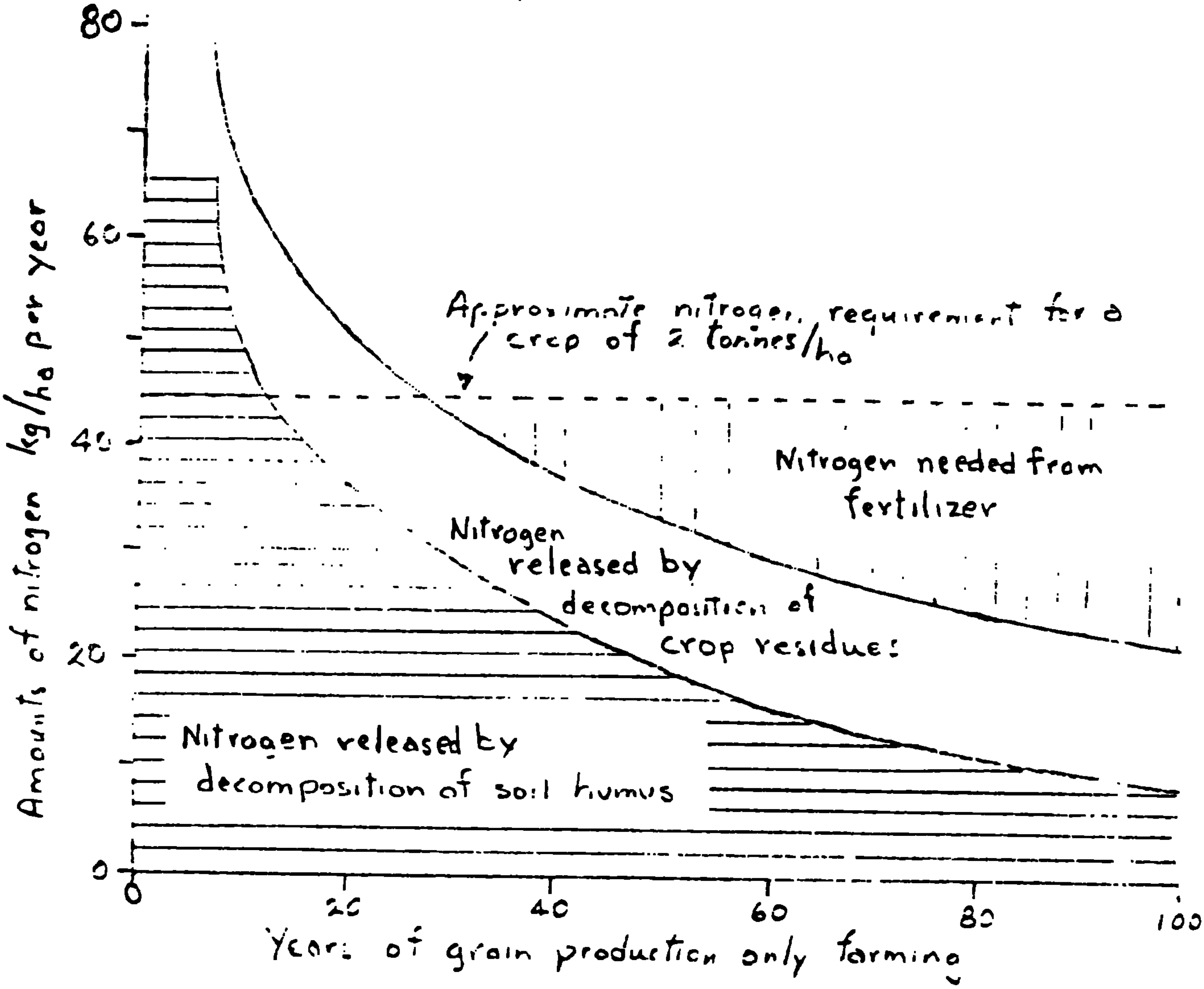


Figure 10. Sources of nitrogen for a crop of 2 tonnes per hectare under Prairie grain production only. The approximately 44 kg per hectare needed can come entirely from soil humus in the early years of cultivation. Later, a significant fraction comes from decomposing crop residues. But after 25 years (roughly) of continuous farming increasing amounts of nitrogenous fertilizer are needed as the soil is impoverished. Leaching to groundwater or to nearby streams may add unwanted nitrates to the water system.

Source: C.F. Bentley (1982)

innumerable depressions and sloughs. Some substances, natural as well as fertilizers, are carried into the local groundwater by the process of dry land saline seepage. Natural prairie ecosystems could retain and use most of the summer rains, and such leaching was limited in scale. But tillage, the early maturing of crops and the widespread use of fallow (to conserve water), have all encouraged seepage. The salinized groundwater reemerges in hollows, where it reevaporates, salinizing the soil (Figure 11).*

These processes, plus related problems with irrigation water, have rendered saline the soils of about 2.5 per cent of Saskatchewan, and the salinity is increasing. In some areas up to 15 per cent of irrigated land is salinized.

In moister parts of the Prairies the problem of salinization is still acute, but discharge into stream systems is more efficient. The black soil belt from Edmonton to Saskatoon, Prince Albert and the Manitoba Lakes is in this category.

The recent history of Lake Manitoba illustrates the point (Last, 1984). This large and very shallow lake (less than 4 m) receives the discharge of Lake Winnipegosis, and some much smaller streams all deriving from the cultivated black soil belt of the Prairies. The water is alkaline and brackish, largely because of sodium and chloride ions. Careful measurement and analysis by Last shows that there . . . "has been a significant increase in sedimentation in the South Basin during the most recent 100-year period . . . most likely the result of increased detrital input to the basin via man-made drainage and diversion canals." The diversion in this case is the Portage Diversion, a flood control structure . . . "designed to carry water

*see Note 2 in Appendix II

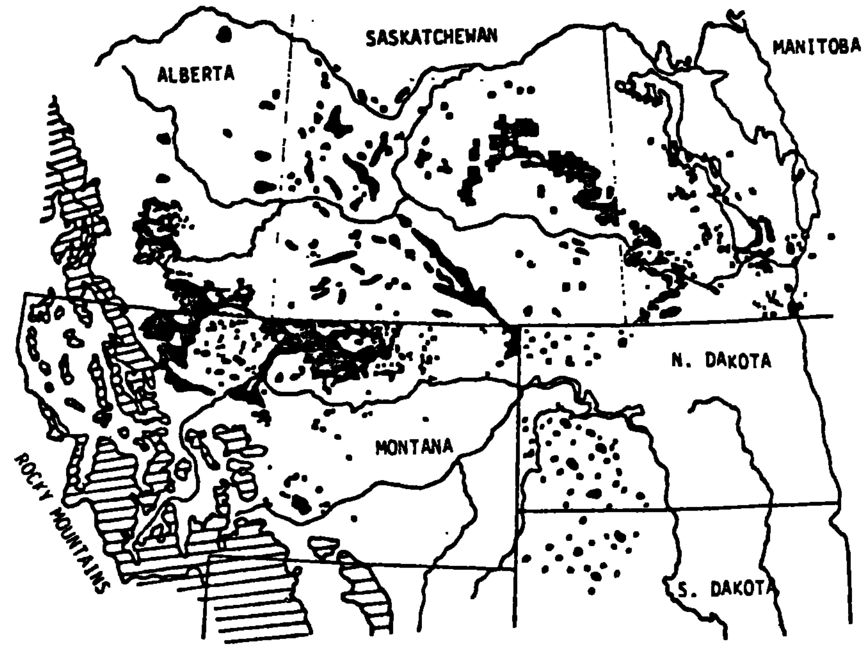


Figure 11. Saline seepage areas in dryland zone of western Canada and the northern Great Plains of the US.

Source: Vanderpluym (1978)

periodically from the Assiniboine River into Lake Manitoba." The mean annual flow into the lake via the Portage Diversion is 20 meters per second.

We shall return later to the issues raised by Last's analysis. It is clear, however, that soil erosion and increased sediment load are not the only effects of agriculture on the river systems. Land drainage (very active in the moister parts of the Prairies, especially on the former Lake Agassiz floor) and flood control measures--also required for protection of cities--are significant in controlling streamflow.

These problems of Prairie agriculture bring into sharp relief another of Canada's central problems--the acute regional disparities in water supply. These are dealt with elsewhere in the Inquiry's papers, but some mention is needed here. Figures 12-13 shows a heavily generalized run-off map of North America, and Figure 14 gives more detail for southern Canada. The charts illustrate the central fact about the cultivated Prairies--that surface run-off is below 25 mm over a wide area. Many southern areas have no net surface run-off, drainage collecting in small, closed basins. This lack of abundant surface discharge is important for much more than the needs of agriculture. It means, for example,

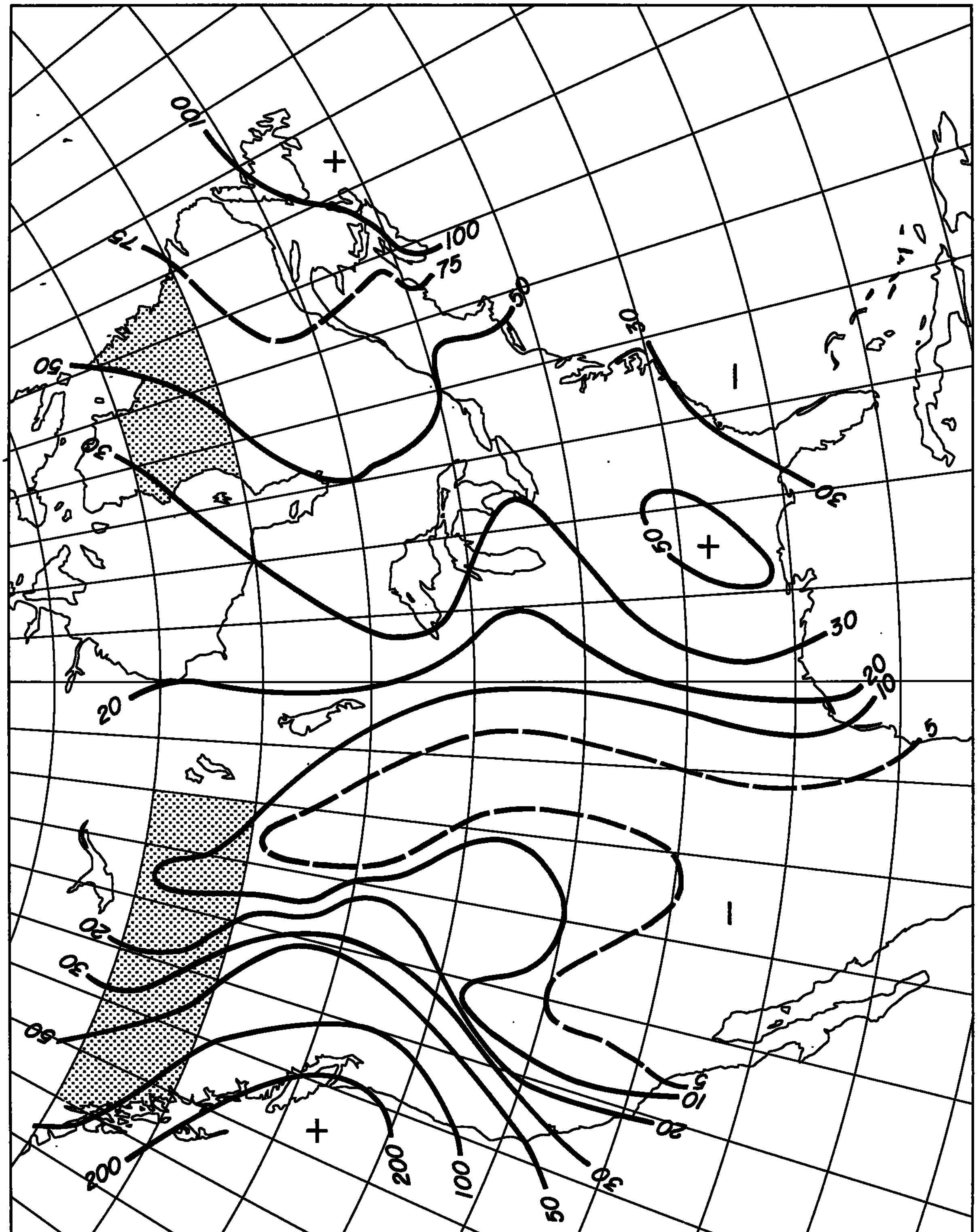
- that high quality drinking and household water supplies will be scarce and expensive. At present one third of the population depends on shallow groundwater for its supply;
- that major needs, such as irrigation, will depend primarily on the major streams (whose flow is derived from Rocky Mountain snowmelt), perhaps augmented by major diversions from the north, and certainly by further withdrawals of groundwater;

Figure 12. Spatially averaged mean annual runoff, in centimetres (1 cm equals 10 kilograms per square metre), showing how the North American drybelt projects northward into western Canada. Stipple indicates poor data.

Source: Hare (1980)

Figure 13. Runoff ratio corresponding to Figure 12, i.e., fraction of annual precipitation running off. Note that the ratio in southern Alberta and Saskatchewan is as low as in the desert south-west of the United States.

Source: Hare (1980)


100
100
75
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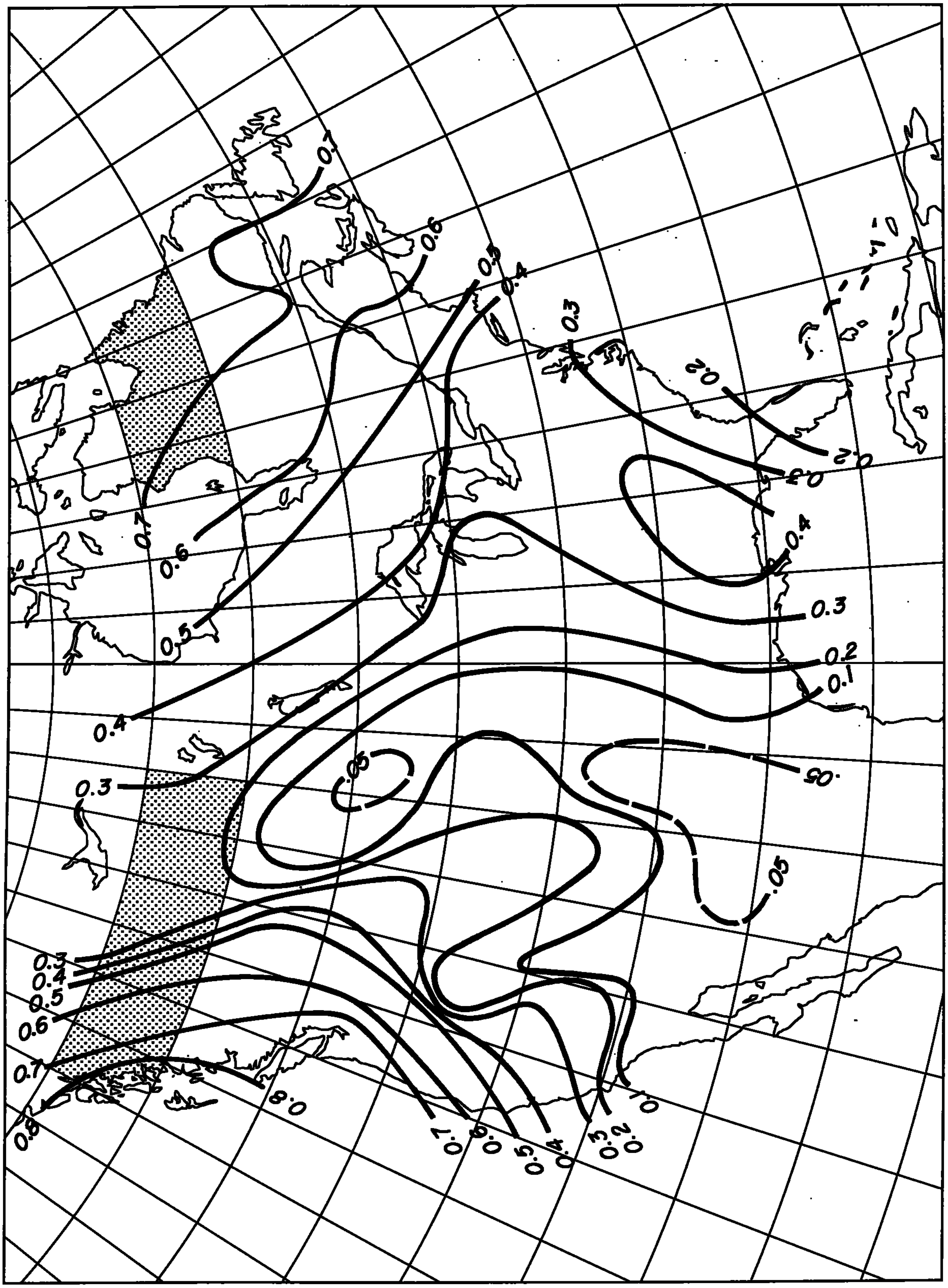


Figure 14. Mean annual runoff over Canada (millimetres; 1 mm equals 1 kilogramme per square metre).

Source: Atlas of World Water Balance, UNESCO, by O.L. Markova, 1976


LABRADOR SEA
Davis Strait
Hudson Bay
L. Superior
L. Michigan
L. Huron
Great Slave L.
Great Bear L.
Lake Winnipeg

- that waste disposal by discharge into streams is vastly less feasible than in the well-watered east;
- that industrial cooling water will also be in short supply; and
- that instream uses of water, and the use of streams and lakes for recreation and as wildlife habitats, will face stiffer competition than in wetter areas.

The bad taste of Regina's drinking water, and the high cost of getting better supplies, are useful reminders of these and other comparable problems. The Prairies present a major paradox to the Inquiry. In many ways the climate is ideal for cereal farming and livestock production. In a good year both the amount and the timing of precipitation is about right for protein-rich spring wheats, canola, barley and flax. But rainfall is very variable, and bad years are common. In any case there is no reliable surplus to feed a healthy stream system, which is a blessing few societies want to do without.

Nor are there cheap answers. Even irrigation is a mixed blessing. The temperatures are such that with more abundant water supply it is hard to grow specialized crops; and to irrigate hay or wheat is on the face of it uneconomic. The time is clearly ripe for yet another examination of Prairie water supplies. I hope that the Inquiry will look hard at this question, to which I revert later in this paper.

Southern Ontario and the St. Lawrence-Ottawa basins witness extensive agriculture of a different sort. It is characterized by smaller farms, extensive pasture (and hay production) supporting many dairy and beef cattle, increasing cultivation of water-demanding row crops, notably corn and various fruits and legumes, and some specialized crops such as tobacco. The agriculture mingles with and serves a dense, high-income industrial and urban system, with many sealed surfaces. Agricultural water demand is high, and has to compete with very high municipal and industrial demand. Supply is increasingly difficult, and problems of quality arise with increasing frequency. (Foster and Sewell, 1981)

Because these relationships are so much intertwined, they will be dealt with below in the context of the Great Lakes-St. Lawrence system.

The remaining agricultural areas of Canada are too small and scattered to pose major threats to the aquatic resource, and vice versa. A possible exception is the Saint John, an international stream where the forest industries, agriculture (especially potato cropping) and the need for power development have combined to create significant water quality and flood control problems. The rich Fraser Delta has problems of flood control and drainage. The Okanagan Valley in British Columbia, extensively dependent on irrigation, is another problem area. For the most part, however, major problems have not arisen outside the Prairies and the Great Lakes-St. Lawrence lowlands.

7. Industrialization and Energy Demand

Canada's industrialization has had three major phases, each placing its special demands on water supply.

The first of these consisted of early water-power based industry, including saw and grist mills, small textile plants and the beginnings of mining. The phase may be said to have ended with the start of hydroelectric power generation late in the nineteenth century. Elora, Ontario, is a living museum for this phase of Canada's history.

A second phase saw the rise of major extractive resource industries, chiefly mining, forest exploitation, and transportation development. The phase included large-scale use of water for hydroelectric power, the construction of major inland navigation, rail and highway systems, and the creation of many small industrial cities near the mines, trees, power, navigation and railway nodes. Lytton, BC, Sault Ste. Marie, Ontario, and Chicoutimi-Arvida in Québec exemplify the type. Water was needed to drive electric generators, on an increasingly large scale (Shipshaw, Québec and Kemano, B.C. being examples of such dedicated developments); to support shipping, as on the Great Lakes-St. Lawrence; to provide for industrial processes, such as pulpwood treatment; and to carry away wastes. This phase is still alive, but no longer consumes most of the new capital investment.

The third, modern phase, essentially post World War II, is that in which urbanization became the dominant fact in Canadian life, and with it the growth of secondary manufacturing and service industries. With the growing technological complexity and rising living standards have come the familiar problems of today: the need for modern sewage treatment and drainage in cities; the need for reliable and high quality domestic and municipal water supply; the rise of air conditioning, consuming much water as well as power; water and air pollution due to wilful and inadvertent release of toxic or noxious wastes; the need for industrial cooling waters; the spread of garden irrigation; the search for recreational water, including lakeshore and river-bank properties; demands for the protection of instream and wetland resources and wildlife, notably for shooting and sport fishing; and concern for the overall health of the aquatic system.

To meet the demand for power have come large hydroelectric developments. The St. Lawrence system supports the Niagara site (Sir Adam Beck), Barnhart Island, Beauharnois (begun in the 1930's) and numerous sites on the tributaries. The huge Columbia and James Bay projects have involved the partial or complete destruction of the original stream profiles. Thermal and nuclear developments have also placed demands on water use in Ontario, and have had some ecosystem impact. Long distance transmission technology makes it possible for such sites to serve the metropolitan power users.

A critical matter for future water management in western Canada lies in the huge demands now being made for water in other energy megaprojects, in the mining industry and in related fields (Ongley, personal communication; Foster and Sewell, 1981). Thermal power production already accounts for almost half the existing withdrawals across the country. The oil sand and heavy oil projects in being or on the drawing board in Alberta and Saskatchewan imply prodigious future demands. Heavy water use is typical of mining technology, often with severe attached quality problems. These are familiar questions in southern Canada. If large scale mining occurs in the north (for example in the Mackenzie Mountains) acute difficulties of supply and quality management may occur. Many of these large future demands appear unattainable at a feasible price.

8. Urbanization

About four Canadians in five now live in cities, or in the urbanized fringes so characteristic of the motorized age. The move to the cities has been almost as emphatic in the prime agricultural areas as elsewhere. The area of cultivation and the value of crops and animals produced have increased in the past half century, while the producing population has diminished. As people have moved into the urban districts, they have transferred their personal demand to municipal or regional water systems. At the same time they have developed the high water consumption so much a part of the technological age. Industrial demand, too, has become focussed on the cities, though less strikingly.

The effect has been sharply to localize demand (and hence the works needed for supply) and to intensify water quality problems, arising from domestic and industrial wastes. About 1,000 municipal water supply systems exist in Canada, and about 700 sewage treatment plants. Water thus flows in and out of our cities in prodigious quantities. The remaining rural population is mostly dependent on wells (from shallow groundwater) and septic tanks or earth closets. Even in the countryside, however, the technology now exists to provide reliable supply and disposal systems. Increasingly these are required by regulation.

The Inquiry will no doubt take detailed evidence on the progress of these changes--which in my own lifetime in Canada (40 years as a resident) have been extraordinary in impact. Here I shall concentrate on the general effects of urbanization on water quantity, régime and quality. The classic reference on this subject is Leopold (1968) but there are other excellent treatments (e.g., Marsalek, 1984; Oke, 1978; Dunne and Leopold, 1978; Mather, 1979; Douglas, 1983).

A flight across Canada soon reminds us that the urban land area is small. In the densely populated Great Lakes basin, for example, urban land on the Canadian side in 1980 amounted to 3,600 km^2, and was expected to rise to 5,200 km^2 by 2020 (Sudar, 1976; IJC, 1980). This is an increase from 1 to 2 per cent of the entire basin land surface. For Canada as a whole the fraction of land occupied by cities is below 0.1 per cent. It follows that, however dramatically urbanization may locally alter the hydrologic cycle, it can have little effect on water quantity on the national scale.

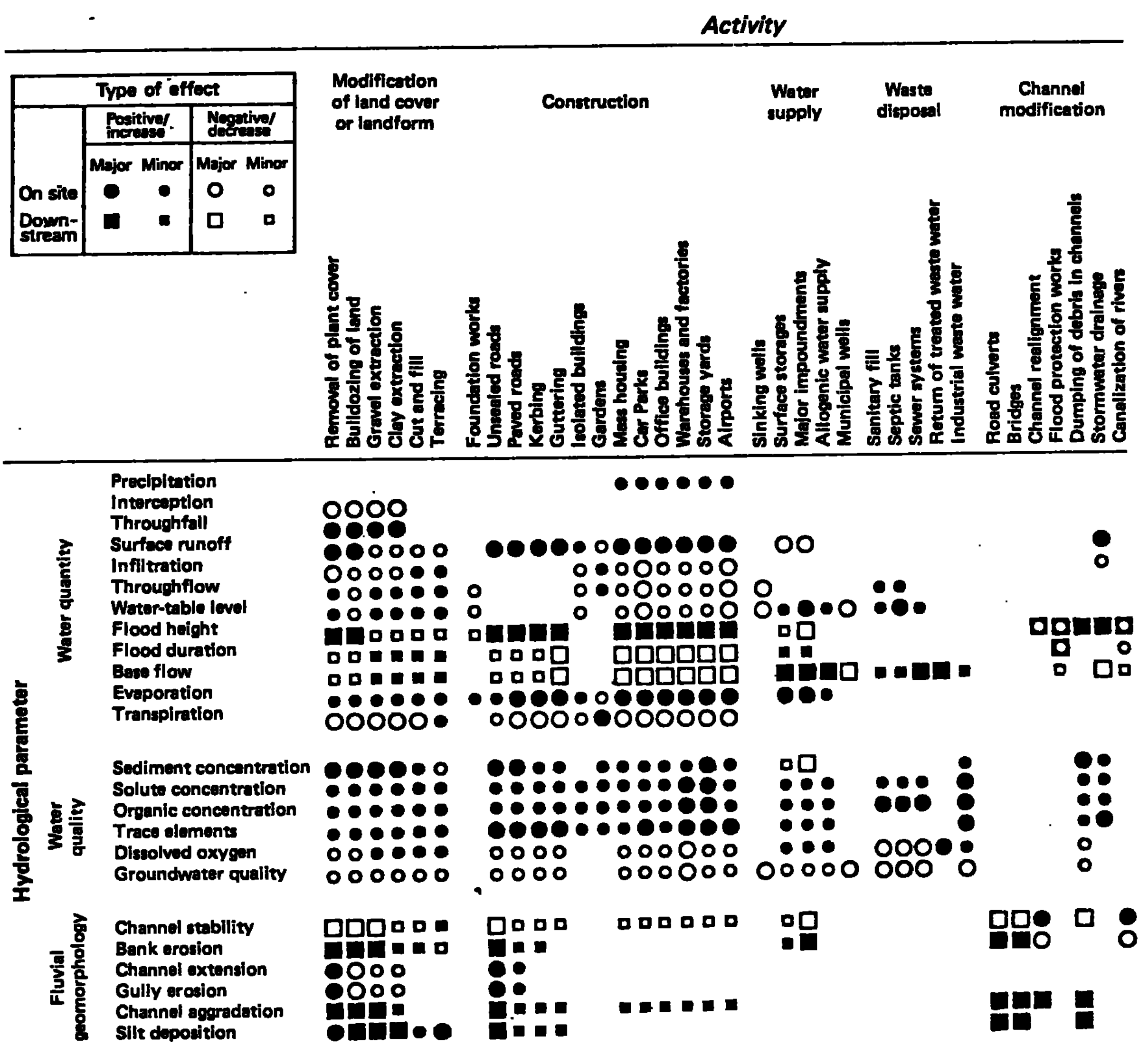
Nevertheless, both quantity and quality effects are large on the local and regional scales. Table II, after Douglas, 1976, gives an excellent summary of impacts on the urban hydrologic cycle, water quality and fluvial geomorphology (i.e., bank, chemical, sediment and tributary behaviour).

The key physical element in urbanization is the extent of permeable natural surfaces that are progressively covered over by concrete, tarmac or brick, in various degrees impermeable to infiltration. Some parts of a city may be over 80 per cent impermeable. Falling rain or melting snow that would normally percolate downwards into the subsoil and groundwater cannot do so. Three consequences ensue. Evaporation off the wet streets, parking lots and buildings may actually exceed that from a natural surface. Infiltration is much reduced. And groundwater levels may fall.

Going with this sealing-off process is the need for storm sewer systems to carry off the remaining surplus precipitation, and in particular to cope with snowmelt and the occasional heavy rainfall. Some systems include extensive seepage basins, storage pools and other means of spreading the load of storm rainfall or snowmelt, allowing some groundwater recharge. Others are more primitive, not infrequently contributing overflow to or receiving it from

TABLE II

Impacts of land use changes and channel modification during urbanization on hydrology and river systems (after Douglas, 1976).



sanitary sewers, in both cases leading to the escape of raw sewage. The streams of Toronto's ravines--the Don, Humber, Highland, Rouge, Etobicoke and Mimico streams--receive the discharge of many of Metropolitan Toronto's storm sewers. Immediately after each major rain the creeks rise to flood stage. In the wake of Hurricane Hazel (1954), when many people died in these ravines, the valley floors are now fairly free of settlement. But each major run-off episode causes some bank or bluff erosion, shifts large quantities of sediment, and often brings unpleasant odours. Much of the heavy sediment load of urban streams, incidentally, comes from construction sites. Each new subdivision, each new expressway, contributes to the added load. All Canadian cities share this problem (see, for example, Marsalek, 1984).

Urban run-off, that is to say, is more abundant and more abrupt than natural run-off, and also carries a much greater sediment and pollution load. Keeping urban streams and ponds attractive for recreation is a perennial headache for city managers. So also is avoidance of flooding, and isolation of the storm system from intruders, especially children. Such problems contribute little to the overall national streamflow picture; but they are common experience to the majority of Canadians who live in cities.

Work by Oke and his students in Greater Vancouver (e.g., Oke, 1979; Grimmond, 1983) has demonstrated in fact that the entire water balance of urban areas is significantly modified by such processes as the above, and also by lawn sprinkling and air conditioning. Grimmond's data indicate that for the Vancouver suburb of Oakridge garden irrigation may comprise over half the total annual household consumption.

But most attention is usually reserved for the effects of city or industrial wastes upon water quality. Pentland (personal communication, 1984) has suggested the following evolution of attention to urban water quality:-

(i) an early phase, extending into the 1930's, when bacterial contamination of drinking water was the major concern of Canada's then relatively small cities;

(ii) the period from the depression through World War II into the early 1950s. During this time of stress, some massive enterprises were undertaken as relief projects, such as the Greater Winnipeg Sanitary System. But industrial pollution was ignored or given little attention;

(iii) a third phase, from the mid-fifties into the sixties, in which increasing attention was given to the Great Lakes, bilaterally with the U.S. Ontario set up a Water Resources Commission in 1956, followed by several other Provinces. Federal assistance to municipal waste treatment began in 1961, followed by pollution control measures;

(iv) a phase during the 1970s of rapid and real progress towards: the completion of adequate municipal sewage treatment; control of the grosser forms of industrial pollution (such as suspended organic solid releases by the pulp and paper industry, or discharge of mercury); and an 80 per cent reduction of phosphorus releases from domestic sewage by control of detergent composition. Essentially this phase concentrated on <u>point</u> sources;

(v) a fifth phase since 1975 in which attention has shifted to the more dispersed form of pollutant release--such as agricultural fertilizers (nitrates and phosphates in particular) and acidifying air pollutants from smelters, thermal power stations, automobiles and other dispersed sources. This phase marks the realization that urban areas, though still the prime pollutant sources, do not merely affect their own water quality, nor do large, identifiable point sources cause all the pollution.

Table III shows the extent to which municipal sewage treatment systems have now been installed in Canada. The situation is still unsatisfactory in Québec, where an abundance of fast-flowing, oxygen-rich streams cannot excuse so little attention. Much needs to be done, too, in the Atlantic Provinces (except PEI) and British Columbia.

Other aspects of urban water quality will be dealt with in connection with the Great Lakes-St. Lawrence system.

TABLE III

URBAN POPULATION SERVED BY SEWAGE TREATMENT SYSTEMS[a]

Province/Territory	Primary	Secondary	Lagoons	Communal Septic Tanks	Other[b]	Total[c]	% of Urban Population Served
Newfoundland	1 200	45 863	1 200	1 425	7 017	56 705	17
Prince Edward Island	37 439	1 878	13 452	722	-	53 491	100
Nova Scotia	-	106 004	19 650	-	3 921	129 575	28
New Brunswick	1 483	124 342	82 246	-	2 662	210 733	60
Quebec	59 177	251 785	69 415	18 712	28 355	427 444	9
Ontario	1 176 410	5 060 394	289 624	8 530	33 466	6 568 424	93
Manitoba	23 500	590 741	182 011	1 975	1 300	799 527	100
Saskatchewan	170 642	31 755	370 446	-	-	572 843	100
Alberta	100 000	1 012 092	385 749	-	8 845	1 506 686	87
British Columbia	206 585	332 783	168 461	1 125	275 746	984 700	46
Yukon	-	160	18 100	-	800	19 060	100
Northwest Territories	-	-	24 375	238	2 193	26 806	100
Totals	1 776 436	7 557 797	1 624 729	32 727	364 305	11 355 944	63

Source: Environment Canada, EPS, National Inventory of Municipal Waterworks and Wastewater Systems in Canada, 1981, with updating through 1982; and Statistics Canada, 1981 Census of Canada, Population, 1982.

[a] Does not include small systems, such as septic tanks serving non-urban population (Communities with less than 1 000 population)

[b] Other category includes tertiary treatment not included under other headings.

[c] Plant totals presented in this column may include some double counting for multiple sewage treatment.

9. The Great Lakes-St. Lawrence System

If the Mackenzie is Canada's greatest river, the Great Lakes-St. Lawrence system is the most heavily used, the most widely known and studied, and the most imminently threatened.

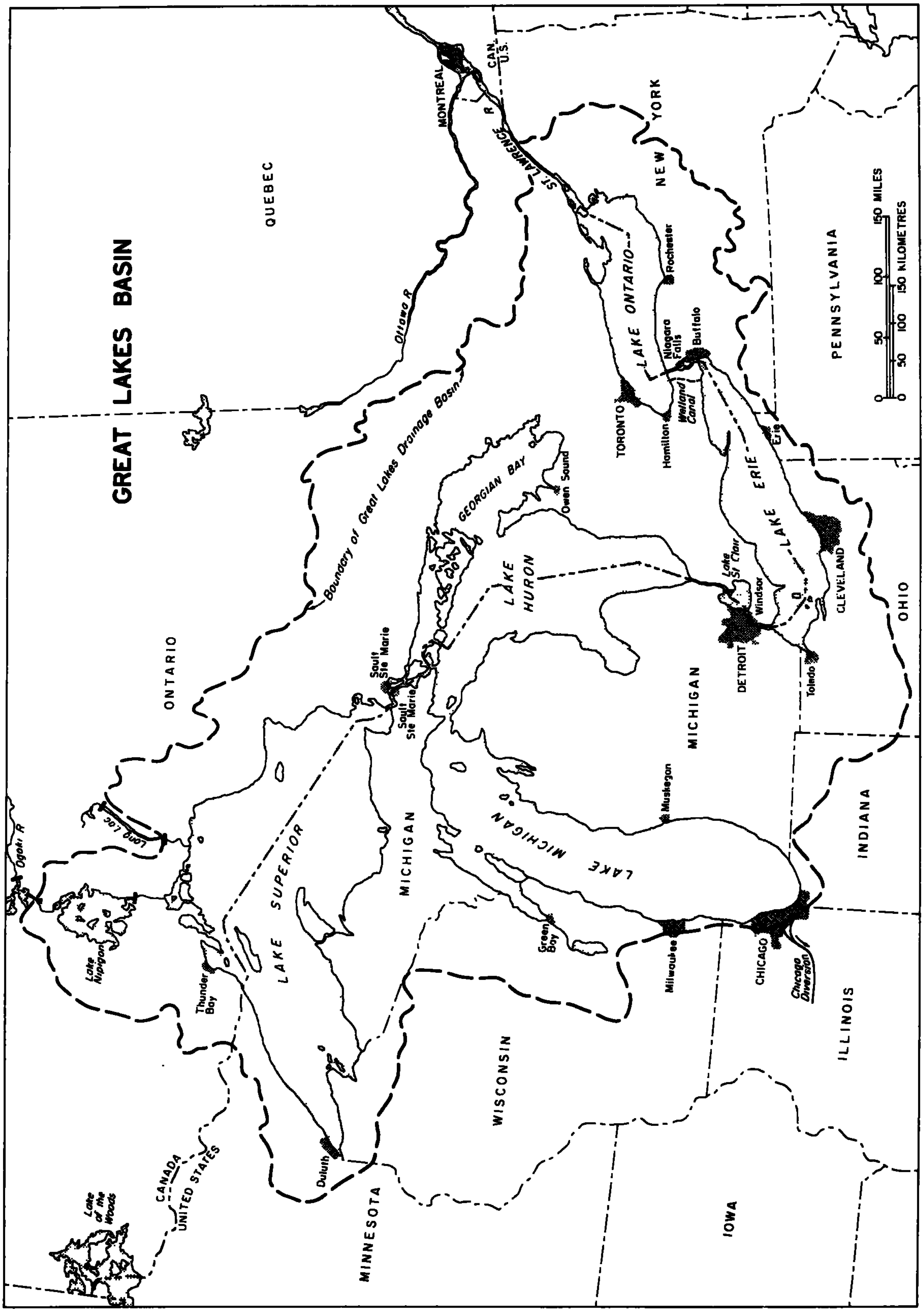
No great river flows into the Great Lakes, which collect their waters from precipitation directly on to their surfaces, or from run-off from numerous small streams mostly rising within 200 km of the Lakes. The latter are huge and mostly deep, occupying basins excavated in Canadian Shield or Palaeozoic rocks close to the continental height of land between northward and southward drainage. Only Erie and St. Clair are shallow, a fact which affects their behaviour and economic value (Figure 15).

The Lakes contain prodigious quantities of fresh water (possibly a fifth of the world's storage), and until recently were free from the grosser pollutants. As indicated above, Lake Superior contains two hundred times its annual discharge via the St. Mary's River. After evaporation, diversion and consumptive use losses, the Lake system still discharges a fairly uniform flow of 7,190 m^3 s^{-1} at Barnhart Island, the Ontario-New York hydroelectric generating station above Cornwall, Ontario. Lake levels, and hence capacity, fluctuate slightly, recently on a near twenty-year cycle. But the striking thing about the entire system is its huge capacity; so great a storage keeps the outflow amazingly uniform.

Below Barnhart Island the river continues as a regulated channel, including the Beauharnois diversion, to Montreal, the former limit of ocean navigation, and hence to tidewater below Trois Rivières. Its estuary is long and splendid, and debouches into an inland sea, the Gulf of St. Lawrence. The

Figure 15. The Great Lakes Basin. Note that no major river enters the system. The Basin is unique in that so high a fraction of the entire surface is occupied by lakes.

Source: A.P. Grima and C. Wilson-Hodges, 1977.


GREAT LAKES BASIN
QUEBEC
ONTARIO
Ottawa R.
Boundary of Great Lakes Drainage Basin
MONTREAL
CAN.
U.S.
ST. LAWRENCE R.
NEW YORK
LAKE ONTARIO
Rochester
Niagara Falls
Buffalo
Welland Canal
Hamilton
TORONTO
PENNSYLVANIA
0 50 100 150 MILES
0 50 100 150 KILOMETRES
Erie
LAKE ERIE
CLEVELAND
OHIO
Toledo
Windsor
Lake St. Clair
DETROIT
GEORGIAN BAY
Owen Sound
LAKE HURON
MICHIGAN
Sault Ste Marie
Sault Ste Marie
Muskegon
LAKE MICHIGAN
INDIANA
CHICAGO
Chicago Diversion
ILLINOIS
Milwaukee
Green Bay
WISCONSIN
IOWA
LAKE SUPERIOR
MICHIGAN
Thunder Bay
Lake Nipigon
Ogoki R.
Long Lac
Duluth
MINNESOTA
CANADA
UNITED STATES
Lake of the Woods

mean annual discharge into the ship channel at Montreal is 9,650 cubic metres per second, about nine-tenths of that of the Mackenzie.

This unique waterway is the modern equivalent of other lakes, some even greater, that accompanied each major glaciation of North America. The present lakes are ringed by old shorelines. The traveller along Ontario Highway 401 between Cobourg and Belleville rides for miles on the abandoned shore and cliffs of Glacial Lake Iroquois, ancestor of Lake Ontario. Ancient spillways formerly took Great Lakes water to the Mississippi, via what is now the Chicago Drainage Canal; to the Hudson via the Mohawk; to Lake Ontario via the Trent River; and via Lake Nippissing to the Ottawa. The beaches, lacustrine sediments and overflow channels have played impressive rôles in economic and geographic development. Many of the channels have been reopened; thus the Beauharnois Canal, 25 km long and 0.5 km wide, and built to supply water to the turbines of the generating station, occupies an abandoned channel between Lac St. François and the Bassin de Laprairie. The existence of these old channels is a standing temptation to those who wish to divert lake water.

Within the 755,200 km^2 of the Great Lakes basin, on the 538,900 km^2 of land surface, live almost 40 million people, in Canadian and US territories. Their lifestyle is heavily urbanized and industrialized. Yet paradoxically the southern lakes--Ontario, Erie, St. Clair, southern Huron and Michigan--are close to some of the richest farmland in North America. The lakes show the impact of all these presences: there is heavy agricultural, industrial and municipal pollution, of both point source and dispersed origins.

Nor is it merely a question of pollution. Much water is withdrawn for industrial purposes, notably for cooling. There is an old established diversion at Chicago into the Mississippi drainage, mainly for sanitary purposes. Extensive withdrawals feed municipal water supply systems. Demands are also made for irrigation, thereby diminishing the flow of tributaries into the Lakes. A large part--of order nine-tenths--of these withdrawals returns, often polluted, and usually warmer; but a significant fraction (100 percent in the case of much irrigation) is evaporated, and can only very partially return to the lakes via precipitation.

The increasing consumptive use, plus impending demands for larger diversions out of the lakes, poses an important threat to water levels and discharge, and accordingly to water quality, shoreline stability, ice régime, navigation and power production. As will appear later, it coincides in timing with an anticipated climatic downturn of streamflow. The entire debate about withdrawals, especially for consumptive use and diversions, has an important environmental content. From the ecological standpoint transfers of water into the Basin also have important implications.

A recent analysis by Bruce (1984) puts these fears in economic perspective. He notes that future consumptive use of Great Lakes water will increase at some rate between 1.9 per cent and 3.2 per cent per annum, the most probable rates being 3.3 per cent for Canada and 2.7 percent in the U.S. --mostly because of increased withdrawals by thermal and nuclear electric generating stations. The loss to the discharge of the lakes is equivalent to 8.6 per cent of present flow, representing a loss of $300 million per annum in hydroelectric power generation. Bruce further estimates that losses due to climatic change may be ten times as great--$3 to $4 billion per annum. 80 per cent of the consumptive uses will be in the US, but climatic change and water level changes will affect the whole system.

Those of us who are also close to this issue usually put the need to protect the discharge from the lakes at the top of the list of priorities. Given the strength of the water-consuming lobbies in the US, this will not easily be achieved.

Water quality issues of the sort summarized above (pp. 32-55) have loomed large in the recent history of Great Lakes research and development. Earliest was the realization that sanitary sewerage could and should ensure that the waters of the lakes were protected against microbial infection. This has been largely achieved in Ontario, less so in the US, and hardly at all in Québec on the St. Lawrence (where, however, the huge and rapid flow of the river prevents catastrophe). Protection is not perfect. Ottawa River and Toronto beaches have been unusable in some recent summers. In many areas there are proven or suspected interactions of storm and sanitary sewer systems due to errors in design or inspection. Nevertheless much progress has been made.

A major effort to remove pollution in the Great Lakes was achieved as the result of references by the Canadian and United States Governments to the International Joint Commission, concurrently with the signing of the Great Lakes Water Quality Agreement in 1972. They asked the question: are the boundary waters of the Great Lakes system being polluted by drainage from land use activities? If so, what should be done? The Commission set up a Pollution from Land Use Activities Reference Group (PLUARG). The reports from this international body are landmarks in Canadian water science. They have been paralleled by a stream of scientific analyses from Canadian and US laboratories on other aspects of the pollution question. PLUARG and the parallel activities established what is now common knowledge, that:

> Unacceptable levels of industrial organic compounds, heavy metals and other trace elements are also present in the waters of the Great Lakes. Lakes Ontario and Erie sediments, particularly those adjacent to the large urban areas, are highly contaminated with PCBs . . . . While these have been used in the basin for over 40 years, steps to ban their use were taken only recently (IJC, 1980).

These and other activities lead to a number of general conclusions about water quality:-

(i) Urban and industrial point sources of the significant pollutants are numerous, but they are relatively easily identified and regulated. Municipal sewage treatment plants, for example, can be designed to remove phosphate (largely from detergents), if that is desired. But, except for Lake Michigan, the greater part of phosphate loading comes from agricultural fertilizer leaching by streams. Hence for many pollutants only basin-wide strategies are likely to succeed.

(ii) Some of the pollutant loading of these waters is of airborne origin. It enters the Lakes as fallout of particles, or precipitation. In many cases the origins are remote, or indeterminable (IJC, 1977). Some water pollution thus depends on the long-range transport of air pollutants.

(iii) A comprehensive approach is needed in relation to the rôle of the pollutants. Thus phosphate and nitrate, many of which originate as agricultural fertilizers, also fertilize aquatic ecosystems, often to the point of overdevelopment (eutrophication). More generally, one must see their rôle in the context of the overall nutrient balance, chemistry, sediment characteristics and limnology of the lakes--in brief, of comprehensive water science.

(iv) The list of threats to human health grows longer annually, as the leaching or leakage of toxic substances into the lakes progresses. The Niagara River, with its leaking chemical dumps, has become the classic illustration of the dangers of poor disposal technology.

I presume that the Inquiry will seek to hear more detailed evidence on these questions. I propose instead to focus on two specific issues--evidence of changes in the nutrient loading, and the special rôle of Lake Erie.

During the past seven years major emphasis has been placed on control of the phosphate loading of the lakes. Specific targets were established that would, in the present view, protect the overall aquatic ecosystem. Table IV shows these targets, lake by lake. Impressive steps have already been taken towards these targets, largely through phosphate removal at sewage treatment plants, and regulation of phosphate content in detergents. The result has been an observed decrease in algal blooms in Lake Huron, Erie and Ontario. Figure 16 shows the trends in input (load) and open lake phosphorus concentrations in Lake Erie (after NWRI, 1984).

Lake Erie stands out among the lakes as an object of public concern. A large concentration of old industrial cities and agricultural settlements surrounds the lake, which is shallow. An intensive study by the National Water Research Institute (Lam, Schertzer and Fraser, 1983) shows large seasonal and interannual variations in phosphorus concentrations and oxygen depletion. These changes are related to the incidence of individual weather systems, especially in spring and early summer. Crucial to the subsequent development

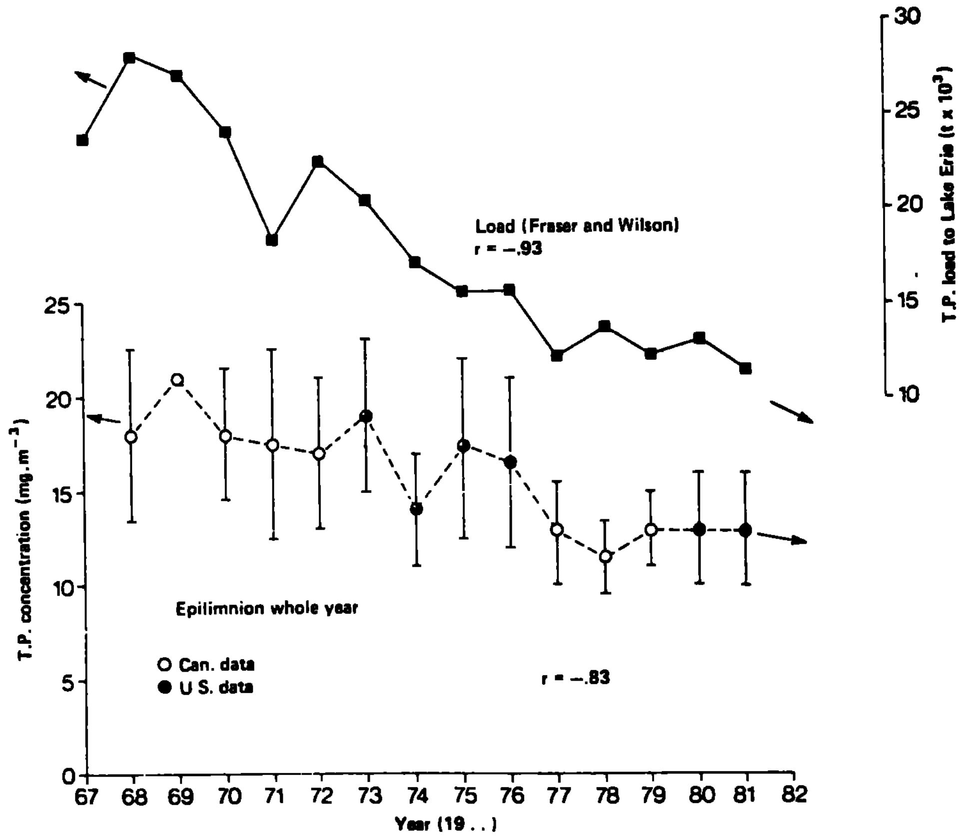


Figure 16. Total phosphorus loading (upper curve) and open lake epilimnion concentration for whole year, Lake Erie, 1968 to 1981, showing downward trends (after National Water Research Institute, 1984).

Source: National Water Research Institute (1984)

TABLE IV

Recent, Target, and 2020 Phosphorus Loadings of the Great Lakes (after PLUARG)

(tonnes per annum load)

Item	Lake				
	Superior	Michigan	Huron	Erie	Ontario
1976 load	6,445	8,241	7,301	25,919	15,336
Target load	4,000	4,900	4,400	11,000	7,000
Reduction scenarios, 2020					
(i) STPs at 1 mg/L	4,000	5,300	4,700	14,700	11,000
(ii) STPs at 0.5 mg/L	-	4,700	4,500	12,600	9,000
(iii) STPs at 0.3 mg/L	-	-	-	11,900	8,300

(STP = sewage treatment plant, with specified permitted levels per litre of phosphorus output)

(dashes indicate that target will be reached, or virtually so, in less stringent scenarios)

Source: IJC (1980)

is the extent to which thermal stratification can develop. It would have been impossible to interpret the observations, and the effectiveness of the phosphorus control measures, without patient monitoring and mathematical modelling of the lake's condition.

In recent years more attention has been given to nitrate levels, which have a bearing on both biological productivity in aquatic systems and on the acidity of surface waters. Widespread, sometimes excessive, use of nitrate fertilizers in grain-growing and intensive pastoral areas has provided much leaching into streams and lakes. In addition rising levels of the oxides of odd nitrogen (NO_x) from car exhausts and high-temperature industrial processes has rendered much rain and snow nitrate-laden, and hence acidic. The spring "shock" of acidity that is sometimes harmful to fish populations comes largely from NO_x stored in the winter snowcover.

Nitrate from both sources has produced long-term changes in the composition of Mississippi River water (see Figure 17), which flows through wheat and corn growing areas, and through regions of frequent acid precipitation. Within the past ten years nitrate concentration just above the delta has increased fourfold, from 2-3 to 9 milligrams per litre (Kempe, 1984). Observation suggests that there has also been a steady 2 per cent per annum rise in nitrate concentration in Lake Superior over the century 1880-1980, and Bennett (1982) shows that this must overwhelmingly be due to inputs from the atmosphere, of anthropogenic origin.

The sediment load on the floor of all these lakes, but especially those with agricultural hinterlands, also contains extensive mineral materials eroded from arable land. It has been estimated (D. Coleman, personal communication) that the Thames basin alone contributes 2.2 million tonnes per annum,

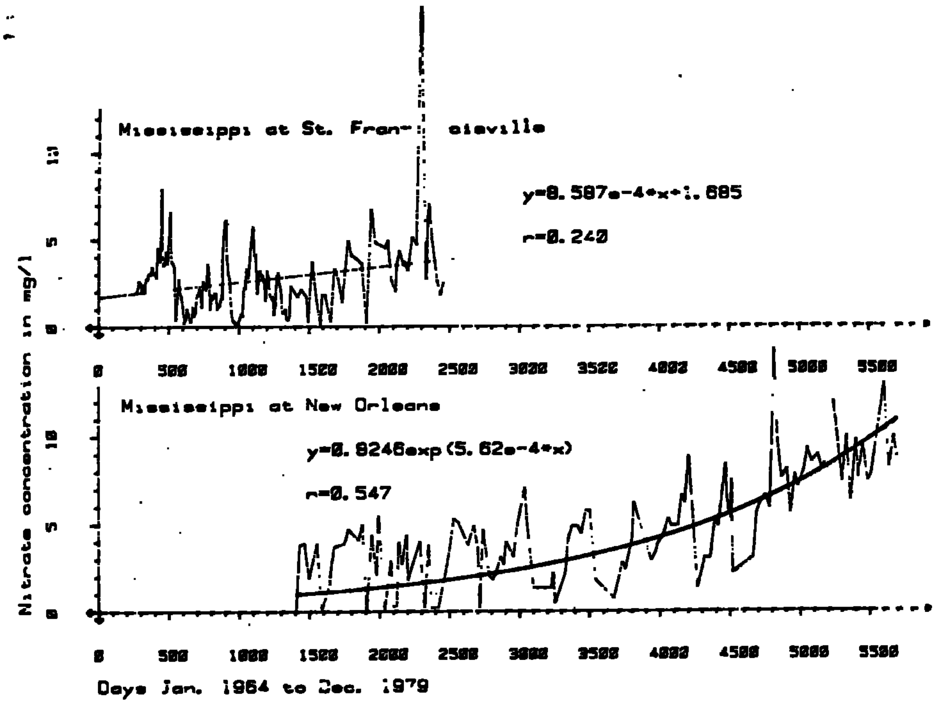


Figure 17. Nitrate concentration in the Mississippi at two stations immediately above the delta. The horizontal scale is days after January 1964 (to December, 1979), and the vertical scale concentration is milligrams per litre. The upward trend is attributed to human sources, such as NO_x emission followed by acid precipitation, and to fertilizer leaching.

Source: Kempe, 1984

though some of this remains in the channel. Most Canadian rivers outside the Prairies have natural lakes along their courses (because of glacial derangement), and these act as sediment traps, reducing discharge of solids to the ocean. Modern reservoir construction, like Lake Diefenbaker, has the same effect; the reservoirs silt up, and in those sediments may be trapped large amounts of carbon and nutrients. Natural lake bottom sediments may be very similar, and those of the industrial east frequently contain toxic residues as well.

10. Long Range Transport of Air Pollutants (LRTAP)

The realization that long-range transport of air pollutants affects the chemistry of the Great Lakes had a marked impact on subsequent events. In 1974 Cogbill and Likens (1974) published a paper alleging that increasing nitrogen oxides and sulphur dioxide were leading to a rise of acidity in precipitation over much of eastern North America, including the lower Lakes. Earlier work in Europe had suggested that sulphate and nitrate loading from distant industrial pollution had produced similar effects in Scandinavia.

Subsequent investigations in Europe clearly indicated that the industrialized countries of western Europe were emitting the pollutants that subsequently fell on Scandinavia. They also demonstrated that areas of granitic rock, like the Canadian Shield, could do little to "buffer" the falling acids, and that lakes and streams would suffer accordingly. Damage to fish populations was demonstrated. Fears were expressed, but not confirmed, for the health of forest vegetation and crops. Lasting losses of alkalinity in some systems were reported.

The outcome was the negotiation of the 1979 Geneva Convention of the Economic Commission for Europe to abate transboundary air pollution. This committed the members (including Canada and the United States), to seek means of reducing transboundary airborne movement of harmful substances. It was ratified, with some painful dissent, in 1984.

Canada and the United States signed a Memorandum of Intent to seek such an accommodation in August, 1980. Work Groups established under the Memorandum have published bi-national surveys of the acidity of precipitation, the concentration and deposition of acidifying substances such as sulphur dioxide and NO_x, and inventories of known emissions of these species. Extensive research was conducted into impacts on fish, water quality, soils, forests, crops and structures. Though substantial agreement was obtained that the main impact was on aquatic systems and their life, and that sulphur was the key element in the aquatic impact, the two governments have been unable to agree on an abatement strategy. The Canadian government has committed itself to the view that a target loading (i.e. deposition) of 20 kg of wet sulphate per hectare per annum would protect all but the most sensitive streams and lakes (Canada-US, 1983; Royal Society of Canada, 1983).

The Inquiry will have more detailed evidence before it on this major environmental issue. But I wish to emphasize its importance, and the perspective that it reinforces: water quality can be affected by distant pollution sources, and in very subtle ways. Only patient monitoring of the system, coupled with good research in the water sector (of Fisheries and Oceans as well as Environment) can demonstrate for sure the impacts, and prescribe the necessary remedies. Again the need for sound water science is demonstrated.

11. Future Changes: The Impact of Climate

So far in this analysis I have concentrated upon the influence of past and present economic activity on water quantity and quality. The underlying assumption has been that nature, left to itself, would have continued in its pristine mode, unchanged and unchanging.

Natural processes of environmental change are indeed slow. On the human time-scale they are barely detectable, except for catastrophic events like landslides, tornadoes, and earthquakes. Nevertheless the processes of natural change are all around us, even if we refrain from speeding them up. Thus a general uplift of the region depressed by the last continental ice-sheets--essentially the vast basin that surrounds Hudson's Bay--is still in progress north of a line through the Great Lakes. Gradually, without help or hindrance from man, the soils and vegetation cover are also changing. So are the beaches, cliffs and headlands, because of erosion or deposition. Most of these natural changes go unnoticed, so short is our life-span.

Many of the environmental impacts discussed above are accelerations of these natural processes, because human interference removes the checks, balances and equilibria so typical of natural ecosystems. We have dealt a blow to the homeostatic mechanisms that have evolved over the long history of the earth.

Even the new toxins that we have released have their parallels in nature. Given time, they would be coped with as natural perils are coped with. But time is exactly what we lack. Human demands, expectations and sheer numbers (at least in cities) advance at exponential rates. Economic opinion suggests that economies can deliver satisfactions and equity only if they achieve exponential growth of a few per cent per annum. In natural systems, however, exponential growth is the symptom of disaster. A growth rate of any natural phenomenon of 3 or 4 per cent per annum cannot be sustained for long. Hence the long, tedious and contradictory debate between economists and ecologists, with the latter demanding that society achieve some kind of steady state. For such a debate to be resolved a century hence by the triumph of the ecologists is not a useful idea in politics. We need stable solutions within the next few years.

In addition it is probable that man-made change is at work on time-scales rather longer than those dealt with above. Again the agent is economic activity, and again there is an acceleration of natural processes. This time the consequences will be world-wide, affecting Canada's foreign relations and trade as well as her own internal environment. I refer to climatic change induced by far-travelled atmospheric pollutants.

The direct cause will be a change in the optical properties of the atmosphere being brought about by a build-up of carbon dioxide and other infra-red absorbing gases, such as nitrous oxide (N_2O), methane (CH_4), and various halocarbons, like the chlorofluoromethanes. These "greenhouse" gases are increasing world-wide, and should tend to raise surface temperatures. They are of diverse origins. The halocarbons are synthetic pollutants released largely in the northern hemisphere. Carbon dioxide is a natural constituent that interchanges with the biota on roughly a ten year turn-around time. But fossil fuel burning and forest clearance are irreversibly releasing perhaps 7 billion tonnes (of carbon itself) to add to the atmospheric store of 724 billion tonnes. About 45 percent stays in the atmosphere. The rest probably goes into the ocean. Net annual increases of atmospheric carbon are near 3 billion tonnes, or 0.4 per cent. Methane is released from soil, organic terrain and thawing permafrost. Small amounts of natural gas also escape. Nitrous oxide is a natural emanation from the soil denitrification process, which is being accelerated by nitrogen fertilizer application (for overviews see Hare, 1981; Clark, 1982; NAS, 1983). The origins are thus diverse, but in each case the work of mankind is involved.

If the trends continue, as the economic outlook makes likely, carbon dioxide concentration will double in the latter part of the next century. The course of the other gases is not as clear, but they too may increase. One must thus ask the questions: what will these changes do to climate? And what will climatic changes do to water resources?

Large-scale modelling exercises at several centres around the world, especially in the U.S., suggest that a doubling of carbon dioxide would raise winter temperatures in southern Canada by about 3°C, and in northern Canada by perhaps 7°C (the models differ appreciably). Summer temperatures would rise by 1 to 3°C. In the 1970s it has been calculated (Hansen et al., 1982) that mean annual world surface temperatures rose by 0.24°C. To this warming carbon dioxide increase contributed 0.14°C, and the other gases 0.10°C. If so, the above figures may need to be increased by as much as 70 per cent.

How striking are the figures, and how will they affect the hydrologic cycle? In terms of long-term changes the rises of <u>mean</u> temperature are larger than any experienced by Canada in the past 9,000 years - the entire course of civilized world history. In that sense they are revolutionary. But in the shorter term they are within recent experience, because of the extreme variability of the existing climate.

Thus 1982-83 dramatically rehearsed the possible impact on our economy. The winter was 3 to 7°C above normal almost coast to coast (see

Figure 18). Snowcover was lacking for much of the winter in many agricultural regions. Winter wheat could have survived and prospered more widely on the Prairies. The Great Lakes saw little ice. Winter navigation could have been practiced throughout. The following summer (1983) was also warm almost everywhere, and in many farming areas droughty. Streamflow, soil, moisture and groundwater drawdowns were highly abnormal. These anomalies were part of a set of hemisphere-wide reactions to the dramatic El Niño--Southern Oscillation effect observed over the Pacific Ocean and Australasia. There were economic costs and benefits from the surprising year, but these did not fully rehearse what the carbon dioxide effect may do in the future. We did not know that the anomaly was coming; if we had, we should have acted differently. But at least there was no disaster.

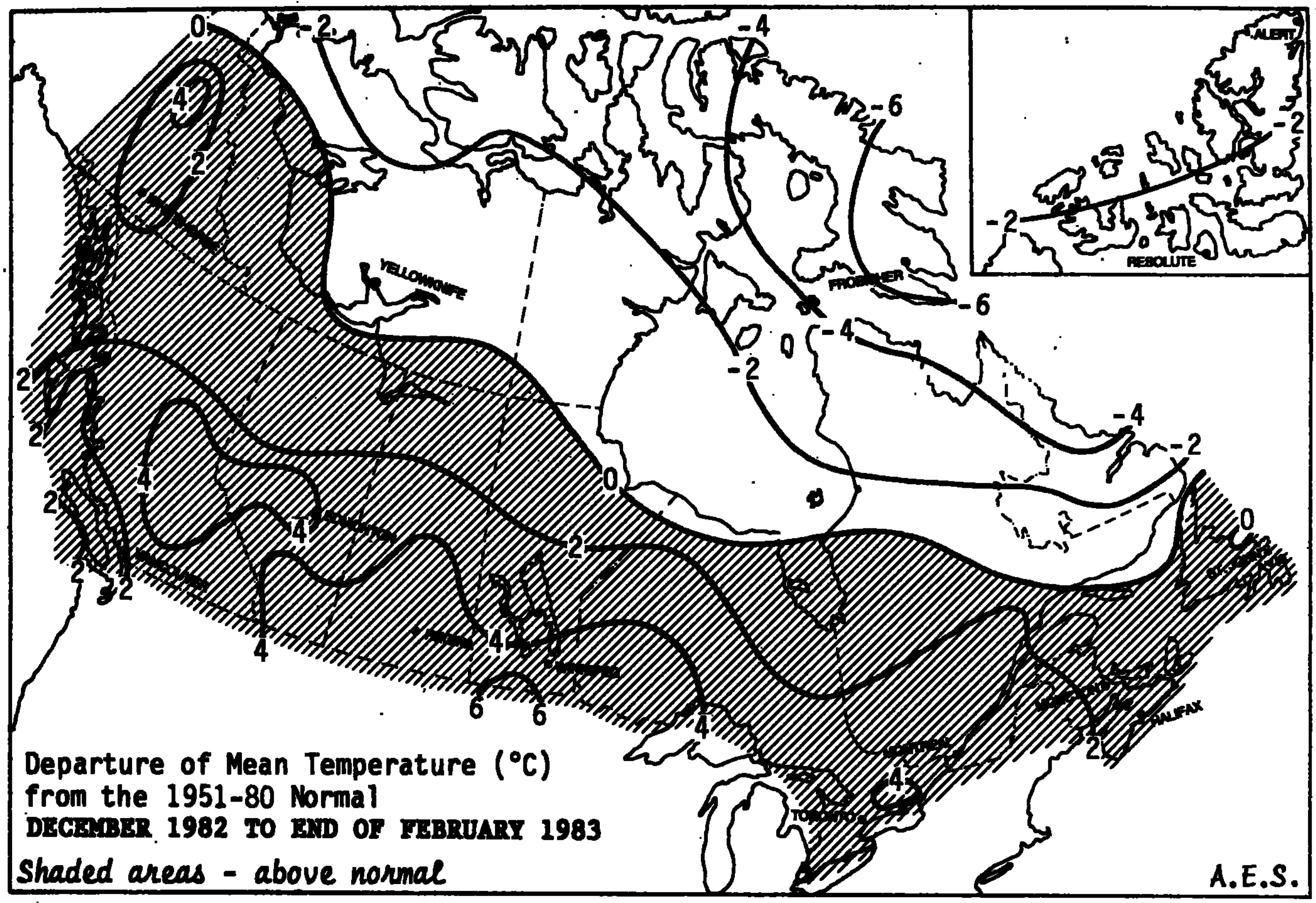
The potential effect of the coming warming on surface waters is much harder to judge. Bruce (1984) has summarised recent analyses for the Great Lakes basin. He foresees reduced run-off into the lakes, because of increased evapotranspiration. A 6.5 per cent increase in precipitation is forecast, but this will be more than offset by lake evaporation. The net predicted result is an eventual 21 per cent decrease in discharge from the Great Lakes basin. Added to the increased demand for consumptive uses discussed earlier, these figures are alarming. Drier, warmer conditions will obviously increase demand for irrigation and municipal supplies. They will be hard to come by, if Bruce's estimate is valid. A firm date cannot, incidentally, yet be put on the effects.

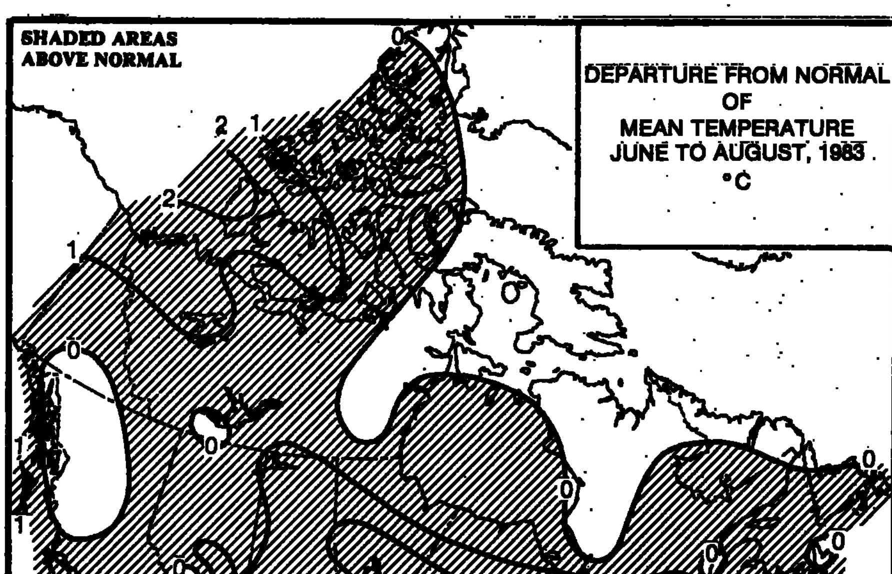
The U.S. Environmental Protection Agency (EPA; Rind and Lebedeff, 1984) has applied a three-dimensional general circulation model of the global atmosphere to the prediction of gross changes in the hydrologic cycle over

Figure 18. Departures of mean air temperature from 1951-1980 normals, winter 1982-83 (above) and summer 1983 (below). In both seasons temperatures were as much above normal in southern Canada as might be expected from the effect of doubled carbon dioxide. The eastern Arctic, however, was colder than usual. The anomalies were actually associated with an el Niño episode in the Pacific.

Source: Atmospheric Environment Service

SEASONAL MAPS





North America. Figures 19 to 21 summarise their results, which are given for large spatial boxes including southern Canada. Models of this kind are not yet trustworthy as to precipitation, so the maps should be taken only as hints as to the future. For doubled carbon dioxide, when temperatures have reached equilibrium (possibly late in the 21st century), the model predictions seem to be as follows:-

(i) annual precipitation is expected to increase in most parts of Canada, by as much as a fifth to a quarter in the western mountains, by 11 to 15 per cent in the Prairies, by 3 to 14 per cent in southern Québec, and by 15 to 20 per cent in the Shield areas north of the Great Lakes. A decrease of 3-5 per cent is foreshadowed for the Maritimes and the Lower Lakes basin;

(ii) annual evapotranspiration is expected to increase everywhere except the Lower Lakes basin, where an 8 per cent decrease is suggested;

(iii) annual run-off is expected to rise strongly in the western Prairies and western mountains (by as much as a third in the core), and to decrease in much of eastern Canada, including the Lakes basin. These results are reasonably consistent with Bruce's analysis, except that the EPA study finds a 10 per cent increase in run-off in the square including Lake Michigan and southern Lake Superior.

I hope that the Inquiry will regard these predictions only as indications of probable trends over the next century, and not as quantitative predictions. I have given numbers, but suggest that they be discounted. The implications for western Canada, however, are so dramatic that I shall spell them out in more detail.

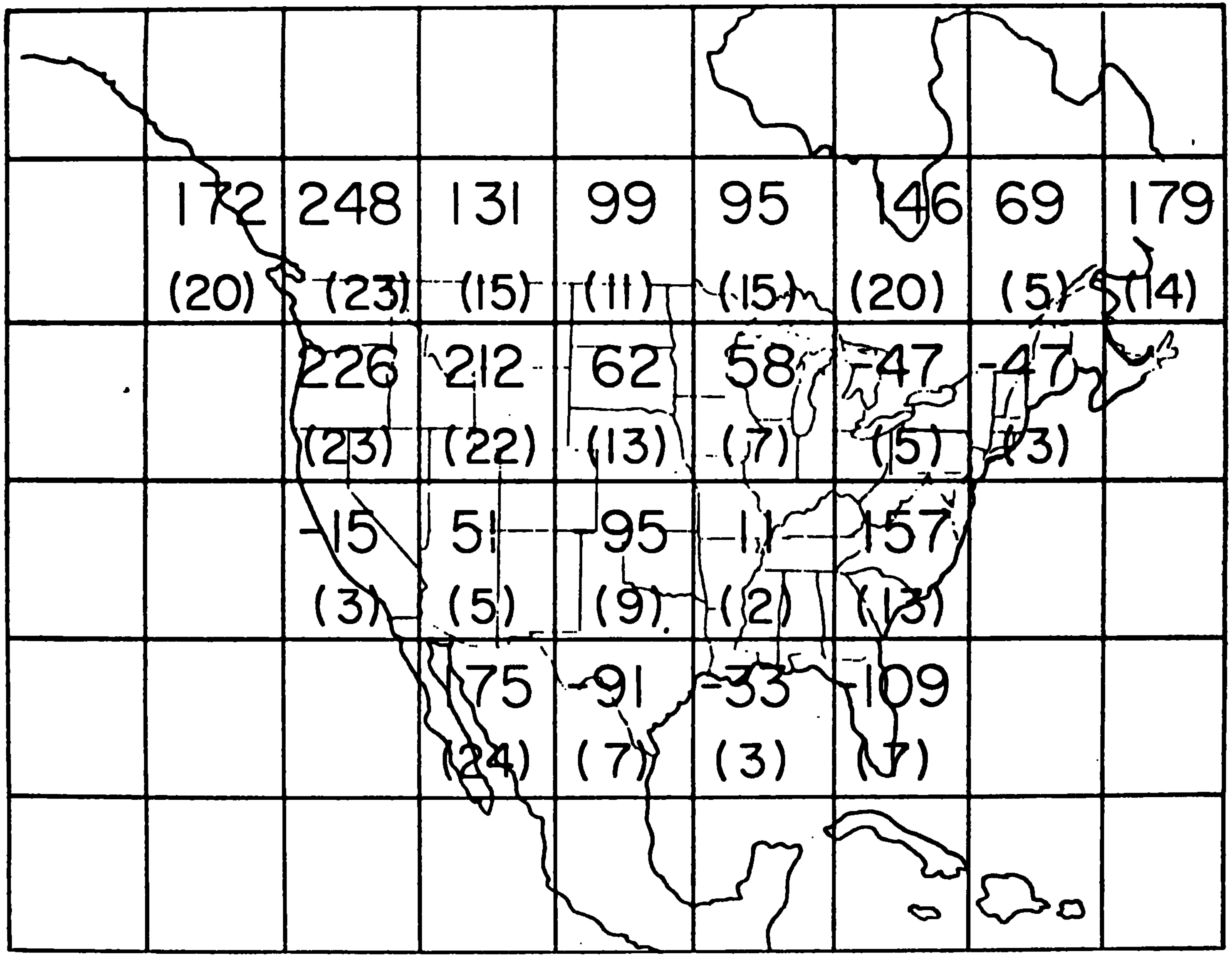


Figure 19. Change in precipitation between the last ten years of the doubled CO_2 run and the last ten years of the control run, for the annual average. The top number indicates the actual change (mm), the bottom number in parenthesis gives the change in % relative to the control run.

Source: Rind & Lebedeff, 1984

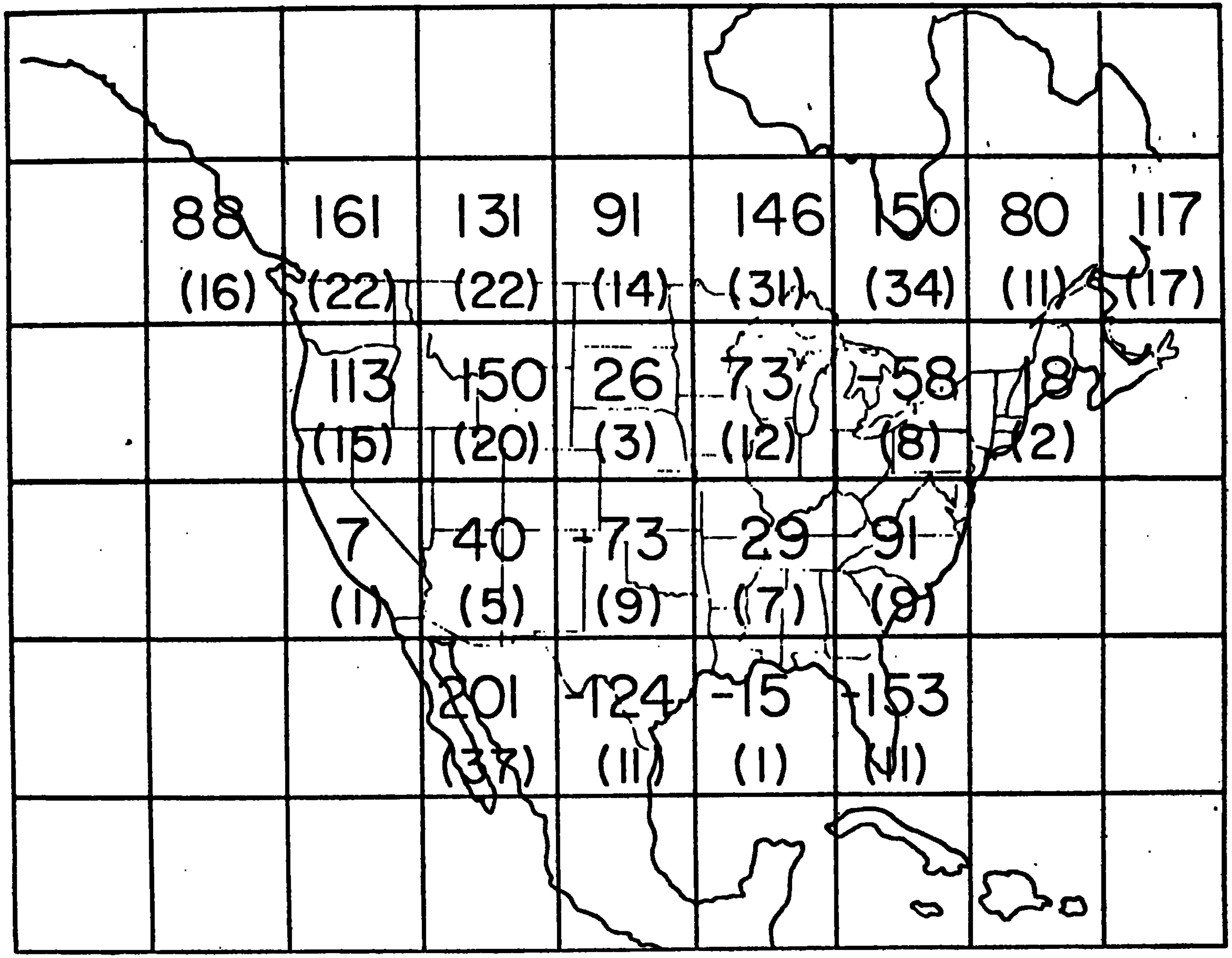


Figure 20. Change in evaporation between the last ten years of the doubled CO_2 run and the last ten years of the control run, for the annual average. The top number indicates the actual change (mm), the bottom number in parenthesis gives the change in % relative to the control run.

Source: Rind & Lebedeff, 1984

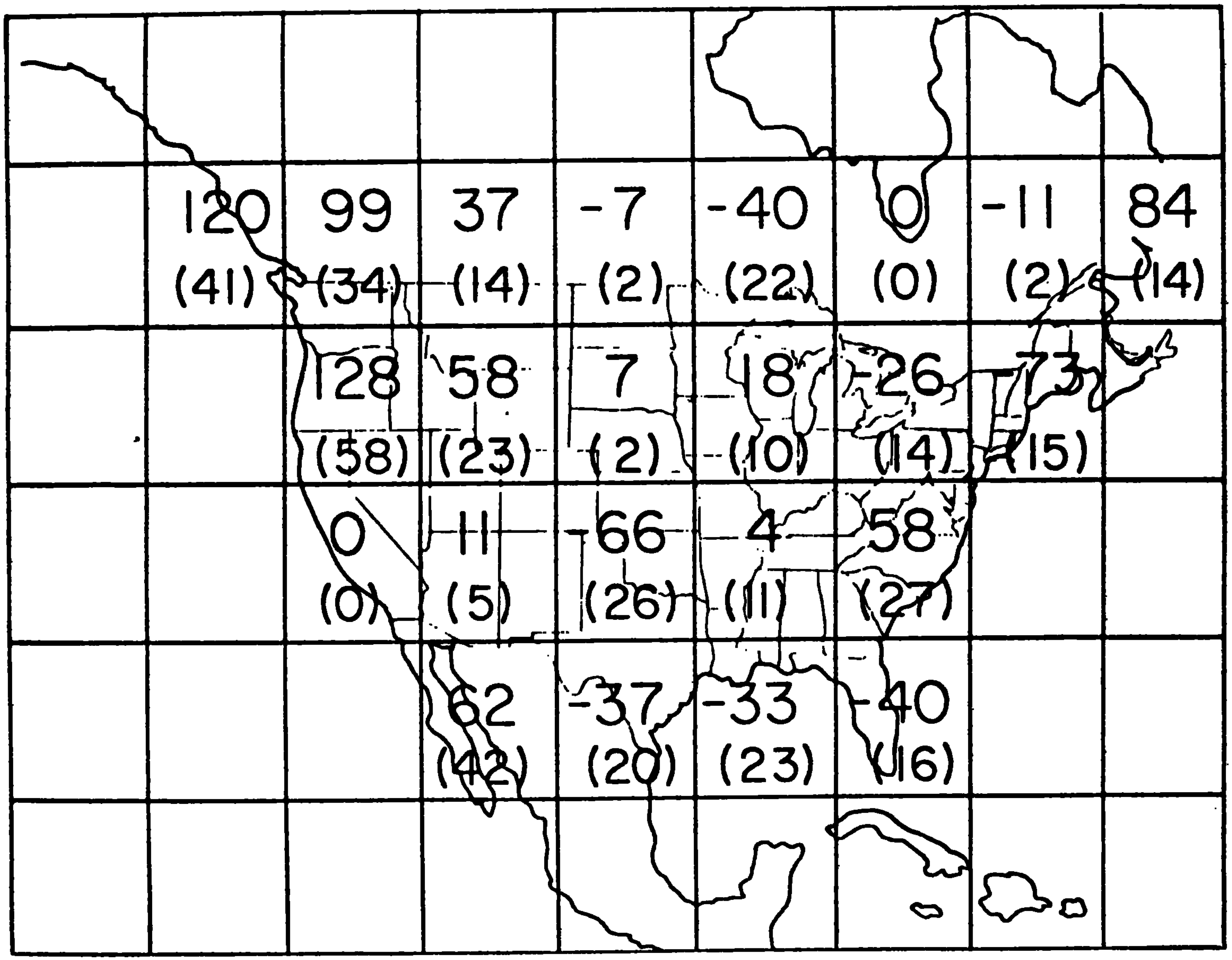


Figure 21. Change in runoff between the last ten years of the doubled CO_2 run and the last ten years of the control run, for the annual average. The top number indicates the actual change (mm), the bottom number in parenthesis gives the change in % relative to the control run.

Source: Rind & Lebedeff, 1984

In British Columbia and Alberta (perhaps excluding the south-eastern dry belt) the already heavy precipitation on the mountains, and the resulting streamflow, are both expected to increase still further. This implies a larger supply of water for irrigation in the inland valleys and foothills, but also means increased erosion, nutrient depletion and flood hazard.

In Saskatchewan and Manitoba the results imply less abundant soil moisture in the growing season, but perhaps increased streamflow from Rocky Mountain and foothill sources, at least in the Saskatchewan drainage basin. The EPA analysis says nothing about the possibility of more frequent and more severe drought. The current drought phase, the worst since the 1960s, and in some areas since the 1930s, has reopened this question. Some other models suggest that droughts of the present intensity will indeed become more frequent as carbon dioxide builds up. Increased availability of irrigation water from the Saskatchewan river system will not offset this hazard because, as we saw above, the short growing season severely restricts the choice of crop for irrigated land. The growing season will increase, perhaps to the extent of more than 25 per cent in growing degree-days. This will make winter wheat more widely a staple crop. It will not answer the conundrum: what more valuable crop can one grow on irrigated land? But at least it should increase the options.

Elsewhere in southern parts of the country the picture is one of decreased run-off, associated with longer growing seasons and more agricultural and municipal water demand in summer. The EPA model suggests a decrease of 14-15 per cent in run-off in southern Ontario, southern Québec and New Brunswick.

What do these predicted trends imply for future water policy? The degree of uncertainty is high, and there is as yet no firm evidence that the changes are in progress. What courses of action will be prudent?

The time-scale is obviously important. The EPA results used above refer to equilibrium conditions after a doubling of carbon dioxide. Because of the heat capacity of the intermediate waters of the oceans there may be a delay--perhaps of two decades after a doubling--before such an equilibrium is established. And no-one knows for sure when these events will happen. Present trends plus predicted consumption make a doubling likely about the year 2075, but this is subject to a probable error of plus or minus several decades. Cautiously one can speculate along the following lines:-

(i) The trends implied by the above treatment will become obvious by the end of this century. They will be well advanced fifty years later.

(ii) Within two decades the perceived changes will create economic and political demands for action.

(iii) This will arise because climatic trends are not normally perceived as gradual changes of the mean state, but as altered frequencies of stressful events, such as droughts, floods, winter cold snaps and summer heat waves. If conditions become, in the mean, drier in the eastern Prairies, this will manifest itself in more frequent droughty summers, like 1984. Such events are very effective in persuading public and politicians alike that action is needed.

From these speculations I derive certain conclusions as to desirable action:-

(i) Given the probability of reduced water supply in much of the Prairies, the Great Lakes region and some other areas, governments should exercise care in use of existing resources, and in protecting their quality and accessibility.

(ii) Given the long life-expectancy of major capital projects in the water sector--dams, hydroelectric plants, navigation and flood control works--attention should be given, in future capital expenditures, to the probable changes in the hydrologic cycle on this time scale.

(iii) All new projects for diversion of the waters of the Great Lakes-St. Lawrence system, or for increased consumptive use (irrigation, cooling of power stations and others) should be avoided, given the probable downturn in discharge. The dominant rôle of the US in such consumption calls for strong diplomatic stances by Canada.

(iv) Given the high level of uncertainty in the models used in such prediction, particularly as regards precipitation, governments should give high priority to research into climatic change and the hydrologic response.

(v) There is a paramount need to bring together all the actors in this approaching drama--the major consumers, who are the power companies, the farmers, the pulp and paper and mining industries, and the large municipalities; the scientists who can foresee the consequences of water consumption; and the politicians who have somehow to accommodate the conflicts of interest.

This is an area in which no country can claim to be sovereign, or to control its environment. The atmosphere is a very effective diffuser. Pollutants added in Canada, if they are poorly water soluble, will be carried world-wide. By the same token Canada's atmosphere contains such pollutants derived from all other major countries. Climatic change, if it comes, will be world-wide (though uneven in nature and impact). It follows that Canada should encourage and be involved in all international enterprises aimed at understanding and influencing the future course of world climate.

12. Coda

I began this essay with the idea of apparent abundance--the evidence all around us of water in huge quantities. It may be frustratingly distant for the inhabitants of Regina or Swift Current, but it is still there, within their own province. And there are signs, as yet uncertain, that the flow of the great rivers of the Prairies may increase within the next century.

Few countries have grown into nationhood with such abundance of water. In few others is water so central to the national history. And in few others does it play so large a rôle in the contemporary economy. I have not spelled this out in detail, because it was not my job to do so. But the centrality of water in the national economy still emerges from my treatment. It could hardly fail to do so.

Two historic processes, I said, lie beneath the list of human impacts on the water system. One was the colonization and exploitation of the Canadian land surface, especially for agriculture and forestry. These huge realities have made Canada a leading power in both industries; we are near the head of the export league in both farm and forest products. But they have also placed strains on Canada's soils, streams and lakes. From this I derive my first general conclusion:-

1. that land use and its management are central to the control of water quantity and quality.

It is important to stress this fact because the structures of government and the body of law and regulation tend to see land and water as different domains, as indeed they are. Nevertheless water management implies land use control.

The second historic process, very marked in the present century, has been the shift from rural to urban living, and from small-scale, locally powered industry to the modern pattern of concentration within urban areas. The result has been the emergence of severe water quality and quantity problems arising from the extreme concentration of demand, and from the poor management of urban wastes and industrial residuals. In the midst of abundance, that is to say, the evolution of our economy has created local shortages of supply, and huge problems of quality management. As I write these words (on August 18th) the beaches of Toronto have just been closed once again for the rest of the summer, because of a single thunderstorm that the sewerage system could not handle. This fiasco is a nice encapsulation of the failure of management in the midst of prodigal nature.

Such failures arise, not from lack of knowledge, but of lack of understanding of that knowledge. Canada has excellent water science. I am not a water scientist, which may add force to my assertion that our national resources in this area are among the world's best: Canada's hydrologists, hydraulic engineers, consultants, hydroelectric power engineers and stream channel managers are recognized world-wide as second to none. One sees Canadian design in many overseas countries. Yet in the home country there are numerous problems of water management, from which I draw a second conclusion:-

2. <u>that Canada needs to make more effective use of integrated water science and technology in the management and future use of natural resources.</u>

One reason for this failure is that the scientific community has not found it easy to take national stock of the water problem. The International

Hydrologic Decade did indeed produce the magnificent Hydrologic Atlas of Canada (Inland Water Directorate, 1978), and the public relations staff of Environment Canada have done their best. So have the senior staff in various position papers. But much remains to be done.

In writing this essay, for example, I was handicapped by the lack of overall national syntheses of such things as sediment and nutrient transport, erosion, the impact of forest and agricultural practices, and the dependence of the major hydrological variables on climate. There are hundreds of research papers on aspects of these subjects, but too little attempt to bring them together in synthesized form*. And it is such syntheses that influence policy. We have excellent scientific skills in the Inland Waters Directorate of Environment Canada, in the Department of Fisheries and Oceans, in the various provincial governments, and in the universities. I urge:-

3. that the scientific community attempt periodic national syntheses of major questions of water quantity and quality, so that public policy may respond more easily.

There is no lack of ability among water scientists for the preparation of such overviews. The Great Lakes Water Quality Agreement, for example, has stimulated much activity of this kind. The PLUARG reports, and many reviews that have emerged from the Canada Centre for Inland Waters, have this quality of generalization.

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* it can be argued (E.D. Ongley, personal communication) that in some fields (such as sediment transport) the evidence available does not justify such syntheses.

One must recognise, nevertheless, that there are major institutional barriers to the proper use of water science in national affairs. Some of these are due to unwise separations of jurisdiction. In both federal and provincial governments lands and water are, as just remarked, typically handled in different departments. In Environment Canada Inland Waters and Lands are separate Directorates. Water quantity and quality management are also typically separated. It will not be lost on the Inquiry that many of the problems discussed above cry out for comprehensive basin planning and management. Such activities are generally hamstrung by the lack of adequate devices to permit them to go forward--especially when, as nearly always, several political jurisdictions are involved. Hence I urge:

4. That the Inquiry investigate the entire jurisdictional tangle in which water issues are caught up, and recommend (i) suitable realignments of managerial responsibilities within governments; and (ii) devices whereby effective comprehensive basin planning can more effectively be carried out.

To quote one senior manager, whom I will leave anonymous: "how does one educate an aging management system that old structures and old approaches are increasingly unable to deal with contemporary and emerging issues?"

I am also deeply disturbed by the failure of the Canadian Universities to give adequate support and depth to water resource studies. Several institutions or centres aiming at comprehensive water resource management were set up more than a decade ago. Only one or two survive, and none has yet faced up to the real challenge of putting it all together. Universities are better at taking things apart!

Last, but not least, I urge that Canada address the question of future environmental change and its implications for water supply and demand. I have listed five possible ways of doing this in the preceding section.

One cannot assume that past experience of climatic variability will be a useful key to the future. There are many signs, discussed above, that human interference is beginning to disturb the climatic system whose variability already causes stresses in the water sector. Those stresses may well increase. The time to prepare for them is now, and the resources to do so are at hand.

I do not imply that the age of natural abundance is thereby at an end. But the time when we could carelessly assume its continuance is long past. The keys to security are political awareness of the issue, and the continued health of Canada's brilliant water science. If the latter can be assured the public gains will be enormous.

I am not competent to discuss how political awareness can be generated. It is there already on the dry Prairies, and in the country's flood-prone areas. Nationally, however, water remains an ill-defined issue --not least because of uneven media coverage and regional political rivalries. I suggest to the Inquiry one persuasive argument: that a nation of 26 million citizens who cannot live abundantly off its present supply should be the laughing stock of the world. Even if that supply shrinks by a third, we still have enough, given good management. It is presumably the Inquiry's job to say how that may be done.

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Appendix I

Area, discharge to ocean (with precipitation equivalent)
from major drainage basins
(annual normals)

Total discharge is 100,700 m^3/sec

Source: International Hydrological Decade Secretariat

Atlantic Coast

Basin	Area (sq. km.)	Discharge m³/sec	Precipitation equivalent cm
Hamilton	79,800	1,580	62
Mecatina to Outardes (5 rivers)	129,800	2,637	70
Saguenay	90,100	1,820	58
St. Maurice	42,700	728	54
St. Lawrence	1,026,000* *includes US drainage	9,860	30
St. John	55,400	1,130	64
Entire Atlantic Slope	2,045,000	33,500	

Hudson's Bay & Strait

Basin	Area (sq. km.)	Discharge m³/sec	Precipitation equivalent cm
Churchill	281,300	1,200	14
Thelon	142,400	841	19
Nelson (includes Saskatchewans)	722,600	2,370	11
Hayes	108,000	589	17
Severn	100,800	482	15
Albany	133,900	1,400	33
Moose	108,500	1,380	40
Nottaway	65,000	1,140	47
Grand River	96,800	1,690	53
Leaf	43,000	620	45
Koksoak	133,400	2,550	60
George	44,800	921	65
Entire Hudson B & S	4,040,000	29,400	

Pacific Coast

Basin	Area (sq. km.)	Discharge m³/sec	Precipitation equivalent cm
Yukon (at Alaskan border)	297,300	2,320	25
Stikine	49,200	1,100	70
Skeena	54,900	1,730	98
Fraser	219,600	3,540	52
Columbia (at US border)	154,600	2,800	57
Total, Pacific Slope	1,086,000	21,300	

Canadian Arctic

Basin	Area (sq. km.)	Discharge m³/sec	Precipitation equivalent cm
Mackenzie	984,195	10,800	35
Back	107,226	524	15
Total, Canadian Arctic	3,583,200	16,500	

Appendix II

Notes in Amplification of the Text

Note 1. Sediment transport has an importance well beyond the points raised in the main text. I am indebted to E.D. Ongley, R.A. Allan and others for the following amplification.

A major advance in the past five years has been the realisation (Allan, 1983) that significant transport of toxic substances, notably metals, takes place in association with sediment transport. The bottom sediments of lakes and rivers may contain large amounts of toxic materials capable of being remobilized by a wide variety of processes. Metals such as mercury achieve high mobility and much increased toxicity by interaction with organic sediment (e.g., methyl mercury). The movement of mercury from the forest industry in the English-Wabigoon River has been intensively studied because of its impact on local populations.

It is doubtful whether erosion of agricultural land really dominates the sediment loads of Prairie rivers. Ongley writes (personal communication):

> . . . my general impression is that the major sediment sources are (i) erosion in source areas (e.g. foothills), (ii) collapse of coulée walls (a massive source on many Prairie rivers--I have personally observed huge collapse events), and (iii) in so-called badland areas. Erosion on Prairie surfaces tends to be localized around gullies except during periods of widespread flooding.

A typical problem of jurisdictional sundering occurs here: physical sedimentation and transport of dissolved substances are handled by separate agencies!

Note 2. Again I am indebted to E.D. Ongley for the following comment:

> . . . there should be mention of extensive degradation of available surface water (sloughs, reservoirs, lakes) by excessive algae production. Manitoba and Saskatchewan identify this as a major problem for many rural potable water supply reservoirs (coincidentally, very little research has been carried out on feasibility of algae control and restoration measures). . . . Similar concerns exist for recreational lakes and reservoirs.