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FRESH WATER BUDGET OF HUDSON BAY

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DEVELOPMENT

RESEARCH AND

OCEAN AND AQUATIC SCIENCES
CENTRAL REGION

CANADA CENTRE FOR INLAND WATERS
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REVISED

FRESHWATER BUDGET
OF
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by

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ABSTRACT

As more rivers draining into the Hudson/James Bay region are being developed for hydroelectric power generation, it is important to know the total freshwater budget of the region in order to predict the modification these projects alone, or combinations thereof, may have on the environment. The freshwater budget for the Hudson/James Bay region is obtained on a monthly time scale and includes runoff from the surrounding land as well as evaporation and precipitation over the water surface itself. The rivers' runoff data was obtained from Water Survey of Canada records, while the evaporation and precipitation rates were obtained using vapour pressure, wind, and precipitation data available from the Meteorological Branch of Environment Canada. The total water surface area was divided into six areas for which monthly evaporation and precipitation rates were calculated.

The monthly runoff rates have minimum values during the winter months and maximum values during the spring freshet. The rivers located in the southern part of the region experience a secondary runoff maximum during the late fall. The total monthly freshwater input for the region can be split into two seasons, winter and summer. From May to October inclusive, the large freshwater input represents a monthly-averaged addition of a 10.0 centimetre layer of fresh water; while, from November to April, about a 1-centimetre layer of fresh water is added. Over a period of one year, a layer of 64 centimetres of fresh water is added over the Hudson/James Bay surface area. Using a base salinity of 33.0 $^{o}/oo$, the 1975 summer oceanographic data produced a freshwater layer content of 4.7 metres, which represents a freshwater addition period of 7.3 years for the total area. For James Bay alone, the summer data produced a 6.0-metre layer, relative to a 31.0 $^{o}/oo$ base salinity, which represents a freshwater addition period of 1.4 years.

The hydroelectric development on the La Grande River will cause major changes in the freshwater runoff rates during the ice-covered winter period of January to April. The runoff rate of the La Grande River itself will increase by 470% above its present winter rate and will cause a 70% runoff increase for the James Bay region and a 20% increase for the Hudson/James Bay system.

ACKNOWLEDGMENTS

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CHAPTER 1

1.0 INTRODUCTION

Although Hudson Bay is the largest body of water within Canada's territory, very little has been written about the conditions and properties of this large inland sea. The two volumes of "Science, History, and Hudson Bay" assemble under one cover as much knowledge as possible concerning science and history of Hudson Bay and its relationship in the development of the rest of Canada. Even though the authors tried to avoid a too-technical approach, enough reference material is provided to give the reader an up-to-date picture of the available information on each particular subject. Compared to regions in southern Canada, however, the information is just barely sufficient to provide general insights into the physical processes that may occur in the air and water environment of the Hudson/James Bay region.

Due to its central location in Canada and to its great size ($8.14 \times 10^5 km^2$), meteorologists must contend daily with the bay's air mass modifying powers, as it will affect the weather pattern throughout most of Canada. In the summer, the dry Arctic air moving across the bay's open water surface cools, increases its moisture content, and provides the southeastern shores of the bay with a general sea climate. In the winter, however, the bay's climate changes to a land climate as the ice cover insulates the air mass from the water. Thus, the winter moderating effect is not present as found in other coastal regions where the ocean acts as a continuous heat source for the overlying air. Therefore, the bay in the winter acts as an extension of the snow-covered land, permitting the Arctic winds with their cold temperature to come down unmodified far southward into Ontario and Quebec.

Hudson Bay is the largest body of water in the world that virtually freezes over each winter and becomes ice-free during the summer. The heat content added during the summer months is not enough to offset the large heat loss of the winter months, and ice will form since the other possible heat supply, Atlantic Ocean water, is located too far away. The great change in surface properties between an ice and a non-ice covered water body makes weather predictions extremely difficult for the more populated areas located south of the bay.

The ice formation and ice breakup patterns are related to weather and water properties and vary from year to year as well as from one locality to another. Even under uniform weather conditions, variability from place to place in ice formation and ice breakup exists due to the variability in the water properties, such as salinity content, water depth, tidal mixing, and surface currents. Open-water conditions occur in regions of persistent high-current conditions, such as south of Akimiski Island in James Bay and at the entrance to Richmond Gulf on the Ungava Peninsula. Heavy ice conditions exist in shallow, low-current areas where ice freezes early and can build up over a longer time span. One of the effects of salinity is the lowering of the freezing point of sea water. However, its major effect on ice formation is caused by its strong effect on the density, which determines the vertical stability and horizontal pressure gradients of the underlying water. The salinity distribution and parameters controlling its changes need to be known before any study on Hudson Bay's long-period currents, ice formation, and ice breakup can be completed.

The present study examines the freshwater budget, one of the parameters controlling the horizontal and vertical salinity distributions. The mean monthly freshwater input by the rivers and by precipitation minus evaporation for the entire Hudson/James Bay area is calculated. Special attention is given to the James Bay rivers, since planned hydroelectric developments will cause major changes in their seasonal runoff rates and since the James Bay rivers account for 45% of the total yearly freshwater runoff of the combined Hudson/James Bay region. A preliminary study on the characteristics of river systems in Canada entitled "Characteristics of River Discharge and Runoff in Canada", by D.K. MacKay (1966), included some of the rivers draining into the Hudson/James Bay region. This work was expanded and became part of "The National Atlas of Canada" (1973) in which maps appeared on the "Drainage Basins", "Seasonal Runoff" (month at which maximum runoff occurs), "Average Annual Runoff" (yearly average runoff in inches per year), "Monthly Distribution of Runoff" (for only seven rivers draining into the Hudson/James Bay region), and "River Discharge" (a visual plot of the yearly-averaged discharge). Although these maps are very instructive, they can only be used as a guide for a quantitative treatment of the Hudson Bay freshwater budget.

CHAPTER 2 - RUNOFF

2.0 DRAINAGE AREAS

Rivers draining into Hudson Bay and James Bay derive their water from a variety of watersheds. They range from dense, boreal forest in the south and east, to grasslands of the Prairies in the west, and to shrubless tundra in the north. The bay itself modifies the vegetation of its watersheds by lowering the air temperature in spring and summer and by allowing higher wind speeds to occur than would be found over continuous land.

The treeline on the west side of the bay breaks away from the coast very abruptly near the 59th parallel, just north of Churchill, and moves northwest to Great Slave Lake. North of the treeline, the granite of the Canadian Shield becomes more exposed with some low shrubs here and there, but these are smaller and too scattered to form a shrub tundra such as that found in the Yukon. Most of the drainage areas of the Northwest Territories consist of shrubless tundra with the headwaters of only the large rivers (Thelon, Dubawnt, and Kazan) located south of the treeline. Runoff of these three rivers enters Hudson Bay via Chesterfield Inlet and constitutes the only major freshwater contributor above the 60th parallel.

The treeline on the east side of the bay leaves the coast just north of Richmond Gulf and moves towards Ungava Bay in a northeasterly direction. The rivers above the treeline on Ungava Peninsula contribute only 3% to the yearly Hudson Bay runoff. The shrub tundra is better developed here than on the eastern side of the bay but is still on a much-reduced scale compared to that of the Yukon or Alaska. The treeline thus dips southward as Hudson Bay is approached from either east or west and is a reflection of the influence the bay has on the weather of central Canada. The extra precipitation it provides and its warming effect in the late fall does not override the effect that the harsh temperatures and strong winds have on the adjacent land flora. The coastal areas are Arctic in nature, with trees starting to appear on the shore only when James Bay is entered.

The distribution of the drainage area for Hudson Bay (shown in Figure 1) covers a total area of 3.1×10^6 square kilometres and borders

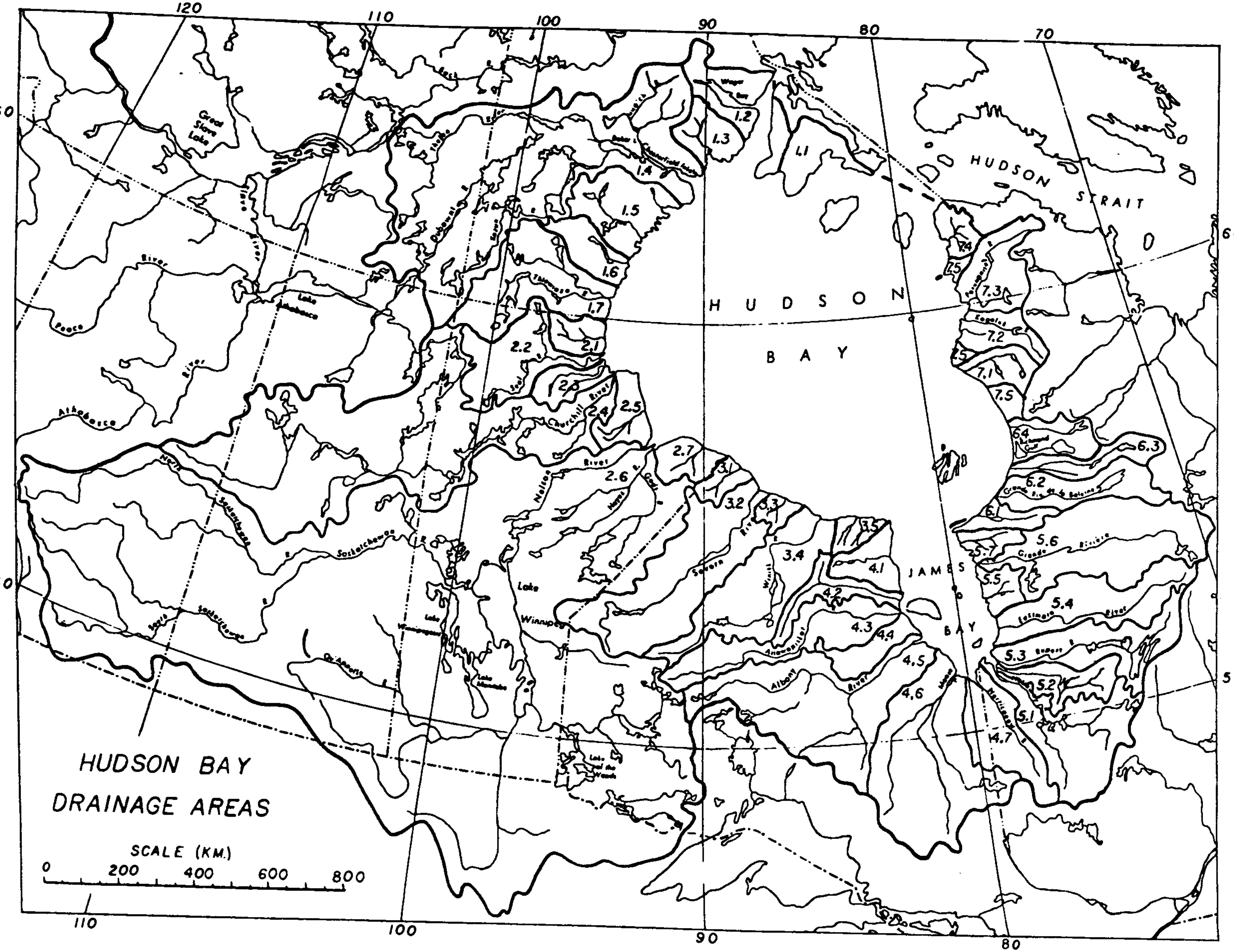

Figure 1: Hudson and James Bays' Drainage Areas

the St. Lawrence River system in the south and east, the Mississippi River system in the southwest, and the Mackenzie River system in the northwest. Due to the high relief terrain, the rivers on the east side of the bay do not extend as far inland as the rivers on the west side. The Nelson River system, for instance, starts as far west as the foothills of the Rocky Mountains and, along with the other Alberta rivers, accounts for 51% of the total Hudson Bay drainage area. However, the large evaporation rate in the Prairies reduces their contribution to the yearly-averaged fresh-water runoff to 25%. Per unit area, the rivers on the east coast provide a larger runoff than their counterparts on the same latitude of the west coast. This is caused by the predominantly eastward-moving weather systems which provide a larger yearly precipitation on the eastern shores than on the western shores. The air moving over the bay receives a large portion of its moisture content from the bay itself.

Tables A-1 to A-3 of Appendix A list the numbers of all the separate drainage areas shown in Figure 1 which combine to form the total drainage area of the Hudson/James Bay system. Each area is split into a section where daily discharge rates are available from Water Survey of Canada and a section where monthly discharge rates are estimated from known values of neighbouring areas of similar topographic features. Measured discharge rates become more scarce the further north a specific area is located. On the west coast, the Quoich River drainage area north of Baker Lake is used to estimate the neighbouring unmonitored areas located above the treeline, while on the east coast the Arnaud River is similarly used. Even the monitored rivers in the south are usually comprised of areas in the lower part of their system for which discharge rates have to be estimated. The combined area for which discharge rates were estimated came to .65 x 10^6 km^2 which amounted to 21% of the total Hudson Bay drainage area.

2.1 YEARLY-AVERAGED RUNOFF AREAS

Tables A-1 to A-3 also list the percentage of area and the percentag of yearly discharge that each separate area contributes to their respective totals of the Hudson Bay region. Starting in the north and proceeding around the bay counterclockwise, the drainage area was divided into seven sections. Section 1 (areas 1.1 to 1.7) is situated in the Northwest Territories and drains land located mainly above the treeline. The major outflow of this section is from Chesterfield Inlet which accounts for 6.6% of Hudson Bay's total yearly runoff. Section 2 (areas 2.1 to 2.7) is situated below the treeline and drains the large Prairie area. The Nelson River accounts for 16% of the yearly runoff but, as seen later, becomes an even larger contributor in the winter months as various dams regulate the runoff in the system. The rivers of northern Ontario, flowing north directly into Hudson Bay, are grouped together in Section 3 (areas 3.1 to 3.5). These rivers, mainly the Winisk and the Severn, contribute 7.8% of the yearly runoff of the region. Thus, the first three sections cover the drainage areas of the north, west, and most of the south and account for 72.8% of the total area but only 45.3% of the yearly runoff of the Hudson/James Bay area.

Rivers entering James Bay are divided into Section 4 on the west side and Section 5 on the east side. Their combined contribution accounts for only 22% of the drainage area but 44.6% of the yearly-averaged runoff. The high runoff per unit area is due to the large precipitation that occurs when warm and humid air is cooled by the cold surface waters of James Bay. All of the major rivers, with the exception of the La Grande River, are situated in the southern half of James Bay below Akimiski Island. Their high runoff per unit area and proximity to the industrial part of Canada make them extremely attractive for hydroelectric development. Most of the rivers with suitable topographic reliefs have been or are being developed, while still others are being seriously considered. The remaining Quebec rivers draining into Hudson Bay directly are grouped in Section 6 (areas 6.1 to 6.4) when located below the treeline and Section 7 (areas 7.1 to 7.5) for those above the treeline. Their combined contribution accounts for 5.2% of the drainage area and for 10.1% of the bay's total runoff. The high discharge rates per unit area and the rugged topographic terrain with steep reliefs make even the rivers of Section 6 profitable for hydroelectric development, even though they are so much farther removed from the industrial areas of Canada than those of James Bay.

The 3.1×10^6 km^2 of drainage area of the Hudson/James Bay basin is the largest in Canada, as it compares to 1.0×10^6 km^2 for both the

Mackenzie River and the St. Lawrence River/Great Lakes systems. The average annual rate of discharge of 12.6 x 10^3 cubic metres per second is also larger than either the 10.8 x 10^3 or 10.1 x 10^3 cubic metres per second of the Mackenzie or St. Lawrence rivers, respectively. James Bay alone, with a drainage area of only .68 x 10^6 km^2, has a similar annual average discharge rate of 10.1 x 10^3 cubic metres per second. In comparison, the largest river in the world, the Amazon River, has an annual average runoff rate of 212.0 x 10^3 cubic metres per second, seven times that of Hudson Bay. Hudson Bay thus receives a large portion of Canada's freshwater runoff, and its effect on ice formation and breakup will be modified by the various hydroelectric developments which are changing not only the timing of the runoff cycle but also the locations of the outflow.

2.2 MONTHLY DISCHARGE RATES PER UNIT AREA

The discharge rates mentioned to this point have all been yearly-averaged values. The rates, however, change drastically during the year and depend upon the latitude of the area and its proximity to the bay, as well as the side of the bay on which it is located. Appendix B contains tables of the monthly rates of all areas shown in Figure 1. Rather than list them all here, only rates per unit area of some of the major areas are listed (see Tables 1 and 2) in order to show some of the significant differences between the areas around Hudson Bay and James Bay. The rivers listed from left to right on Table 1 are situated counterclockwise around Hudson Bay, starting in the Northwest Territories with the Quoich River and finishing in northern Quebec with the Arnaud River. When the Nelson River is ignored, the mean runoff rate per unit area increases by going south from the Quoich River, reaches a maximum value in the southeastern corner of the bay, and decreases again somewhat in going north from there. This pattern reflects the increase of precipitation found in the southeastern and eastern areas around the bay and is due to general easterly- to southeasterly-moving weather systems. The Arnaud River, situated above the treeline on the east side, produces three times as much runoff per unit area as the Quoich River on the west side of the bay and does not go through such extreme low runoff rates during the winter months. The Kazan River, which lies further inland and south of the Quoich River, has a yearly mean value similar to rivers

MONTHLY DISCHARGE RATES PER AREA ($m^3 sec^{-1}/10^3 km^2$) INTO HUDSON BAY

Month	Quoich River	Kazan River	Seal River	Nelson River	Gods River	Winisk River	Great Whale River	Arnaud River
January	.2	2.7	3.3	1.9	3.2	4.4	7.6	3.2
February	.1	2.2	2.6	1.8	3.1	3.1	5.3	2.3
March	.2	1.9	2.1	1.9	3.0	2.4	4.1	1.9
April	.2	1.8	2.0	1.9	3.6	2.3	5.2	1.7
May	1.5	3.4	8.4	2.7	11.1	15.3	21.5	2.8
June	17.6	16.9	16.8	3.1	10.8	21.7	31.3	35.9
July	12.2	18.9	12.4	3.2	8.8	17.0	24.8	35.9
August	6.3	13.7	11.1	3.0	7.4	14.3	19.5	23.3
September	9.7	10.7	10.4	2.9	7.6	12.6	19.6	20.8
October	4.1	8.2	8.6	2.8	9.5	15.7	21.0	15.7
November	1.5	5.8	6.2	2.4	7.4	12.1	17.1	8.7
December	.4	3.9	4.6	2.1	5.1	6.8	11.9	5.2
Mean	4.5	7.5	7.4	2.5	6.7	10.6	15.7	13.1
Area ($10^3 km^2$)	28.8	58.8	48.2	1010.0	65.5	50.0	42.2	26.9

Table 1: Monthly Discharge Rates per unit area for rivers draining into Hudson Bay.

in Manitoba and northern Ontario where boreal forests are present. The river drains northward before turning east toward the bay and obtains a lot of precipitation from the eastern slopes of the mountains which face the oncoming weather systems.

All of the rivers experience a runoff peak in spring or early summer with those in the southern region having a secondary peak during the rainy season in late fall. The spring runoff peak occurs in the middle of May in southern areas, while in the Kazan and Quoich River areas it occurs as late as the middle of June since the further north the area is situated the later the spring runoff peak will occur. The large drainage area of the Nelson River and the hydroelectric dams along its river system smooth out the yearly discharge rate cycle. The difference in winter minimum and spring maximum discharge rates, which amounts to a factor of four for the southern rivers and to a factor of twenty for the northern rivers, has been reduced to one and a half for the Nelson River. Any hydroelectric development using a river's runoff to its maximum efficiency will have a similar effect on the river's runoff cycle.

All watersheds of James Bay consist of boreal forest with trees often appearing right up to the shore in the southern half of the bay. The relatively milder climate, plus the larger precipitation rates, cause it to have larger runoff rates per unit area than the eastern and southern areas of Hudson Bay. The discharge rates per unit area for major rivers of James Bay are listed from left to right in Table 2 in a counter-clockwise direction around the bay. The amplitudes of the mean discharge rates expressed in $m^3 sec^{-1}/10^3 km^2$ are 12.0 and 20.0, for the east and west sides of James Bay respectively, as compared to 7.0 and 14.5 for the east and west sides of Hudson Bay. On the average, the discharge rates per unit area are 50% larger for James Bay than for Hudson Bay. Due to their proximity to the industrial areas of southern Ontario, the river systems of southern James Bay (Moose and Rupert) have been partly developed for hydroelectric power use. The low relief of the western shore does not lend itself to hydroelectric development, but use has been made of the large drainage systems, such as that of the Albany River, by diverting some of their headwaters. These include the diversion of 12,300 km^2 of Lake St. Joseph drainage area to the Nelson River

MONTHLY DISCHARGE RATES PER AREA ($m^3sec^{-1}/10^3km^2$) INTO JAMES BAY

Month	Attawapiskat River	Albany River	Moose River	Harricana River	Nottaway River	Rupert River	Eastmain River	La Grande River
January	4.0	2.5	4.1	4.3	8.2	15.8	8.5	8.3
February	2.9	2.0	3.8	2.9	6.0	12.6	6.1	6.0
March	2.2	1.8	4.0	2.5	5.0	10.4	4.7	4.8
April	2.4	4.9	15.9	8.1	7.4	11.1	6.5	4.9
May	25.7	29.0	48.9	44.5	35.1	25.2	38.2	22.9
June	24.5	17.5	20.3	17.0	40.7	29.8	44.1	37.4
July	18.0	11.7	11.1	15.7	26.7	26.8	25.7	27.4
August	15.6	9.8	7.6	13.0	19.2	25.7	27.2	20.9
September	14.0	7.8	9.4	15.6	18.4	26.0	27.1	23.4
October	18.0	10.2	13.4	11.7	22.5	27.8	32.1	27.3
November	12.5	7.3	9.6	10.2	20.2	25.6	22.1	21.0
December	6.4	3.1	6.0	7.1	13.7	20.6	13.8	13.3
Mean	12.2	9.0	12.8	12.7	18.6	21.4	21.3	18.1
Area (10^3km^2)	36.0	117.6	61.1	10.0	57.5	40.9	44.3	97.4

Table 2: Monthly discharge Rates per unit area for rivers draining into James Bay.

system, the diversion of 15,000 km^2 of Lake Ogoki drainage area to Lake Superior via Lake Nipigon, and the diversion of 4,170 km^2 of Long Lake drainage area to Lake Superior.

2.3 MONTHLY RUNOFF RATES

The individual discharge rates of each of the James Bay rivers (listed in tables of Appendix B), as well as their combined rate, follow a similar yearly pattern as shown in Figure 2. A low discharge rate during the winter months of January to early May is followed by an abrupt high discharge maximum during the spring period of mid May to early June. A constant summer discharge rate during July, August, and September is followed by a secondary discharge peak in October and a gentle decrease to the winter minimum values during November and December. The spring discharge peaks occur during the middle of May in the Moose and Harricana River systems, a week later in the Albany and Nottaway Rivers, during the first week of June in the Attawapiskat River on the west and the Rupert and Eastmain Rivers on the east, and finally during the start of the second week of June in the La Grande River. Ice breakup of James Bay is strongly dependent upon the large quantity of relatively warm, fresh water of the spring discharge peaks. It produces a stable, less dense surface layer underneath the ice which can both supply some heat to the ice for melting and insulate it from the underlying cold salt water.

The monthly discharge rates into Hudson Bay are listed in Table 3 and are shown in Figure 3 with Sections 4 and 5 combined to form the northern Quebec contribution. The yearly-averaged values reveal the large contribution the James Bay rivers (45%) and the Manitoba rivers (25%) make to the total region's freshwater runoff. The remaining three areas, northwest, south, and east sides of the bay, each contribute only 10% of the total runoff. The spring runoff peak is so much earlier in James Bay (May) than everywhere else that, while all the other areas still are experiencing their low winter discharge rates, James Bay's contribution reaches 62%. On the other hand, the winter contribution from the Manitoba rivers (Nelson and Churchill) increases from an average of 22% in the spring and summer to 40% in the winter. Their contribution is the same as that of the James Bay region during the winter period from the start of January to the end of April. The Manitoba River system discharge rate only doubles

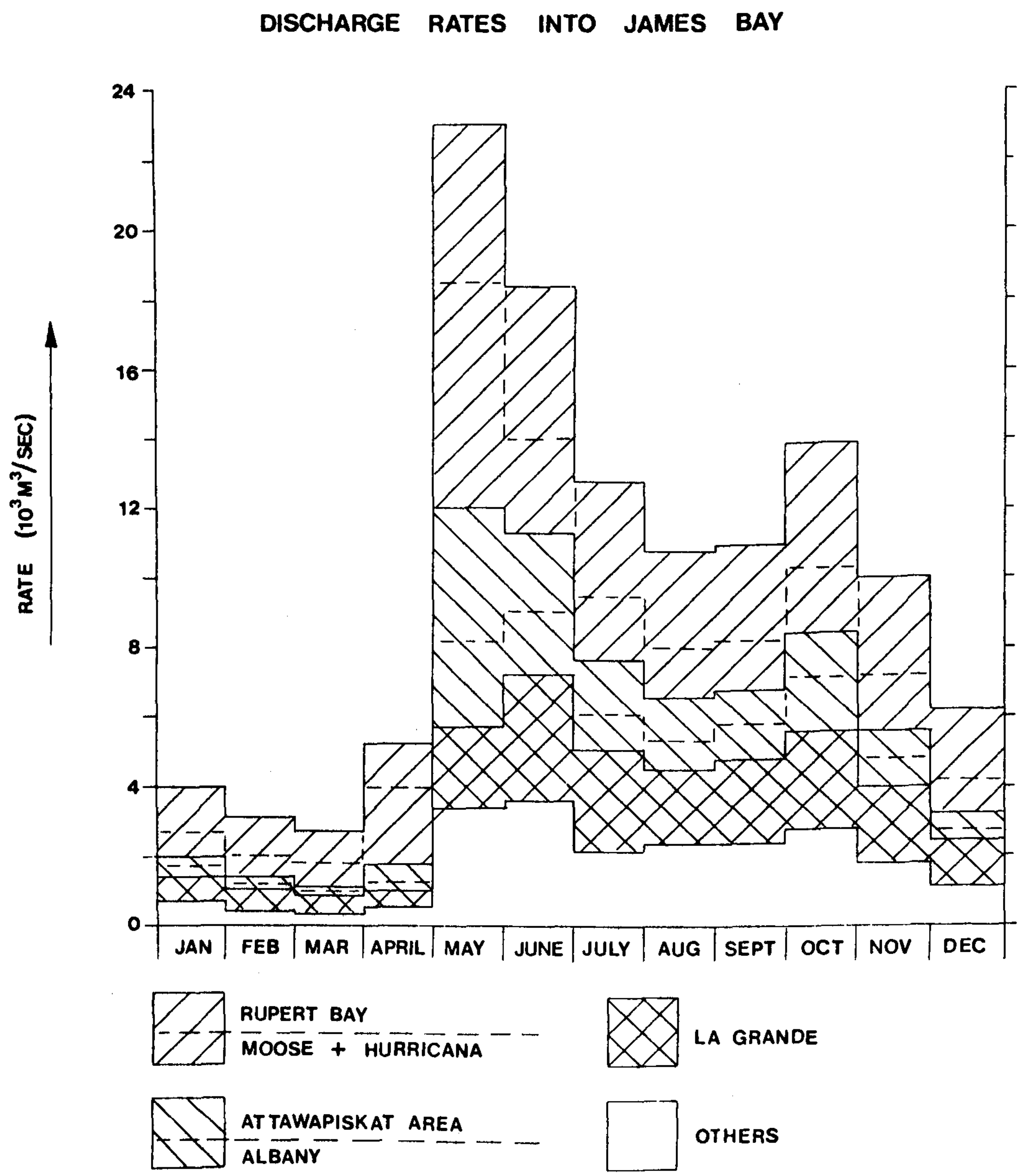

Figure 2: Monthly Freshwater Contributions of the major James Bay River systems.

MONTHLY DISCHARGE RATES ($10^3 m^3/sec$) INTO HUDSON BAY

Month	N.W. Territories		Manitoba		Ontario		James Bay		Quebec		Total
	Rate	%	Rate	%	Rate	%	Rate	%	Rate	%	Rate
January	0.846	8.2	3.923	37.7	0.677	6.5	4.006	38.5	0.945	9.1	10.397
February	0.703	8.1	3.667	42.4	0.519	6.0	3.090	35.7	0.670	7.8	8.649
March	0.618	7.9	3.560	45.6	0.429	5.5	2.664	34.2	0.532	6.8	7.803
April	0.648	6.2	3.737	35.6	0.467	4.4	5.092	48.6	0.544	5.2	10.488
May	1.487	4.0	7.313	19.7	3.490	9.4	23.089	62.1	1.786	4.8	37.165
June	8.052	18.3	8.697	19.7	3.605	8.2	18.444	41.8	5.274	12.0	44.072
July	6.259	18.6	7.726	22.9	2.569	7.6	12.855	38.1	4.327	12.8	33.736
August	4.239	15.4	7.026	25.6	2.181	7.9	10.828	39.4	3.208	11.7	27.482
September	4.270	15.8	6.810	25.1	2.013	7.4	10.934	40.3	3.083	11.4	27.110
October	2.891	10.2	6.354	22.5	2.493	8.8	13.449	47.6	3.088	10.9	28.275
November	1.874	8.8	5.239	24.5	1.794	8.4	10.069	47.2	2.362	11.1	21.338
December	1.214	8.6	4.204	29.6	1.063	7.5	6.191	43.6	1.525	10.7	14.197
Mean	2.758	12.2	5.688	25.2	1.775	7.9	10.059	44.6	2.279	10.1	22.559

Table 3: Monthly Discharge Rates for regions around Hudson Bay.

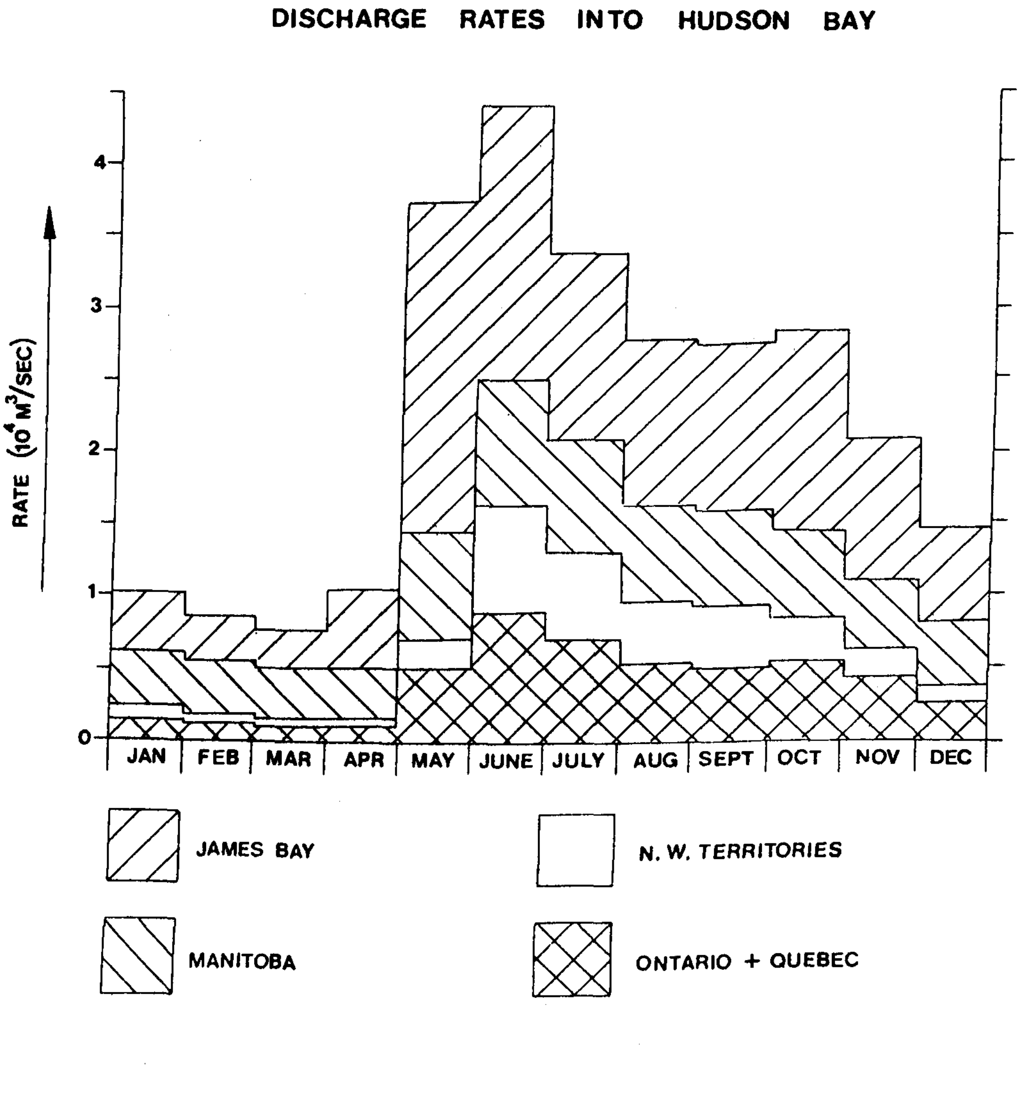

Figure 3: Monthly Freshwater Contributions of the major Hudson Bay River systems.

between the winter low value to the summer value and is a reflection of the moderating effect the hydroelectric dams have on the yearly discharge cycle. All other areas of Hudson Bay experience a tenfold increase between their winter and summer discharge rates. The hydroelectric development of the La Grande River will double the James Bay winter outflow and decrease its summer output slightly.

CHAPTER 3 - PRECIPITATION, EVAPORATION, AND ADVECTION

3.0 AREA REPRESENTATION

The Hudson/James Bay surface area was divided into six areas (see Figure 4) for which monthly-averaged precipitation and evaporation rates were calculated. For all of the six areas, the data in inches per month was later converted to cubic metres per second comparable to the river discharge units. James Bay was further divided into six sub-areas, so that the freshwater drift through each cross-sectional area could be calculated from the addition of fresh water to each successive area down the bay. This information is needed in an analytic estuarine model which predicts the current and salinity changes that occur if the discharge cycle is changed.

3.1 EVAPORATION

Evaporation per unit area in energy per day was calculated similarly to Danielson's work, "Surface Heat Budget of Hudson Bay". Calculations were carried out for the six separate sections although the units were changed from energy per day to cubic metres per second. The equation used was:

$$E(m^3 sec^{-1}) = .07676\ A\ [(e_s - e_a)(1 + .07V)V] \times 10^3$$

where E is the evaporation in $m^3 sec^{-1}$, A is the area of the section in units of $10^5 km^2$, V is the monthly-averaged wind speed in m sec^{-1}, and e_a and e_s are the mean vapour pressure and saturated vapour pressure at mean dew point measured in millibars. Vapour pressure values were obtained from the "Atlas of Climatic Maps" published in 1969, while wind speeds were obtained from the "Climatic Normals, Vol. 5, Wind" published in 1968. The monthly wind speeds of the following six weather stations were used for the six areas of the total region: 1) Churchill; 2) Baker Lake; 3) Coral Harbour; 4) Port Harrison; 5) Great Whale; and 6) Moosonee. Although the terrain around Hudson Bay is very flat, the observed wind speeds from land-based stations underestimated the speeds by 25% as observed by ships on Hudson Bay (Danielson, 1969). The wind speeds for ice-free areas were thus increased by 25% relative to the land-based values. In comparison, a 60% increase is used for the Great Lakes area where a better wind protection is

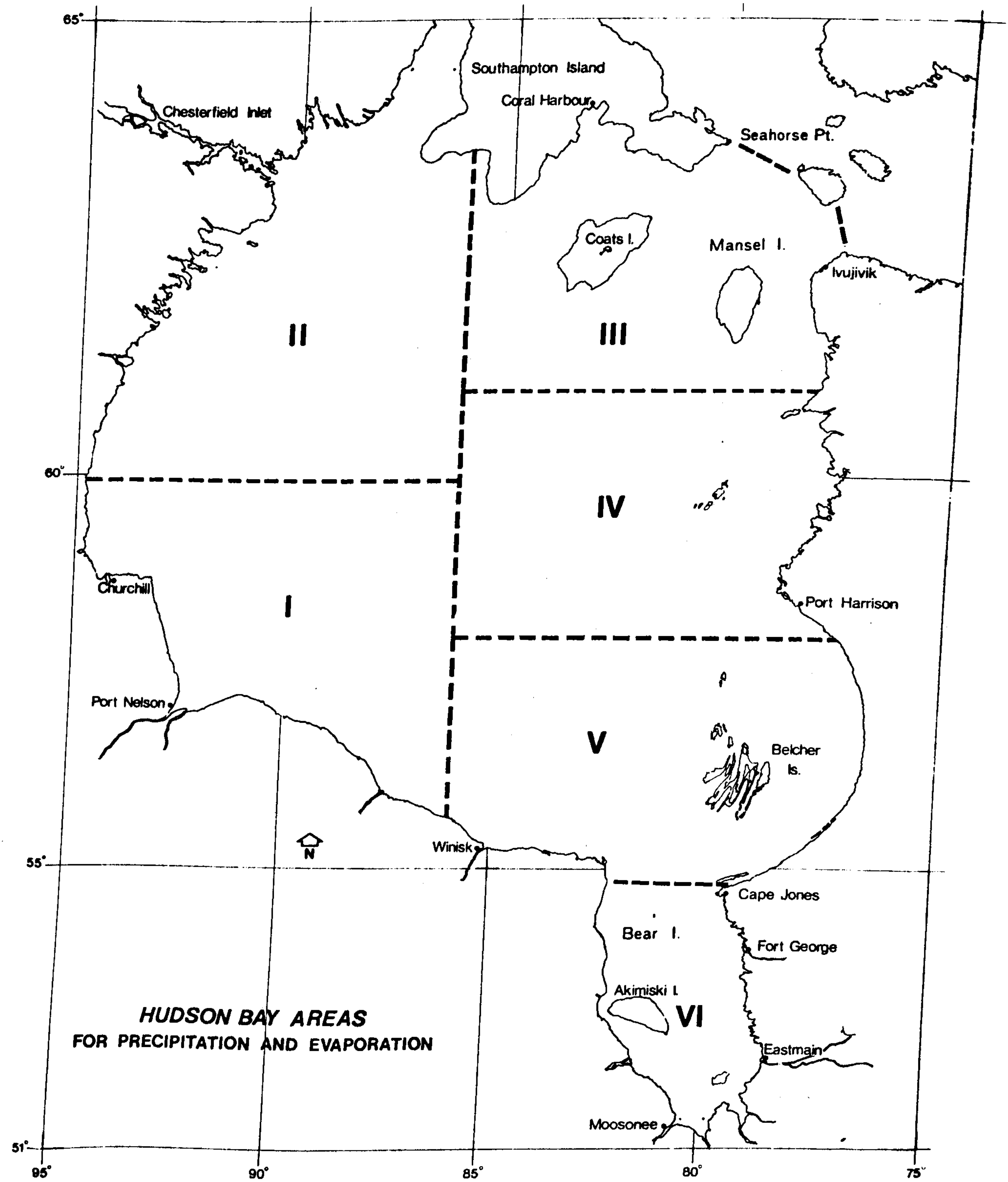

Figure 4: Area of the Hudson/James Bay Region used for Calculation of Evaporation and Precipitation Rates

provided by vegetation (Richards and Philips, 1970). The AIDJEX Data (Albright, 1977) showed that the wind speed ratio of observed to geostrophic winds at ice stations were the same as those observed at the land stations around Hudson Bay (Danielson, 1969). The ice cover of the Bay thus acts as an extension to the adjoining land mass and the wind speeds of land-based stations can be used directly for the offshore areas.

The increase of the wind speeds for the offshore areas above those of the land-based station values are given as a wind factor in the tables of Appendices C and D. The factors range from 1.00 for a 100% ice cover in the winter months to 1.25 for the ice-free condition in the summer months. Appendix C consists of separate tables for each of the five Hudson Bay regions, whereas area six (James Bay) is treated separately in Appendix D. The tables list the average evaporation and precipitation rates as well as the mean wind speed and direction, wind factor, and vapour pressure difference for each month. The monthly mean wind varies at the most by 1 m sec^{-1} from its yearly mean; a minimum value is experienced in the summer (July) and a maximum in the fall (November). The yearly mean wind speed for the total Hudson Bay area is 6.1 m sec^{-1} and ranges from 6.8 m sec^{-1} in the Churchill section to 5.3 m sec^{-1} in the Great Whale section. Since the surface area differs for each of the six sections, it is difficult to visualize the differences across the bay in evaporation and precipitation when the monthly means are expressed in the same units as the river discharges (volume per unit time). Values of the evaporation and precipitation rates in Table 4 are thus presented in centimetres per month for all six areas.

Evaporation decreases across the bay from west to east, since the air picks up moisture and cools as it travels in the general easterly direction. Evaporation increases across the bay from north to south because the air temperature is relatively higher in the south, and thus its moisture content can be greater. For James Bay, the incoming air from the northwest and west is relatively warm and saturated due to its passage over northern Ontario land terrain. The air is so much warmer than the water that the air will be cooled and will thus decrease the evaporation rate by both the decrease in wind strength and the reduction in saturation vapour pressure. The monthly evaporation values for each area reveal two peaks, Monthly Evaporation and Precipitation Rates

Area / Month	Evaporation (cm/month)						Precipitation (cm/month)					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
Jan.	3.49	2.57	3.61	3.94	4.17	3.38	1.52	.76	1.02	1.52	2.27	3.59
Feb.	4.64	3.53	3.72	4.20	4.27	4.12	1.40	1.02	1.14	1.65	2.16	3.26
Mar.	3.89	2.28	1.88	3.44	3.26	3.91	1.78	1.27	1.27	1.78	2.16	2.89
Apr.	8.31	7.01	5.14	7.18	5.38	5.59	2.03	1.52	1.52	2.03	2.54	3.27
May	7.90	6.94	5.30	6.63	5.50	5.74	3.05	1.78	1.78	2.16	3.56	5.40
June	4.16	2.87	2.50	3.76	4.72	6.00	4.70	3.43	3.05	3.81	5.08	7.43
July	5.32	4.86	3.98	4.92	4.31	4.54	4.32	5.97	4.19	4.70	5.84	8.09
Aug.	2.36	1.88	2.56	2.54	4.08	4.71	5.33	4.32	4.32	4.70	6.10	6.80
Sep.	5.94	4.47	4.58	4.82	4.59	6.96	5.33	4.19	4.19	4.83	6.10	7.72
Oct.	8.60	8.41	7.83	5.61	5.98	5.55	3.94	3.18	3.43	4.32	5.72	7.24
Nov.	13.20	11.60	9.33	9.92	9.99	9.87	3.05	1.91	2.79	3.81	4.83	6.01
Dec.	5.73	5.11	5.05	5.85	6.16	6.21	2.03	1.52	1.52	2.03	3.30	4.87
Total	73.54	61.53	55.58	62.81	62.41	66.58	38.48	30.87	30.22	37.34	49.66	66.57

Table 4: Monthly Evaporation and Precipitation Rates for the six surface areas of Hudson/James Bay region.

one in the spring when the air temperature increases due to increased solar heating, and one in the fall when the air is heated by the water itself. In both cases, the difference in vapour pressure and saturated vapour pressure is increased, and, with an increased wind strength at these times as well, the evaporation rates increase above their yearly mean.

3.2 PRECIPITATION

Precipitation rates increase over the bay from north to south during any one season as well as from winter to summer at any one place. Warm air can carry more moisture so that, when it is cooled during the summer in the south by cold surface water of the bay, it can produce a greater amount of precipitation than the colder, dryer air over the northern areas, or over the same area in the winter. The right-hand side of Table 4 lists precipitation per unit area in centimetres of water per month. The areas are again listed from I to VI clockwise around the bay starting with the area outside Churchill and finishing in James Bay. James Bay has nearly double the precipitation of the rest of the Hudson Bay region and is the only section where precipitation offsets the loss of water by evaporation. On a yearly average, the other areas all lose water.

3.3 ADVECTION

The only other freshwater contributor for each area will be the difference of the in and out freshwater advective components. The freshwater advective components of the total water transport, related to a common base salinity, are mainly concentrated in the surface layer and can be in the form of moving ice floes. In order to calculate the advective freshwater contribution on a monthly time scale, the current and salinity distributions of the total Hudson/James Bay region need to be known for the same time scale. Only an average summer salinity distribution and a few summer current values, either from direct current meter records or inferred from surface salinity distributions, are available. Thus, the advective freshwater contribution cannot be dealt with directly and should only be considered as a result of the other contributors using continuity of volume.

During the freeze-up and break-up periods, the ice floes are relatively free to move around the bay under the influence of the wind stress and surface currents. They may advect a portion of the freshwater column in a different direction than the surface currents beneath the ice. When the bay is completely covered, an ice cover of one metre accounts for about one-eighth of the total freshwater portion of the region as found in the summer relative to a base salinity value of 33 $^{o}/oo$. The ice cover is fairly well fixed in place, and the surface currents with the remainder of the freshwater portion of the water column move beneath it. To understand the advection of fresh water on a monthly scale, additional monthly information is required on the ice thickness distribution and ice pack movement. The net advection of fresh water by currents and ice for each area of the Hudson/James Bay system, separately as well as for the total region, cannot be handled directly and should be considered as the result of the other freshwater contributors.

CHAPTER 4 - FRESHWATER BUDGETS

4.0 JAMES BAY

The surface area of James Bay is divided into six areas whose boundaries correspond to oceanographic station transects during the period 1972 to 1976 and are numbered consecutively from north to south (see Figure 5). The topographic details of the areas, such as the width, depth, and surface area, are listed in Table D-8 of Appendix D. The total James Bay area is approximately 150 kilometres wide and 400 kilometres long. It accounts for only 1/11th of the Hudson Bay surface area and for only 1/70th of its volume; but it contributes nearly half of the yearly freshwater runoff of the combined region. The shallow average depth of 28 metres, as well as the concentration of the rivers in the southern part of the bay, makes all its yearly properties very dependent on the runoff cycle.

The evaporation rates were calculated similarly to those of the Hudson Bay area. However, only two weather stations are located close enough to provide useful information. The Moosonee station is located at the southern end of James Bay, while the Great Whale station is just northeast of the entrance of the bay. Wind data of these two stations were used to calculate the monthly evaporation rates of the most northerly and southerly areas of James Bay. Evaporation rates of the remaining areas were obtained by linear interpolation of the values of the top and bottom areas, using the spacing distance between each area. Evaporation in the northerly area of James Bay is 77.2 centimetres of water per year, while it reduces to 58.2 centimetres in the southern area. This decrease is due to the decrease in wind strength going south into the bay, as the difference between the vapour pressure and saturation vapour pressure actually increases going south, slightly increasing the evaporation. Appendix D contains tables for evaporation rates of the northerly and southerly areas as well as the interpolated rates for the areas in between.

Precipitation over James Bay increases from north to south since the southern warmer air masses can carry more moisture and thus, when cooled by the cold surface water of the bay, produce more

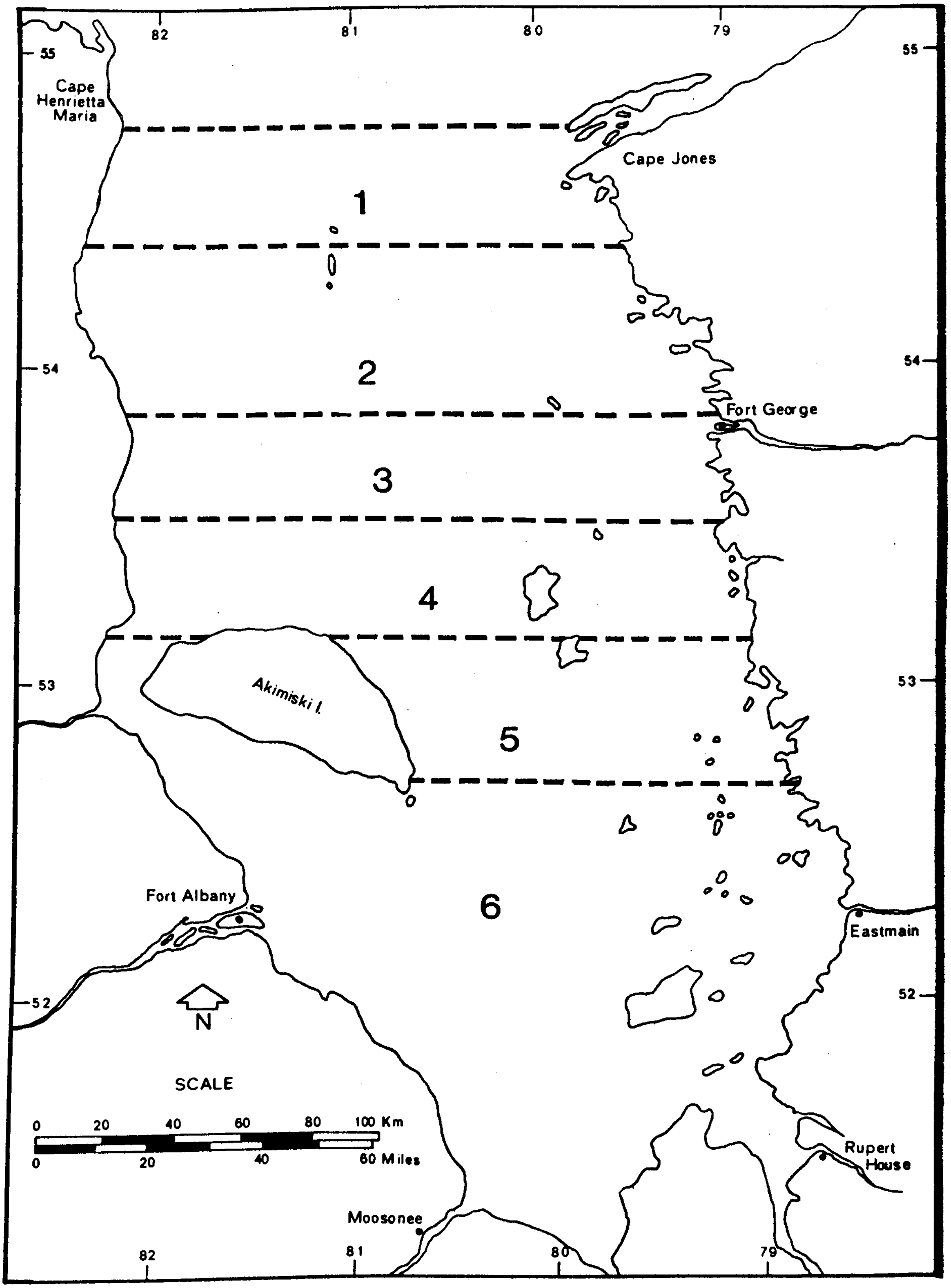

Figure 5: James Bay Area Used for Calculation of Evaporation and Precipitation Rates

precipitation. The yearly precipitation cycle has a maximum value in the summer months, whereas the evaporation cycle has maxima in the spring and fall. The net freshwater gain through the surface of the bay is shown in Table 5 for all six areas of James Bay in units of volume per unit time. Positive values represent net gains for each area and are found in the summer months when large rainfall offsets the loss of water by evaporation. Negative values occur during spring and fall evaporation peaks as well as during the winter months when the colder air is actually heated by the ice cover. On a yearly basis, James Bay gains as much water in the form of precipitation from the overlying air in the summer as it loses water by evaporation in the fall and spring.

As shown in Chapter 2, James Bay receives a large amount of runoff from its surrounding shores. The major rivers, however, are not evenly distributed around the bay and, with the exception of the La Grande River, all enter the bay in the most southerly area where the greatest precipitation rates per unit area are found. The rivers all have a major runoff peak during the latter part of May or early June, with a secondary peak during the month of October. Appendix D contains Tables D-6 and D-7, which list the monthly discharge rates for the James Bay river systems and the runoff rates for each of the six James Bay areas. The southernmost area receives about 80% of all James Bay runoff, with the La Grande River area receiving most of the remaining runoff. The total monthly freshwater input for each area is listed in Table 6 and represents the net gain by runoff and precipitation minus evaporation. Only during the winter does the evaporation cause a net monthly loss of water for areas without major river systems. Runoff peaks of the spring and fall combine with the precipitation peak of the summer to form a single, broad peak which abruptly increases to its maximum value at the end of May and decreases throughout the rest of the year to its minimum value in March; a smaller secondary fall peak is still present.

The hydroelectric development of the La Grande River will change the river's seasonal runoff rates to a constant runoff rate of 3.400×10^3 $m^3 sec^{-1}$. This constant value will be just below its present spring maximum

Precipitation - Evaporation

(10^3 m^3/sec)

Area / Month	1	2	3	4	5	6	Total
Jan.	-.040	-.050	-.012	+.004	+.014	+.128	+ .044
Feb.	-.066	-.089	-.040	-.029	-.018	+.006	- .236
Mar.	-.046	-.067	-.033	-.036	-.020	-.053	- .255
Apr.	-.097	-.151	-.098	-.076	-.048	-.149	- .619
May	-.048	-.057	-.026	-.014	+.001	+.059	- .085
June	+.005	+.039	+.031	+.043	+.039	+.215	+ .372
July	+.068	+.137	+.094	+.113	+.088	+.390	+ .890
Aug.	+.028	+.067	+.052	+.060	+.053	+.260	+ .520
Sept.	-.032	+.019	-.001	+.020	+.011	+.205	+ .195
Oct.	+.005	+.036	+.038	+.048	+.054	+.242	+ .423
Nov.	-.185	-.285	-.143	-.131	-.083	-.171	- .997
Dec.	-.104	-.138	-.064	-.049	-.014	+.035	- .334
						mean	- .007

Table 5: Monthly Freshwater Input from Precipitation minus Evaporation for each of the James Bay areas.

Freshwater Input to James Bay

(10^3 m^3/sec)

Month \ Area	1	2	3	4	5	6	Total
Jan.	.034	.796	.027	.038	.048	3.107	4.050
Feb.	-.016	.522	-.012	-.005	.006	2.359	2.854
Mar.	-.003	.427	-.012	-.017	.001	2.015	2.409
Apr.	-.053	.352	-.070	-.050	-.022	4.316	4.473
May	.257	2.497	.242	.139	.155	19.715	23.004
June	.370	3.963	.274	.219	.215	13.764	18.816
July	.336	2.994	.238	.213	.191	9.770	13.745
Aug.	.241	2.266	.200	.169	.162	8.310	11.348
Sept.	.206	2.483	.155	.128	.119	8.067	11.129
Oct.	.297	2.940	.233	.176	.182	10.044	13.872
Nov.	.023	1.915	-.020	-.043	.005	7.192	9.072
Dec.	.018	1.239	.004	.006	.041	4.549	5.857
						mean	10.052

Table 6: Total Monthly Freshwater Input for each of the James Bay areas.

runoff rate of 3.688 x 10^3 m^3sec^{-1}. The yearly mean will double from the present value of 1.788 x 10^3 to 3.400 x 10^3 m^3sec^{-1} with the additional water coming from the Eastmain River and the headwaters of the Koksoak River presently draining into Ungava Bay. The Eastmain River's runoff rate will drop to 20% of its present annual mean value of 1.19 x 10^3 to .237 x 10^3 m^3sec^{-1}; whereas the Koksoak River will lose .646 x 10^3 m^3sec^{-1} of its yearly mean runoff rate. More information on the La Grande River project can be found in publications by the Société de Développement de la Baie James (1974) and Environment Canada (1975).

James Bay's freshwater runoff will thus increase annually by 6.5% at the expense of Ungava Bay, but what is more important is the monthly temporal and spacial changes it will experience. The average La Grande River runoff values during the ice-covered season of January to April will increase by 470% above its present mean rate of .590 x 10^3 to the proposed rate of 3.400 x 10^3 m^3sec^{-1}. Its effect on the total James Bay freshwater budget (Table 6) will be to increase the average winter-month input of area 2 from the present rate of .520 x 10^3 to 3.3 x 10^3 and to decrease the input of area 6 from 2.950 x 10^3 to 2.750 x 10^3 m^3sec^{-1}. The total James Bay input will increase in the winter months from 3.450 x 10^3 to 6.060 x 10^3 m^3sec^{-1}, a gain of 75% and will become equal in strength to the Nelson River region. During the six summer months, the total freshwater input will not be affected as drastically since, although an average reduction of .542 x 10^3 m^3sec^{-1} will be experienced, it will only amount to a reduction of 4% relative to the total summer input rate. The La Grande River project will thus affect mainly the winter salinity distribution in James Bay downstream of the La Grande River estuary. The decrease of salinity in the surface layer, due to the 470% increase in runoff rate, might be observed as far as the Belcher Islands since, at the present winter runoff rate, the northward-flowing boundary current on the Quebec coast transports the river dilution effect as far as Cape Jones (G.S. Peck, 1977).

4.1 HUDSON AND JAMES BAY

The monthly-averaged freshwater input rates for the total Hudson/James Bay region are listed in Table 7 and are graphically shown in Figure 6. The table shows the differences in the freshwater budget of

Freshwater Input to James and Hudson Bays
($10^3 m^3/sec$)

Month	James Bay		Hudson Bay*		Total Fresh Water Input
	P - E	Run-off	P - E	Run-off	
Jan.	.04	4.01	- 5.84	6.39	4.60
Feb.	- .24	3.09	- 7.99	5.56	.42
Mar.	- .26	2.66	- 3.70	5.14	3.84
Apr.	- .60	5.09	-13.52	5.40	- 3.63
May	- .09	23.09	-11.05	14.08	26.03
June	.37	18.44	1.17	25.63	45.61
July	.89	12.86	1.06	20.88	35.69
Aug.	.52	10.83	6.41	16.65	34.41
Sep.	.20	10.93	.34	16.18	27.65
Oct.	.42	13.45	- 8.45	14.83	20.25
Nov.	-1.00	10.07	-21.84	11.27	- 1.50
Dec.	- .33	6.19	- 9.61	8.01	4.26
Mean	.01	10.06	- 6.09	12.50	16.47

* Excluding James Bay

Table 7: Monthly Freshwater Input for James Bay and Hudson Bay.

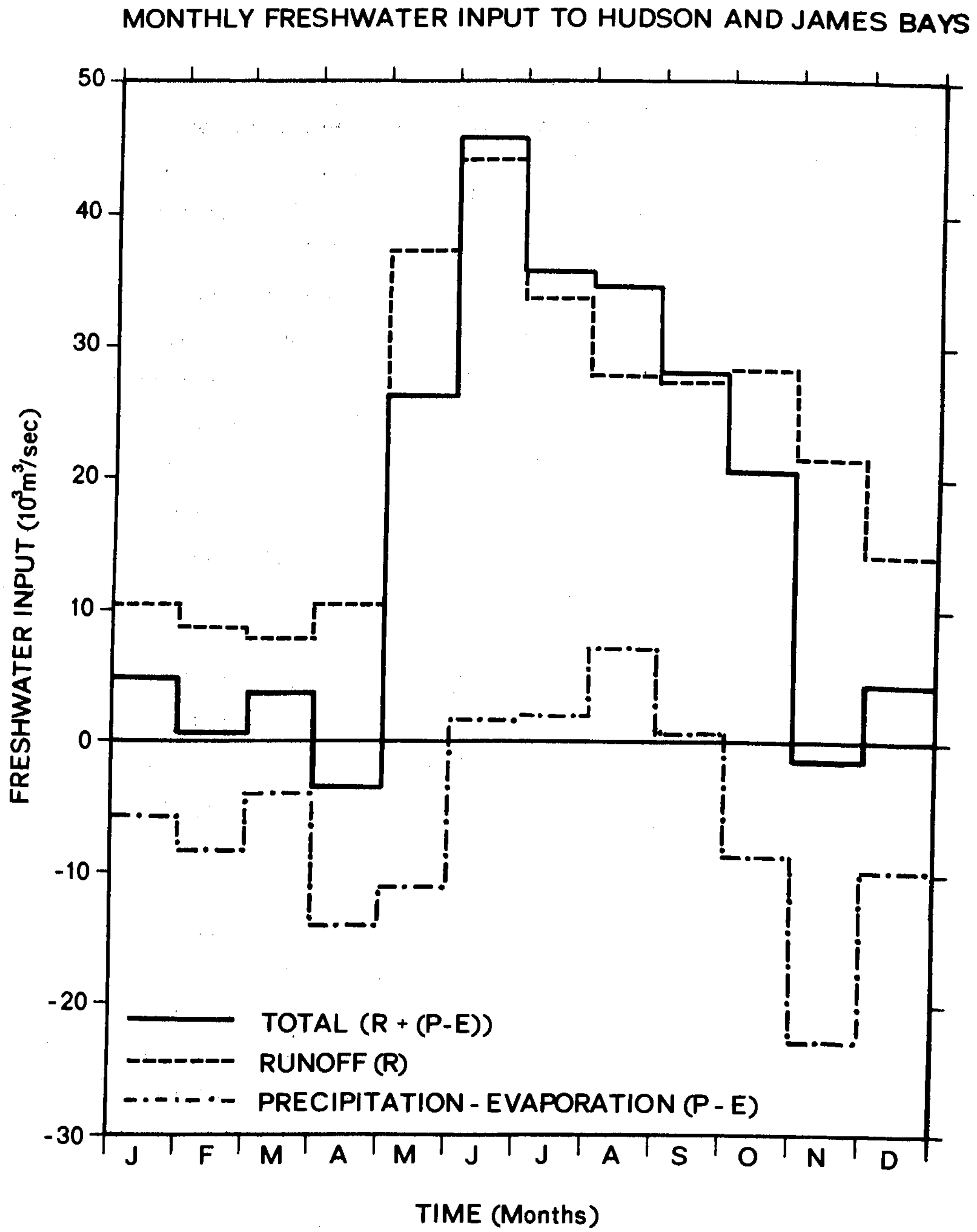

Figure 6: Monthly Contributions of the Freshwater Input for the Hudson/James Bay Region

James Bay and Hudson Bay caused by the smaller size in surface area and the more southerly location of James Bay. The precipitation minus evaporation rate will, on a yearly basis, average out so that James Bay gains no water through its air-sea surface interface. Hudson Bay, on the other hand, acts more like an oceanic region and loses water on a yearly basis to the overlying air mass. Both areas experienced large evaporation rates in the spring and fall and precipitation rates of smaller magnitude during the summer months.

When the monthly runoff rates are added to the precipitation minus evaporation rates, the yearly freshwater input cycle is divided into the winter season of November to April and the summer season of May to October. The large input of the summer months, as shown in Figure 6, represents an average monthly addition of a 10.0-centimetre layer of water over the total surface of Hudson and James Bays; while during the winter the monthly addition amounts to only a 1-centimetre layer of fresh water. Over a period of one year, the area thus receives a layer of 64 centimetres of fresh water, mostly during the summer months. This yearly addition of $5.23 \times 10^{11} m^3$ of water, which represents .53% of the total Hudson/James Bay volume, leaves the area as a surface outflow between Nottingham Island and Ungava Peninsula. Some return flow, mainly in the bottom layers where the salinity value is 33.3 $^o/oo$, is expected in order to conserve salt.

4.2 OBSERVED FRESHWATER VOLUME

During the summer of 1975, the Research and Development Division of Ocean & Aquatic Sciences, Central Region, took part in a multi-disciplinary survey of Hudson Bay. The objective of the program was to incorporate as many scientific disciplines as possible into an underway program conducted from CCGS "Narwhal" (B.M. Wright, 1975). The oceanographic part of the survey was to test and evaluate an underway towed-body collection system for baseline oceanographic data. Two reports by S. Baird (1975) describe the data collection system in detail, while the processed data was published in a data report (S.J. Prinsenberg, 1977). Although some problems with the underway system did arise, it collected a large quantity of oceanographic station data distributed very evenly over Hudson Bay. The data collected by the CTD probe (Guildline Model 8701) mounted inside the towed body (Fathom Oceanology) was calibrated against data collected by several standard bottle station casts using an onboard salinometer (Guildline 8400).

Figure 7 shows the salinity and temperature profile station locations used to calculate the freshwater content within Hudson Bay relative to a variable base salinity. Twelve stations were added to the 1975 observation stations to help the computer program in areas where no reliable 1975 data was available. These were obtained by extrapolation of the 1975 data, keeping in mind the general horizontal changes that occurred in previous cruises of the "Calanus" and "Theta". The 1958 and 1959 "Calanus" data was described in the manuscript: "Some physical oceanographic features of southeast Hudson Bay and James Bay" (E.H. Grainger, 1960); and the 1961 "Calanus" and "Theta" data in: "On the Oceanography of Hudson Bay, an atlas presentation of data obtained in 1961" (F.G. Barber and C.J. Glennie, 1964). Barber, in 1967, calculated the freshwater content of Hudson and James Bays using a base salinity of 33 $^{o}/oo$ and the 1961 and 1962 Hudson Bay data. However, for stations where the salinity was less than 33 $^{o}/oo$ at the deepest depth of observation, the remaining freshwater content below this depth was ignored since no depth extrapolation of the data was done. In the present study, the salinity and temperature profiles were extrapolated to the surface and bottom before the freshwater content of the complete depth profile was calculated.

The freshwater content in James Bay was calculated separately from profile data collected during the summers of 1973 and 1976 by the Ocean and Aquatic Sciences Branch of Environment Canada. Although this data is not yet available from the data base for computer usage, it was used to obtain the freshwater content of James Bay relative to a variable base salinity. The freshwater content of the Hudson/James Bay region and James Bay alone were divided by their respective yearly freshwater input so that a freshwater residence time for the areas could be plotted as a function of base salinity (Figure 8). The proper base salinity value for each area should represent the lowest salinity value of the water entering the area at its boundary and is found at depths just below the halocline.

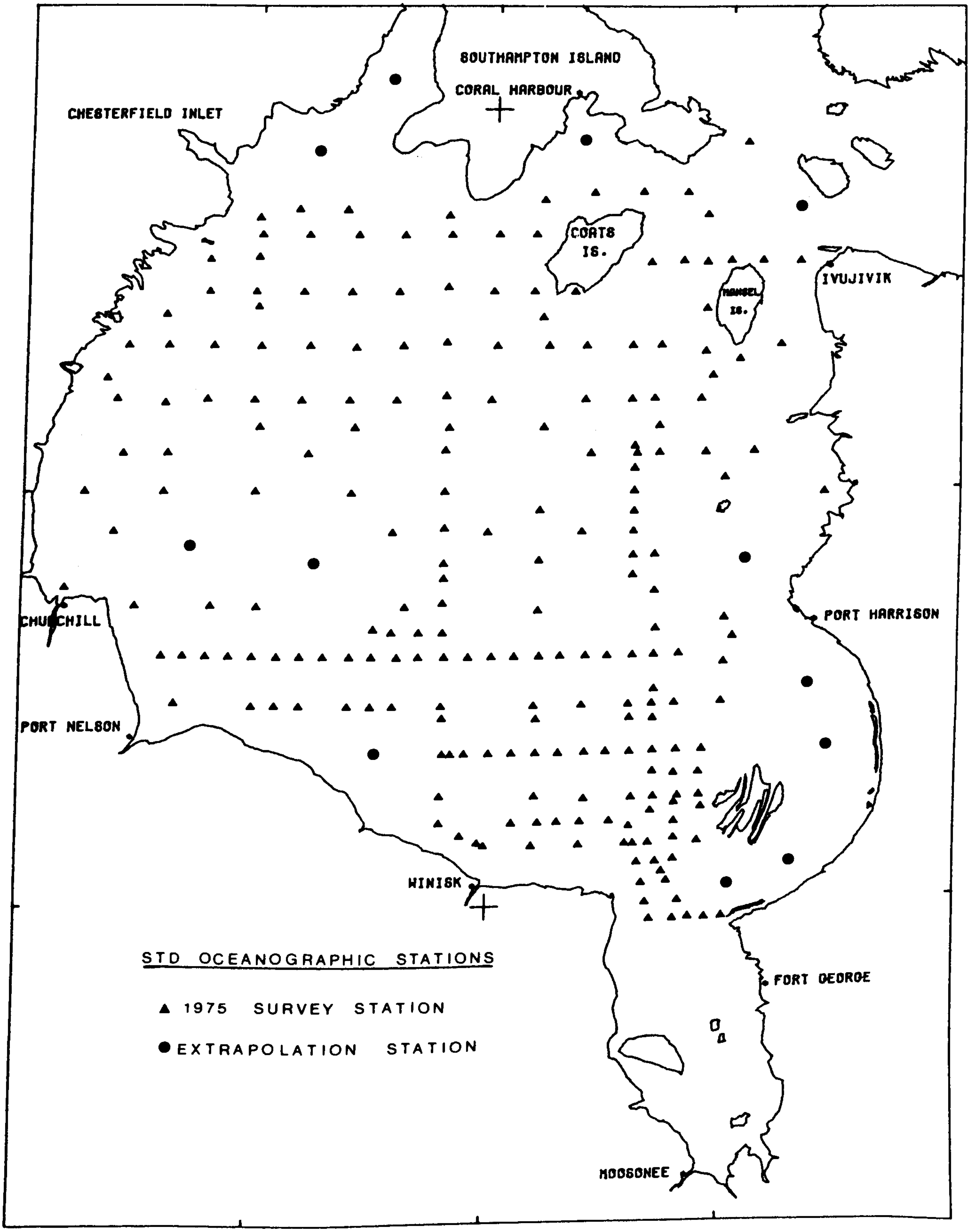

Figure 7: Locations of the Oceanographic Stations used for the Freshwater content calculations.

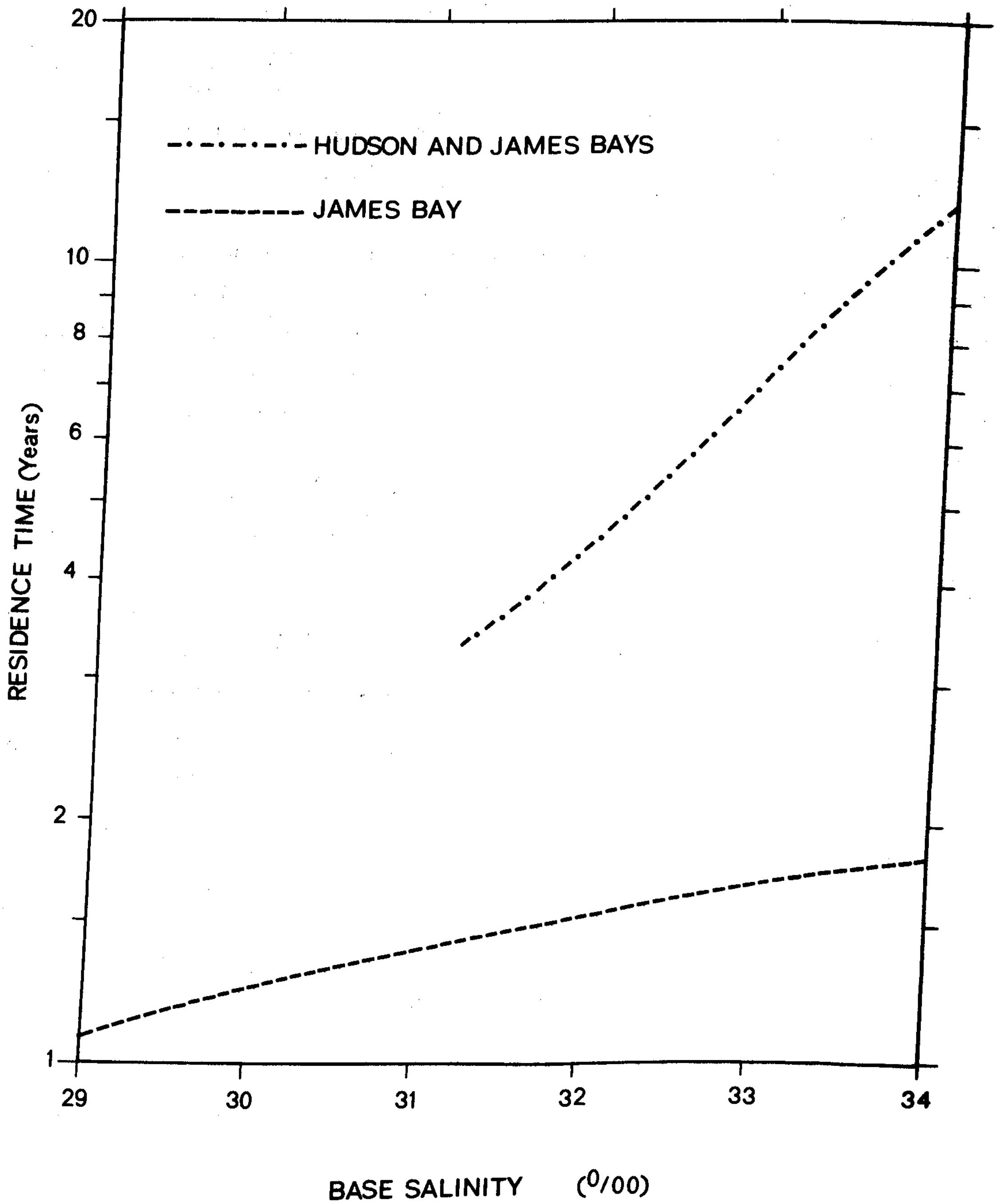

Figure 8: Freshwater Residence Time of James Bay and the Hudson/James Bay Region.

Figure 9 shows the observed salinity profiles found at the James Bay and Hudson Bay entrances. The salinity profiles of four stations located north of Mansel Island were averaged to obtain the Hudson Bay entrance profile #1, which represents the southerly portion of the entrance. Profile #2 was obtained from data of four stations located closer to Bell Peninsula and represents an average salinity profile in the northerly portion of the entrance. Both profiles were extrapolated below the deepest depths of observation (~100 metres). A base salinity value for the Hudson/James Bay region would thus be the average of the salinity values just below the haloclines of the two curves. This base salinity value is between 32.8 $^{o}/oo$ to 33 $^{o}/oo$ which gives a residence time between 6.4 and 7.3 years (Figure 8) and a freshwater layer thickness between 4.2 and 4.6 metres. F. G. Barber (1967), using a base salinity of 33 $^{o}/oo$ and the "Calanus" and "Theta" data, obtained a similar freshwater layer depth of 4.8 metres. The small difference in the freshwater layer depth between the 1961-62 and 1975 data is caused by the seasonal salinity distribution variation of the region.

The freshwater content of James Bay, using a base salinity between 30.5 $^{o}/oo$ and 31.5 $^{o}/oo$ (Figure 9), represents a residence time of 1.3 to 1.5 years and a freshwater layer depth between 5.7 and 6.5 metres. When James Bay is considered as part of the total Hudson/James Bay region and a base salinity of 33 $^{o}/oo$ is used, then the freshwater layer depth is 7.6 metres.

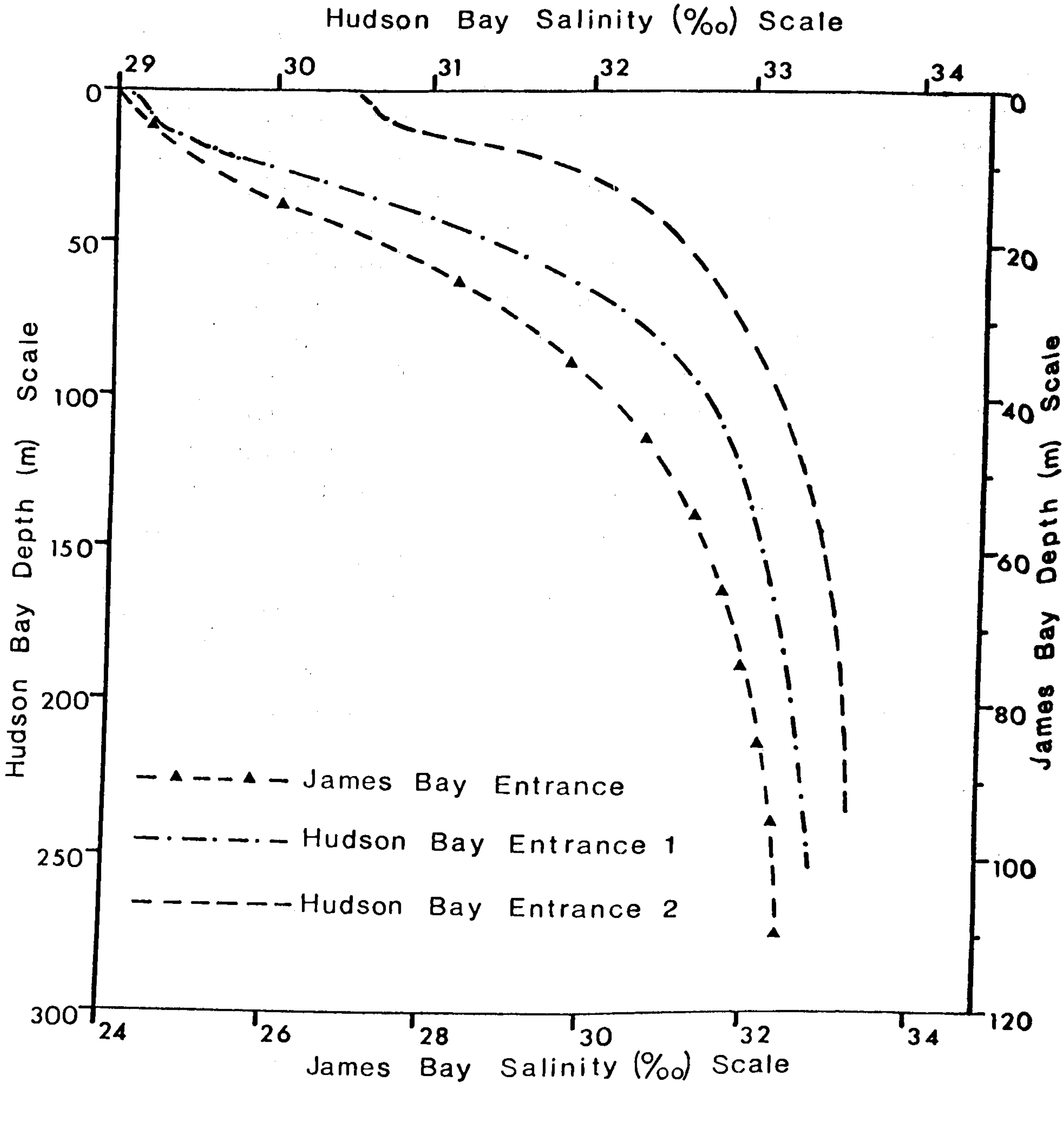

Figure 9: Salinity Profiles at the entrance of Hudson Bay and James Bay.

CHAPTER 5

5.0 CONCLUSIONS

The freshwater budget of the Hudson/James Bay area is obtained on a monthly time scale and includes the contributions of the rivers' runoff, evaporation, and precipitation. The yearly mean precipitation minus evaporation rate value for Hudson Bay was $-6.09 \times 10^3 m^3/sec$, thus supplying the overlying air mass with moisture, as expected from a large body of water. James Bay's yearly mean value was only $-.01 \times 10^3 m^3/sec$; the large precipitation rates in the summer months offset the evaporation rates of the winter months. The monthly runoff rates for both areas have minimum values during the winter months and maximum values during the spring freshet. When the monthly runoff rates are added to the precipitation minus evaporation rates, the yearly freshwater input cycle can be divided into both a winter and summer season. The large freshwater input of the summer season, May to October, represents an average monthly addition of a 10.0-centimetre layer of fresh water, while the smaller input of the winter season, November to April, represents an average monthly addition of about a 1-centimetre layer of fresh water. Annually, the total surface area receives a layer of 64 centimetres of fresh water.

The 1975 oceanographic data from the CCGS NARWHAL was used to obtain a freshwater layer content of 4.6 metres for the Hudson/James Bay system relative to a base salinity of 33.0 $^o/oo$. This represents a freshwater addition period of 7.3 years. For James Bay alone, the summer salinity distribution represented an 6.0-metre freshwater layer for the total surface area relative to a 31.0 $^o/oo$ base salinity. This represents a freshwater accumulation period for James Bay of 1.4 years.

The hydroelectric development will increase the runoff rates of the La Grande River by 470% during the ice-covered winter period of January to April. This change will increase the mean winter runoff for the James Bay region by 70% and for the Hudson/James Bay region by 20%. No significant changes for the total region will occur in the summer months as the proposed discharge rates through the power dams will be around the presently-measured summer rates.

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APPENDICES

APPENDIX A

Hudson Bay Drainage Areas

Appendix A contains three tables listing the two segments of each drainage area for which measured runoff rates were available and estimated runoff rates were calculated. Each area's contribution to the total area, as well as to the total yearly mean runoff, is listed.

Watersheds		Area for Measured Rate ($x10^3$ km^2)	Area for Estimated Rate ($x10^3$ km^2)	Total Area ($x10^3$ km^2)	% of Total Area	% of Total Discharge
Number	Name					
1.1	Southampton Island	0.0	18.5	18.5	0.6	0.4
1.2	Roes Welcome Sound	0.0	45.0	45.0	1.5	0.9
1.3	Lorillard River	0.0	18.5	18.5	0.6	0.4
1.4	Chesterfield Inlet	241.1	40.8	281.9	9.0	6.6
1.5	Ferguson River	0.0	31.5	31.5	1.0	1.0
1.6	Maguse River	0.0	20.8	20.8	0.7	0.7
1.7	Thlewiaza River	0.0	67.5	67.5	2.2	2.2
2.1	Caribou River	0.0	15.8	15.8	0.5	0.5
2.2	Seal River	48.2	0.0	48.2	1.6	1.6
2.3	N.& S. Knife R.	0.0	16.3	16.3	0.5	0.5
2.4	Churchill River	274.7	9.7	284.4	9.2	6.0
2.5	Owl River	0.0	16.7	16.7	0.5	0.4
2.6	Nelson & Hayes Rivers	1149.8	36.0	1185.8	38.2	16.0
2.7	Kaskattawa R.	0.0	10.3	10.3	0.3	0.3
3.1	Niskibi River	0.0	8.8	8.8	0.3	0.2
3.2	Severn River	94.3	8.8	103.1	3.3	3.7
3.3	Shagamu River	0.0	8.8	8.8	0.3	0.2
3.4	Winisk River	54.7	14.0	68.7	2.2	3.2
3.5	Sutton River	0.0	10.5	10.5	0.3	0.5
Sub-total		1862.8	398.3	2261.1	72.8	45.3

Table A-1: **Hudson Bay Drainage Areas located in N.W.T., Manitoba, and Ontario.**

Watersheds		Area for Measured Rate (x10^3 km^2)	Area for Estimated Rate (x10^3 km^2)	Total Area (x10^3 km^2)	% of Total Area	% of Total Discharge
Number	Name					
4.1	Opinnagau River	0.0	14.0	14.0	0.4	0.7
4.2	Ekwan River	7.4	10.4	17.8	0.6	0.8
4.3	Attawapiskat River	36.0	18.5	54.5	1.8	2.8
4.4	Kapiskau River	0.0	9.0	9.0	0.3	0.3
4.5	Albany River	117.6	15.0	132.6	4.3	5.2
4.6	Moose River	99.5	5.0	104.5	3.4	6.0
4.7	Harricana River	21.2	17.5	38.7	1.2	2.3
5.1	Nottaway River	57.5	8.0	65.5	2.1	5.2
5.2	Broadback River	17.1	3.0	20.1	0.6	1.6
5.3	Rupert River	40.9	9.0	49.9	1.6	4.4
5.4	Eastmain River	44.3	11.5	55.8	1.8	5.3
5.5	Castor River	0.0	12.0	12.0	0.4	1.1
5.6	La Grande River	97.4	1.2	98.6	3.2	8.0
5.7	Roggan River	0.0	11.0	11.0	0.3	0.9
	Sub-total	538.9	145.1	684.0	22.0	44.6

Table A-2: Hudson Bay Drainage Areas located in the James Bay Region.

Watersheds Number	Name	Area for Measured Rate ($x10^3$ km^2	Area for Estimated Rate ($x10^3$ km^2)	Total Area ($x10^3$ km^2)	% of Total Area	% of Total Discharge
6.1	Little Cape Jones River	0.0	3.5	3.5	0.1	0.2
6.2	Great Whale River	42.2	0.0	42.2	1.4	3.0
6.3	Little Whale River	12.5	4.2	16.7	0.6	1.0
6.4	Nastapoca River	0.0	20.0	20.0	0.6	1.2
7.1	Innuksuac River	0.0	16.5	16.5	0.5	1.0
7.2	Kogaluk River	0.0	13.0	13.0	0.4	0.7
7.3	Povungnituk River	0.0	27.5	27.5	0.9	1.6
7.4	Kovik River	0.0	10.0	10.0	0.3	0.6
7.5	Others (3 areas)	0.0	13.0	13.0	0.4	0.8
	Sub-total	54.7	107.7	162.4	5.2	10.1
	Total	2456.4	651.1	3107.5	100.0	100.0

Table A-3: Hudson Bay Drainage Areas located in Northern Quebec.

APPENDIX B
Averaged Monthly River Discharge Rates

Appendix B contains tables (B-1 to B-7) of the averaged monthly discharge rates in $10^3 m^3 sec^{-1}$ of all the rivers draining into Hudson Bay or James Bay. The monthly rates of the monitored rivers were taken from the records of the "Water Survey of Canada", which published daily rates for each province except Quebec in the "Surface Water Data" as well as the monthly-averaged values in the "Historical Streamflow Summary". The daily discharge rates for rivers located in Quebec were obtained from the "Annuaire Hydrologique" published by the Quebec Government under the Ministère des Richesses Naturelles. Only the monthly-averaged discharge rates were used in this manuscript, and the data includes all available data to the end of 1975.

RIVERS OF NORTHWEST TERRITORIES

MONTHLY DISCHARGE RATES ($10^3 m^3$/sec) INTO HUDSON BAY

Month	Southampton * Island	Roes Welcome * Sound	Lorillard * River Area	Chesterfield Inlet	Ferguson * River	Maguse * River	Thlewiaza * River	Total
Jan.	0.004	0.008	0.004	0.466	0.084	0.055	0.225	0.846
Feb.	0.002	0.005	0.002	0.403	0.068	0.045	0.178	0.703
March	0.003	0.007	0.003	0.365	0.059	0.039	0.142	0.618
April	0.004	0.010	0.004	0.400	0.058	0.038	0.134	0.648
May	0.028	0.068	0.028	0.620	0.108	0.071	0.564	1.487
June	0.325	0.803	0.325	4.586	0.531	0.351	1.131	8.052
July	0.225	0.547	0.225	3.438	0.596	0.394	0.834	6.259
Aug.	0.116	0.283	0.116	2.258	0.432	0.285	0.749	4.239
Sept.	0.179	0.435	0.179	2.214	0.336	0.222	0.705	4.270
Oct.	0.076	0.185	0.076	1.549	0.257	0.170	0.578	2.891
Nov.	0.028	0.068	0.028	1.032	0.183	0.120	0.415	1.874
Dec.	0.008	0.018	0.008	0.662	0.123	0.082	0.313	1.214
Mean	0.083	0.203	0.083	1.500	0.236	0.156	0.497	2.758

* Estimated Values

Table B.-1: Monthly Discharge Rates of N.W.T. rivers draining into Hudson Bay.

MANITOBA RIVERS

MONTHLY DISCHARGE RATES ($10^3 m^3/sec$) INTO HUDSON BAY

Month	Caribou * River	Seal River	N & S Knife * River	Churchill River	Owl * River	Nelson and Hayes Delta	Kaskattawa *	Total
Jan.	0.053	0.161	0.054	1.199	0.027	2.396	0.033	3.923
Feb.	0.042	0.127	0.043	1.128	0.019	2.276	0.032	3.667
March	0.033	0.101	0.034	1.077	0.016	2.268	0.031	3.560
April	0.031	0.095	0.032	1.014	0.053	2.475	0.037	3.737
May	0.132	0.402	0.136	1.300	0.317	4.911	0.115	7.313
June	0.265	0.807	0.273	1.690	0.262	5.288	0.112	8.697
July	0.195	0.595	0.202	1.734	0.157	4.753	0.090	7.726
Aug.	0.175	0.535	0.181	1.621	0.102	4.336	0.076	7.026
Sept.	0.165	0.503	0.170	1.605	0.109	4.180	0.078	6.810
Oct.	0.135	0.413	0.140	1.503	0.095	3.971	0.097	6.354
Nov.	0.097	0.296	0.100	1.222	0.056	3.392	0.076	5.239
Dec.	0.073	0.223	0.076	1.095	0.043	2.642	0.052	4.204
Mean	0.116	0.355	0.120	1.349	0.105	3.574	0.069	5.688

* Estimated Values

Table B-2: Monthly Discharge Rates of Manitoba rivers draining into Hudson Bay.

ONTARIO RIVERS

MONTHLY DISCHARGE RATES ($10^3 m^3/sec$) INTO HUDSON BAY

Month	Niskibi * River Area	Severn River	Shagamu * River Area	Winisk River	Sutton * River	Total
January	0.028	0.352	0.028	0.252	0.017	0.677
February	0.027	0.278	0.027	0.175	0.012	0.519
March	0.026	0.235	0.026	0.134	0.008	0.429
April	0.031	0.253	0.031	0.142	0.010	0.467
May	0.098	1.555	0.098	1.391	0.348	3.490
June	0.095	1.717	0.095	1.497	0.201	3.605
July	0.077	1.239	0.077	1.050	0.126	2.569
August	0.065	1.064	0.065	0.865	0.122	2.181
September	0.067	0.923	0.067	0.820	0.136	2.013
October	0.083	1.061	0.083	1.066	0.200	2.493
November	0.065	0.789	0.065	0.771	0.104	1.794
December	0.044	0.541	0.044	0.397	0.037	1.063
Mean	0.059	0.834	0.059	0.713	0.110	1.775

* Estimated Values

Table B-3: Monthly Discharge Rates of Ontario rivers draining into Hudson Bay.

ONTARIO RIVERS

MONTHLY DISCHARGE RATES ($10^3 m^3/sec$) INTO JAMES BAY

Month	Opinnagau * River Area	Ekwan River	Attawapiskat River	Kapiskau * River	Albany River	Moose River	Harricana River	Total
Jan.	0.022	0.028	0.173	0.008	0.308	0.525	0.123	1.187
Feb.	0.015	0.020	0.123	0.005	0.242	0.505	0.089	0.999
March	0.011	0.014	0.093	0.004	0.214	0.531	0.093	0.960
April	0.013	0.016	0.101	0.039	0.640	1.569	0.475	2.853
May	0.463	0.588	1.537	0.335	3.970	4.627	1.953	13.473
June	0.267	0.339	1.235	0.112	2.242	1.986	0.699	6.880
July	0.168	0.214	0.870	0.093	1.528	1.224	0.581	4.678
Aug.	0.162	0.206	0.778	0.061	1.249	0.896	0.510	3.862
Sept.	0.181	0.229	0.743	0.061	1.031	1.056	0.480	3.781
Oct.	0.266	0.337	1.001	0.089	1.349	1.430	0.623	5.095
Nov.	0.139	0.176	0.632	0.063	0.967	1.065	0.426	3.468
Dec.	0.049	0.063	0.295	0.015	0.389	0.701	0.249	1.761
Mean	0.146	0.186	0.632	0.074	1.177	1.343	0.525	4.083

* Estimated Values

Table B-4: Monthly Discharge Rates of Ontario rivers draining into James Bay.

QUEBEC RIVERS

MONTHLY DISCHARGE RATES ($10^3 m^3/sec$) INTO JAMES BAY

Month	Nottaway River	Broadbank River	Rupert River	Eastmain River	Castor * River Area	La Grande River	Roggan * River	Total
Jan.	0.493	0.181	0.668	0.472	0.101	0.813	0.091	2.819
Feb.	0.363	0.134	0.532	0.340	0.073	0.588	0.061	2.091
March	0.306	0.109	0.444	0.260	0.056	0.476	0.053	1.704
April	0.530	0.167	0.568	0.360	0.077	0.483	0.054	2.239
May	2.426	0.615	1.473	2.132	0.459	2.259	0.252	9.616
June	2.466	0.650	1.361	2.459	0.529	3.688	0.411	11.564
July	1.668	0.520	1.247	1.435	0.308	2.698	0.301	8.177
Aug.	1.217	0.438	1.176	1.519	0.326	2.060	0.230	6.966
Sept.	1.153	0.425	1.171	1.513	0.325	2.309	0.257	7.153
Oct.	1.431	0.454	1.295	1.793	0.385	2.696	0.300	8.354
Nov.	1.248	0.413	1.144	1.229	0.264	2.072	0.231	6.601
Dec.	0.837	0.298	0.897	0.770	0.166	1.316	0.146	4.430
Mean	1.178	0.367	0.998	1.190	0.256	1.788	0.199	5.976

* Estimated Values

Table B-5: Monthly Discharge Rates of Quebec rivers draining into James Bay.

QUEBEC RIVERS (CAPE JONES TO 57° LAT)

MONTHLY DISCHARGE RATES ($10^3 m^3/sec$) INTO HUDSON BAY

Month	Little Cape * Jones River	Great Whale River	Little Whale River	Nastapoca * River	Total
January	0.018	0.321	0.112	0.134	0.585
February	0.013	0.224	0.080	0.096	0.413
March	0.011	0.172	0.064	0.077	0.324
April	0.012	0.221	0.057	0.068	0.358
May	0.086	0.907	0.164	0.196	1.353
June	0.102	1.321	0.514	0.616	2.553
July	0.060	1.047	0.355	0.425	1.887
August	0.059	0.822	0.290	0.347	1.518
September	0.065	0.829	0.287	0.344	1.525
October	0.080	0.888	0.335	0.401	1.704
November	0.059	0.723	0.288	0.345	1.415
December	0.033	0.503	0.183	0.219	0.938
Mean	0.050	0.665	0.227	0.272	1.214

* Estimated Values

Table B-6: Monthly Discharge Rates of Quebec rivers draining into Hudson Bay south of 57° North Latitude.

QUEBEC RIVERS (NORTH OF 57^{o} LAT)

MONTHLY DISCHARGE RATES ($10^3 m^3$/sec) INTO HUDSON BAY

Month	Innuksuac * River	Kogaluk * River	Povungnituk * River	Kovik * River	Others	Total
January	0.111	0.042	0.088	0.032	0.087	0.360
February	0.079	0.030	0.063	0.023	0.062	0.257
March	0.063	0.025	0.052	0.019	0.049	0.208
April	0.056	0.022	0.047	0.017	0.044	0.186
May	0.163	0.037	0.077	0.028	0.128	0.433
June	0.510	0.466	0.986	0.359	0.400	2.721
July	0.353	0.466	0.986	0.359	0.276	2.440
August	0.288	0.302	0.641	0.233	0.226	1.690
September	0.285	0.270	0.572	0.208	0.223	1.558
October	0.330	0.204	0.432	0.157	0.261	1.384
November	0.286	0.112	0.238	0.087	0.224	0.947
December	0.182	0.068	0.143	0.052	0.142	0.587
Mean	0.226	0.170	0.360	0.131	0.177	1.064

* Estimated Values

Table B-7: Monthly Discharge Rates of Quebec rivers draining into Hudson Bay north of 57^{o} North Latitude.

APPENDIX C

Evaporation and Precipitation Rates for Hudson Bay Areas

Appendix C lists, for each Hudson Bay area, the monthly-averaged wind speeds and directions, differences in saturated and observed vapour pressure, calculated evaporation rates, and observed precipitation rates. The data was obtained from records of the Meteorological Branch of Canada's Department of Transport, which published, in 1968, the mean monthly wind conditions across Canada in Volume 5 "Wind" of the "Climatic Normals". The same department published, between 1967-1970, an "Atlas of Climatic Maps" based on data collected between 1931 and 1960. The information of the 1969 maps (mean vapour pressure minus saturation vapour pressure at mean dew point) was used in the evaporation rate calculations, and the information of the 1967 maps (mean monthly amount of precipitation in inches) was used in the precipitation rate calculations.

Evaporation (E) and Precipitation (P)
of Area I ($1.557 \times 10^5 km^2$)

Month	Wind *1		Wind Factor	$e_s - e_a$ *2 mb	E $10^3 m^3/sec$	P *3 $10^3 m^3/sec$	P - E $10^3 m^3/sec$
	m/sec	dir.					
Jan.	7.1	WNW	1.00	1.6	2.03	.89	-1.14
Feb.	7.0	WNW	1.00	2.4	2.99	.9	-2.09
Mar.	6.5	WNW	1.00	2.0	2.26	1.03	-1.23
Apr.	7.0	NW	1.00	4.0	4.99	1.22	-3.77
May	6.7	NW	1.00	3.9	4.59	1.87	-2.72
June	6.0	NW/NE	1.05	2.3	2.50	2.82	+ .32
July	5.7	NW/NE	1.15	2.7	3.09	2.51	- .58
Aug.	6.0	NW	1.25	1.0	1.37	3.10	1.73
Sep.	7.3	NW	1.25	2.0	3.57	3.20	- .37
Oct.	7.3	NW	1.25	2.8	5.00	2.39	-2.61
Nov.	7.6	NW	1.25	4.2	7.93	1.83	-6.10
Dec.	6.8	WNW	1.15	2.3	3.33	1.28	-2.05

*1 Climatic Normals Vol. 5 "Wind", 1968, Churchill Station.

*2 Atlas of Climatic Maps, 1969.

*3 Atlas of Climatic Maps, 1967.

Table C-1: Monthly Evaporation and Precipitation Rates of the Hudson Bay Area I.

Evaporation (E) and Precipitation (P)
of Area II ($1.625 \times 10^5 km^2$)

Month	Wind *1		Wind Factor	$e_s - e_a$ *2 mb	E $10^3 m^3/sec$	P *3 $10^3 m^3/sec$	P - E $10^3 m^3/sec$
	m/sec	dir.					
Jan.	6.6	N/NW	1.00	1.3	1.56	.46	-1.10
Feb.	6.5	N/NW	1.00	2.0	2.37	.68	-1.69
Mar.	6.0	N	1.00	1.3	1.38	.77	- .61
Apr.	6.5	N	1.00	3.7	4.39	.96	-3.43
May	6.6	N	1.00	3.5	4.21	1.08	-3.13
June	5.7	N/SE	1.10	1.6	1.80	2.15	.35
July	5.2	N/SE	1.25	2.5	2.95	3.62	.67
Aug.	6.0	NW/SE	1.25	.8	1.14	2.62	1.48
Sep.	6.4	N/NW	1.25	1.8	2.80	2.63	- .17
Oct.	7.0	N/NW	1.25	2.9	5.10	1.93	-3.17
Nov.	6.8	N/NW	1.25	4.3	7.27	1.19	-6.08
Dec.	7.2	N/NW	1.15	1.9	3.10	.92	-2.18

*1 Climatic Normals Vol. 5 "Wind", 1968, Baker Lake Station.

*2 Atlas of Climatic Maps, 1969.

*3 Atlas of Climatic Maps, 1967.

Table C-2: Monthly Evaporation and Precipitation Rates of the Hudson Bay Area II.

Evaporation (E) and Precipitation (P)
of Area III ($1.098 \times 10^5 km^2$)

Month	Wind *1		Wind	*2 $e_s - e_a$	E	*3 P	P - E
	m/sec	dir.	Factor	mb	$10^3 m^3/sec$	$10^3 m^3/sec$	$10^3 m^3/sec$
Jan.	5.9	NNW	1.00	2.1	1.48	.42	-1.06
Feb.	5.9	NNW	1.00	2.4	1.69	.52	-1.17
Mar.	4.6	NNW	1.00	1.5	.77	.52	- .25
Apr.	5.5	NNW	1.00	3.4	2.18	.65	-1.53
May	5.9	NNW	1.05	3.0	2.25	.73	-1.52
June	5.7	N/SE	1.10	1.4	1.06	1.29	.23
July	5.1	N/SE	1.25	2.1	1.63	1.72	.09
Aug.	6.4	NNW	1.25	1.0	1.05	1.77	.72
Sep.	6.8	NNW	1.25	1.7	1.94	1.78	- .16
Oct.	7.0	NNW	1.25	2.7	3.21	1.41	-1.80
Nov.	6.6	NNW	1.25	3.6	3.95	1.18	-2.77
Dec.	6.4	NNW	1.15	2.2	2.07	.62	-1.45

*1 Climatic Normals Vol. 5 "Wind", 1968, Coral Harbour Station.

*2 Atlas of Climatic Maps, 1969.

*3 Atlas of Climatic Maps, 1967.

Table C-3: Monthly Evaporation and Precipitation
Rates of the Hudson Bay Area III.

Evaporation (E) and Precipitation (P)
of Area IV ($1.447 \times 10^5 km^2$)

Month	Wind *1		Wind Factor	*2 $e_s - e_a$ mb	E $10^3 m^3/sec$	*3 P $10^3 m^3/sec$	P - E $10^3 m^3/sec$
	m/sec	dir.					
Jan.	5.9	S/N	1.00	2.3	2.13	.82	-1.31
Feb.	5.6	S/N	1.00	2.9	2.51	.99	-1.52
Mar.	5.3	N/S	1.00	2.3	1.86	.96	- .90
Apr.	6.4	N/S	1.00	3.9	4.01	1.13	-2.88
May	6.5	N/W	1.05	3.2	3.58	1.17	-2.41
June	5.9	N/W	1.10	2.0	2.10	2.13	.03
July	5.6	N/W	1.25	2.3	2.66	2.54	- .12
Aug.	5.2	N/W	1.25	1.3	1.37	2.54	1.17
Sep.	6.5	W/N	1.25	1.9	2.69	2.69	0
Oct.	5.8	N/W	1.25	2.5	3.03	2.33	- .7
Nov.	6.4	N/W	1.25	4.0	5.54	2.13	-3.41
Dec.	6.5	N/W	1.15	2.5	3.16	1.10	-2.06

*1 Climatic Normals Vol. 5 "Wind", 1968, Port Harrison Station.

*2 Atlas of Climatic Maps, 1969.

*3 Atlas of Climatic Maps, 1967.

Table C-4: Monthly Evaporation and Precipitation Rates of the Hudson Bay Area IV.

Evaporation (E) and Precipitation (P)
of Area V ($1.746 \times 10^5 km^2$)

Month	Wind *1 m/sec	Wind *1 dir.	Wind Factor	$e_s - e_a$ *2 mb	E $10^3 m^3/sec$	P *3 $10^3 m^3/sec$	P - E $10^3 m^3/sec$
Jan.	5.6	ESE	1.00	2.6	2.72	1.49	-1.23
Feb.	5.0	ESE	1.00	3.4	3.08	1.56	-1.52
Mar.	4.1	ESE	1.00	3.0	2.12	1.41	- .71
Apr.	5.0	ESE	1.00	4.0	3.62	1.71	-1.91
May	5.4	N/WSW	1.00	3.6	3.59	2.32	-1.27
June	4.9	N/WSW	1.10	3.2	3.18	3.42	.24
July	4.6	N/WSW	1.25	2.6	2.81	3.81	1.00
Aug.	5.4	WSW	1.25	2.0	2.66	3.97	1.31
Sep.	6.0	W	1.25	2.0	3.07	4.11	1.04
Oct.	5.9	E/W	1.25	2.6	3.90	3.73	- .17
Nov.	6.2	ESE	1.25	4.2	6.73	3.25	-3.48
Dec.	5.9	ESE	1.15	3.0	4.02	2.15	-1.87

*1 Climatic Normals Vol. 5 "Wind", 1968, Great Whale Station.

*2 Atlas of Climatic Maps, 1969.

*3 Atlas of Climatic Maps, 1967.

Table C-5: Monthly Evaporation and Precipitation Rates of the Hudson Bay area V.

APPENDIX D

Evaporation, Precipitation, and Runoff Rates for James Bay Areas

Appendix D contains tables (D-1 to D-5) used in the calculation of evaporation and precipitation for the six areas located in James Bay. The evaporation rates for the most northerly area use the Great Whale wind data, whereas the most southerly area uses the Moosonee wind data. The vapour pressure information of the two areas is obtained from the "Atlas of Climatic Maps" of 1969 as was done for the tables of Appendix C. The evaporation rates for each of the six areas of James Bay were then obtained by interpolation. The precipitation rates were obtained from the "Climatic Maps" of 1967. Tables D-6 and D-7 list the monthly discharge rates of the James Bay river systems separately and the monthly discharge rates into each of the six James Bay areas. The last table of Appendix D (D-8) lists the topographical data of the six areas of James Bay.

Evaporation

Southern half of James Bay

(Winds of Moosonee were used)

Month	V (m/sec)	Wind Factor	$e_s - e_a$** (mb)	E cm/month	E* $10^2 m^3/sec$
Jan.	3.4	1.00	3.0	2.59	.97
Feb.	3.8	1.00	4.2	3.75	1.55
Mar.	3.7	1.00	4.1	3.92	1.46
Apr.	4.0	1.00	5.0	5.09	1.96
May	4.3	1.00	4.5	5.17	1.93
June	3.9	1.05	5.0	5.24	2.02
July	3.7	1.20	3.5	4.18	1.56
Aug.	3.7	1.25	3.5	4.39	1.64
Sept.	3.9	1.25	4.5	5.87	2.26
Oct.	4.0	1.25	3.5	4.86	1.81
Nov.	4.3	1.25	5.6	8.24	3.18
Dec.	3.6	1.15	4.5	4.92	1.84
Mean	3.8		Total	58.22	

* Area = 1.0×10^4 km^2
** Atlas of Climatic Maps (1969)

Table D-1: Monthly Evaporation Rates of the James Bay Area 6.

Evaporation

Northern Half of James Bay

(Winds of Great Whale were Used)

Month	V (m/sec)	Wind Factor	$e_s - e_a$ ** (mb)	E cm/month	E * $10^2 m^3/sec$
Jan.	5.6	1.00	2.8	4.48	1.67
Feb.	5.0	1.00	3.7	4.63	1.91
Mar.	4.1	1.00	3.6	3.90	1.46
Apr.	5.0	1.00	4.7	6.30	2.43
May	5.4	1.05	4.0	6.51	2.43
June	4.9	1.20	4.2	6.94	2.68
July	4.6	1.25	3.0	4.97	1.86
Aug.	5.4	1.25	2.5	5.10	1.91
Sept.	6.0	1.25	3.6	8.20	3.16
Oct.	5.9	1.25	2.8	6.44	2.40
Nov.	6.2	1.25	5.0	11.89	4.59
Dec.	5.9	1.15	3.8	7.82	2.92
mean	5.3		Total	77.18	

* Area = $1.0 \times 10^4 km^2$
** Atlas of Climatic Maps (1969)

Table D-2: Monthly Evaporation Rate of the James Bay Area 1.

James Bay Evaporation Rates*

($10^2 m^3$/sec) for a 10^4km unit area)

Area / Month	1	2	3	4	5	6
Jan.	1.67	1.52	1.38	1.28	1.15	.97
Feb.	1.91	1.83	1.76	1.71	1.64	1.55
Mar.	1.46	1.46	1.46	1.46	1.46	1.46
Apr.	2.43	2.33	2.24	2.17	2.08	1.96
May	2.43	2.33	2.23	2.15	2.06	1.93
June	2.68	2.55	2.44	2.34	2.24	2.02
July	1.86	1.80	1.75	1.71	1.66	1.56
Aug.	1.91	1.86	1.81	1.77	1.73	1.64
Sep.	3.16	2.99	2.83	2.70	2.86	2.26
Oct.	2.40	2.29	2.18	2.10	2.00	1.81
Nov.	4.59	4.32	4.07	3.87	3.65	3.18
Dec.	2.92	2.71	2.52	2.37	2.20	1.84

*Evaporation rates based on rates in Northern James Bay (Great Whale winds) and Southern James Bay (Moosonee winds)

Table D-3: Monthly Evaporation Rates per unit area of the James Bay areas.

James Bay Evaporation

(10^3 m^3/sec)

Month \ Area	1	2	3	4	5	6	Total
Jan.	.127	.200	.109	.109	.074	.227	.846
Feb.	.146	.241	.139	.146	.105	.363	1.140
Mar.	.111	.192	.115	.125	.093	.342	.978
Apr.	.186	.306	.177	.185	.133	.459	1.446
May	.186	.306	.176	.184	.132	.452	1.436
June	.205	.335	.193	.200	.143	.473	1.549
July	.142	.237	.138	.146	.106	.365	1.134
Aug.	.146	.245	.143	.151	.111	.384	1.180
Sep.	.241	.393	.223	.231	.183	.529	1.800
Oct.	.183	.301	.172	.179	.128	.424	1.387
Nov.	.350	.568	.321	.332	.234	.745	2.550
Dec.	.223	.356	.199	.203	.141	.431	1.553
						mean	1.417

Table D-4: Monthly Evaporation Rates of the James Bay areas.

James Bay Precipitation*
(10^3 m^3/sec)

Month \ Area	1	2	3	4	5	6	Total
Jan.	.087	.150	.097	.113	.088	.355	.890
Feb.	.080	.152	.099	.117	.087	.369	.904
Mar.	.065	.125	.082	.089	.073	.289	.723
Apr.	.089	.155	.097	.109	.085	.310	.845
May	.138	.249	.150	.170	.133	.511	1.351
June	.210	.374	.224	.243	.182	.688	1.921
July	.210	.374	.232	.259	.194	.755	2.024
Aug.	.174	.312	.195	.211	.164	.644	1.700
Sept.	.209	.374	.224	.251	.194	.734	1.995
Oct.	.188	.337	.210	.227	.182	.666	1.810
Nov.	.165	.284	.178	.201	.151	.574	1.553
Dec.	.119	.218	.135	.154	.127	.466	1.219
						Mean	1.411

* Based on period 1931 - 1960
(Atlas of Climatic Maps, 1967)

Table D-5: Monthly Precipitation Rates of the James Bay areas.

JAMES BAY RIVERS

MONTHLY DISCHARGE RATES ($10^3 m^3/sec$) INTO JAMES BAY

Month	Attawapiskat River Area	Albany River	Moose and Harricana	Rupert Bay	Eastmain River	La Grande River	Others *	Total
Jan.	0.209	0.308	0.648	1.342	0.472	0.813	0.214	4.006
Feb.	0.148	0.242	0.594	1.029	0.340	0.588	0.149	3.090
March	0.111	0.214	0.624	0.859	0.260	0.476	0.120	2.664
April	0.156	0.640	2.044	1.265	0.360	0.483	0.144	5.092
May	2.460	3.970	6.580	4.514	2.132	2.259	1.174	23.089
June	1.686	2.242	2.685	4.477	2.459	3.688	1.207	18.444
July	1.177	1.528	1.805	3.435	1.435	2.698	0.777	12.855
Aug.	1.045	1.249	1.406	2.831	1.519	2.060	0.718	10.828
Sept.	1.033	1.031	1.536	2.749	1.513	2.309	0.763	10.934
Oct.	1.427	1.349	2.053	3.180	1.793	2.696	0.951	13.449
Nov.	0.871	0.967	1.491	2.805	1.229	2.072	0.634	10.069
Dec.	0.373	0.389	0.950	2.032	0.770	1.316	0.361	6.191
Mean	0.892	1.177	1.868	2.543	1.190	1.788	0.601	10.059

* Estimated Values

Table D-6: Monthly discharge rates of James Bay river systems.

River Discharge of James Bay

(10^3 m^3/sec)

Area / Month	1	2	3	4	5	6	Total
Jan.	.074	.846	.039	.034	.034	2.979	4.006
Feb.	.050	.611	.028	.024	.024	2.353	3.090
Mar.	.043	.494	.021	.019	.019	2.068	2.664
Apr.	.044	.503	.028	.026	.026	4.465	5.092
May	.305	2.554	.268	.153	.153	19.656	23.089
June	.375	3.924	.244	.176	.176	13.549	18.444
July	.268	2.857	.144	.103	.103	9.380	12.855
Aug.	.213	2.199	.148	.109	.109	8.050	10.828
Sept.	.238	2.464	.154	.108	.108	7.862	10.934
Oct.	.292	2.904	.195	.128	.128	9.802	13.449
Nov.	.208	2.199	.123	.088	.088	7.363	10.069
Dec.	.122	1.377	.068	.055	.055	4.514	6.191

* Based on "Water Survey of Canada" up to 1975

Table D-7: Monthly Freshwater Input from Runoff for each of the James Bay areas.

JAMES BAY TOPOGRAPHIC DETAILS

Transect #	1	2	3	4	5	6
Latitude	54°46'	54°23'	53°50'	53°30'	53°7.5'	52°42'
Cross-sectional area ($10^5 m^2$)	102.4	74.7	57.1	52.8	40.1	46.0
Width (km)	162.5	190.0	190.5	204.5	138.0	130.0
Mean depth (m)	63.0	39.3	30.0	25.8	29.1	35.4
Largest depth (m)	119	75	57.5	62	57.5	70.0
Distance (km) between transects	45	62.5	37.5	42	50	130 *
Area ($10^4 km^2$) between transects	.7634	1.3151	.7893	.8547	.6400	2.3412**

* to Rupert house

** Area below 52° Lat. = 1.6336×10^4 km².

Total area = 6.7037×10^4 km² (up to Lat. 54°46' North)

Table D-8: James Bay Topographical Details.

JAMES BAY TOPOGRAPHIC DETAILS

Transect #	1	2	3	4	5	6
Latitude	$54^{o}46'$	$54^{o}23'$	$53^{o}50'$	$53^{o}30'$	$53^{o}7.5'$	$52^{o}42'$
Cross-sectional area ($10^5 m^2$)	102.4	74.7	57.1	52.8	40.1	46.0
Width (km)	162.5	190.0	190.5	204.5	138.0	130.0
Mean depth (m)	63.0	39.3	30.0	25.8	29.1	35.4
Largest depth (m)	119	75	57.5	62	57.5	70.0
Distance (km) between transects	45	62.5	37.5	42	50	130 *
Area ($10^4 km^2$) between transects	.7634	1.3151	.7893	.8547	.6400	2.3412**

* to Rupert house

** Area below 52^{o} Lat. = 1.6336×10^4 km^2.

Total area = 6.7037×10^4 km^2 (up to Lat. $54^{o}46'$ North)

Table D-8: James Bay Topographical Details.

Date Due
