WAYNE R. ROUSE and MING-KO WOO
Department of Geography, McMaster University, Hamilton, Ontario, Canada L8S 4K1

JONATHAN S. PRICE
Department of Geography, Queen's University, Kingston, Ontario, Canada K7L 3N6

DAMMING JAMES BAY: I. POTENTIAL IMPACTS ON COASTAL CLIMATE AND THE WATER BALANCE

The proposed GRAND *Canal project calls for the damming of James Bay and the diversion of its water southward. This first part of a two-part study models some potential impacts on the climate, water balance, and growth patterns in the James Bay coastal zone. Use is made of a linear relationship of Bowen ratio and temperature, developed from studies of coastal wetlands in southern and northwestern James Bay and central Hudson Bay. It is hypothesized that changing James Bay into a fresh-water lake and disrupting its coastal currents would result in a delayed Bay ice melt of unknown length in the spring. Allowing a delay to vary between 0 and 30 days results in the prediction of lesser evaporation and greater water surplus. These differences in magnitude increase with the length of delayed melt, but in all cases are most strongly evident during the peak of the growing season. Colder and wetter conditions would have a strong ecological impact on all coastal areas of western and southern James Bay. In the northwest this could change the species composition of coastal flora, cause forests to retreat from the coast, and result in the growth of permafrost there.*

Le projet du Canal Grand suppose la construction d'un barrage dans la baie James et la dérivation de ses eaux vers le sud. Cette première partie d'une étude en deux parties modélise certains impacts potentiels sur le climat, sur la balance des eaux et sur les schémas d'accroissement dans la zone littorale de la baie James. Les rapports linéaires de la proportion de Bowen et de la température seront développés à partir des études des marais littoraux du sud et du nord-ouest de la baie James et dans le centre de la baie d'Hudson. Notre hypothèse est que le changement de la baie James en lac d'eau douce et la dislocation de ses courants littoraux auront un impact sur le délai du dégel printanier des glaces de la baie d'une temporalité incertaine. En adoptant un délai entre zéro et trente jours, nous arrivons à la prédiction d'une évaporation réduite et à une augmentation d'un peu plus d'eau. Ces différences de magnitude augmentent avec la longueur du délai mais sont, dans tous les cas, les plus évidentes dans la pointe de la saison d'accroissement. Des conditions plus froides et plus humides causeraient un fort impact écologique dans toutes les régions littorales de l'ouest et du sud de la baie James. Dans le nord-ouest ceci pourrait changer la composition des espèces de la flore littorale et aussi provoquer la diminution des forêts de la côte et la croissance du permafrost.

The coastal marshes of southern and western James Bay lie along the main flight corridor of the migratory birds of eastern North America, providing them with essential habitat (Thomas and Prevett 1982). The existence of these marshes is controlled by sensitive interrelationships between vegetation growth and energy, salt and water balances.

In the mid-1980s, the GRAND Canal concept, first conceived by T.W. Kierans in 1959, was being reconsidered. The project proposes to impound James Bay, either at its mouth, or using Akimiski Island as a bridging point (Figure 1), thus transforming the Bay into a freshwater lake (Kierans 1987). The purpose is to capture river water from the impoundment, divert it via pumps, canals, and natural drainage networks, and to deliver it to the Great Lakes, thence to supply the water-deficient regions in the Canadian Prairies and in the U.S. midwest and southwest (Gamble 1987). This mega-project will significantly modify the natural rhythm under which the James Bay coastal marshes have evolved. The low topographic gradient of the western James Bay hinterland (1 to 5 m/km) makes it particularly sensitive to even small fluctuations of water levels.

In the absence of prior experience of such impoundment impacts, numerical modelling is a feasible and practical approach to predicting the potential impacts. The present research was undertaken to develop climatic

The Canadian Geographer / Le Géographe canadien 36, no 1 (1992) 2–7

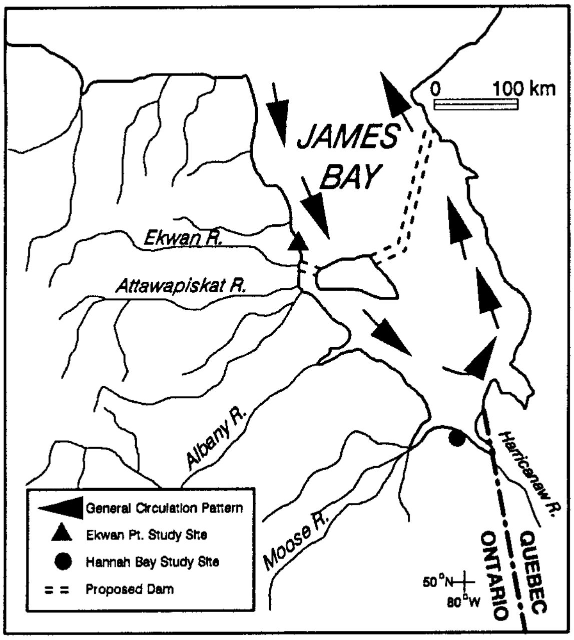

Figure 1
James Bay, showing the general circulation of the currents, the proposed dam site and the two study sites

and hydrologic models that address, in a preliminary manner, impoundment impacts on the coastal marshes.

The western shores of James Bay are occupied by extensive wetlands. Rapid postglacial emergence has led to progressive seaward encroachment of the marshes. Inland, the climatic influence of the Bay diminishes and tidewater effects are replaced by freshwater hydrological processes (Price and Woo 1988; Rouse 1991). Vegetation patterns are notably influenced by a spatially changing climate and salinity in marshes whose relative positions have shifted inland due to coastal emergence (Glooschenko and Clarke 1982; Ewing and Kershaw 1986).

The James Bay region has a subarctic continental climate with mean January and July temperatures at Moosonee of –20.0°C and 15.5°C, respectively. Mean annual precipitation is 727 mm, 30% of which falls as snow (Hutton and Black 1975). Towards the northern end of western James Bay, discontinuous permafrost underlies the wetlands, but only seasonal frost occurs at the southern end of the Bay. The marine circulation is dominated by a counterclockwise flow along the western shore (Figure 1; Prinsenberg 1982). Moving southward, its salinity is continuously diluted by river runoff so that the salinity of tidewater in the northwest is an order of magnitude higher than at Hannah Bay in the south (Price et al. 1989).

To contrast the spatial variation of climate, salinity, and marsh vegetation, this study focuses on two sites 300 km apart (see Figure 1). The northern site is located near Ekwan Point (53°18' N, 82°07' W); the southern site is near the mouth of Harricanaw River (51°10' N, 79°47' W). Other data from central Hudson Bay, near Churchill, Manitoba, are also used. Paleozoic sedimentary bedrock is overlain by sparsely fossiliferous blue silt-clay, deposited in the postglacial Tyrrell Sea, and by more recent sediments, including beach materials (Hutton and Black 1975). Peat formation is currently active in the marshes, which are emerging at a rate of 0.7 to 1.25 m/century (Clarke et al. 1982), thus extending the coastline into the Bay at a rate of about 1 km/century.

The GRAND Canal scheme would lengthen the sea-ice season, leading to cooling of coastal air over western James Bay during the growing season. This would change the energy and water balances, the hydrologic regime, the development of permafrost, the species composition of coastal vegetation and the distribution of boreal forest. It is postulated that the coastal sea ice would thaw later in the spring as a result of the higher freezing point of fresh water and the elimination of longshore currents which flush the sea ice. The potential impact of later sea-ice melt is explored using models based on measurements made at Ekwan Point in 1988 and on previous work done in southern James Bay and central Hudson Bay.

Methods

SITE AND FIELD MEASUREMENT

The field research was centred at the Ekwan Point site over a large homogeneous stand of the sedge *Carex acquatilis* (Wahlenb). The measuring program was designed to document components of the surface energy balance

$$Q^* - Q_G = Q_E + Q_H \quad (1)$$

in which Q^* is net radiation (measured with a net radiometer), Q_G is heat flux into the ground (measured with soil heat flux plates) and Q_E and Q_H are the atmospheric fluxes of latent and sensible heat, respectively. Equation (1) can be rearranged to give

$$Q_E = (Q^* - Q_G)/(1 + \beta) \quad (2)$$

with

$$\beta = Q_H/Q_E = \tau\,\Delta T/\Delta e \quad (3)$$

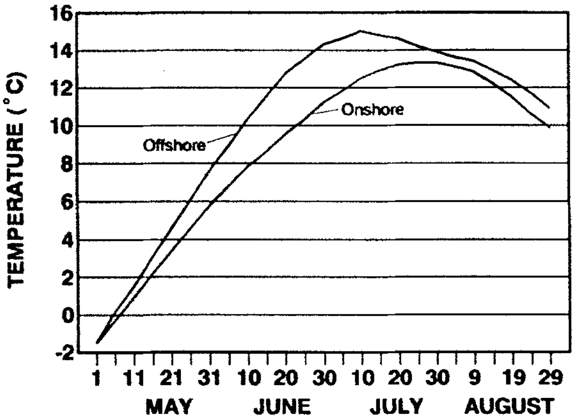

Figure 2
Calculated air temperatures (°C) for Ekwan Point during onshore and offshore winds

in which β is the Bowen ratio, τ is the psychrometer constant, and ΔT and Δe are the vertical gradients of air temperature and vapour pressure measured over the same height intervals. βs were determined using a four-level mast with psychrometers to measure dry and wet bulb temperatures from which ΔT and Δe were derived. Measurements spanned June 28 to August 4, 1988. During this period the water table dropped from the surface at the start of measurements, to 0.5 m below the surface on July 22. With several rains in late July, the water table moved back to near the surface. The implications of this dry spell for the overall modelling are discussed later.

ANALYSIS AND MODEL DEVELOPMENT

The water balance model for the coast near Ekwan Point was developed in the steps described below.

Assumptions

1. (a) Damming of James Bay would lead to a longer ice-covered season and later sea-ice melt in spring. We hypothesize a most likely delay of 12 days in spring melting of ice off Ekwan Point. This would arise from a change in salinity from 31% (Prinsenberg 1983) to zero, and the resulting change in the freezing point from −1.6°C to 0°C. Based on current rates of air temperature cooling of 0.273°C/day this would result in a 6-day-earlier freeze-back in the fall. Earlier freezing would lead to thicker Bay ice by the time of spring melt. A change in freezing point would also lead to a 6-day lag in spring melt, based on the present temperature increase of 0.291°C/day during the melt period. Combined effects produce a 12-day delay in ice melt. This calculation ignores other factors, such as changes in current and heat-flow patterns, the loss of heat through water diversion, and the elimination of heat exchange with Hudson Bay.

(b) Later sea-ice melt would cool onshore and offshore temperatures and change wind direction frequencies. A 6-day-later ice melt would be the temperature equivalent of moving June 1 to May 25, a 12-day-later melt to May 19, etc. Growing season temperatures would move along the curves in Figure 2, according to the wind frequency changes accompanying later sea-ice melt, as shown in Figure 3.

2. The cooler temperature which results from later sea-ice melt is given by

$$T_m = f(ON)_m T(ON)_m + f(OFF)_m T(OFF)_m \qquad (4)$$

where T_m is air temperature for a specified number of days of later melt, m; and $f(ON)_m$, $f(OFF)_m$, $T(ON)_m$, $T(OFF)_m$ are onshore and offshore wind frequencies and temperatures, respectively, for m derived from Figures 2 and 3.

3. Long-term growing season temperatures, calculated as an average for Moosonee (lat. 51°16') and Churchill (lat. 58°45') for onshore and offshore wind direction frequencies, were used as long-term seasonal averages at Ekwan.

4. Onshore wind frequencies are greater for Churchill than for Moosonee (Rouse et al. 1989). Because Churchill is an open coastal location similar to Ekwan, whereas Moosonee lies 20 km inland and is forested, the differences in frequencies between these stations were weighted 2:1 toward the Churchill values in order to develop the long-term seasonal frequencies shown in Figure 4, which

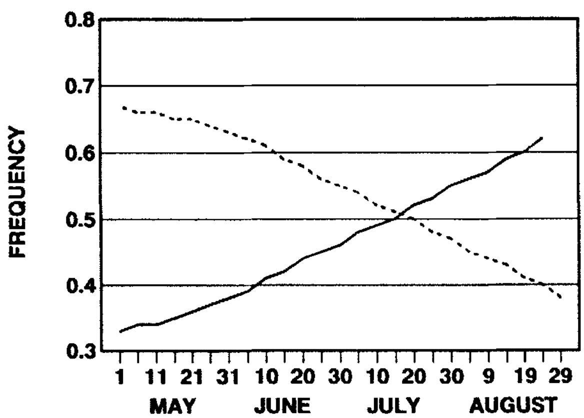

Figure 3
Average calculated onshore (dotted) and offshore (solid) wind frequencies during the growing season

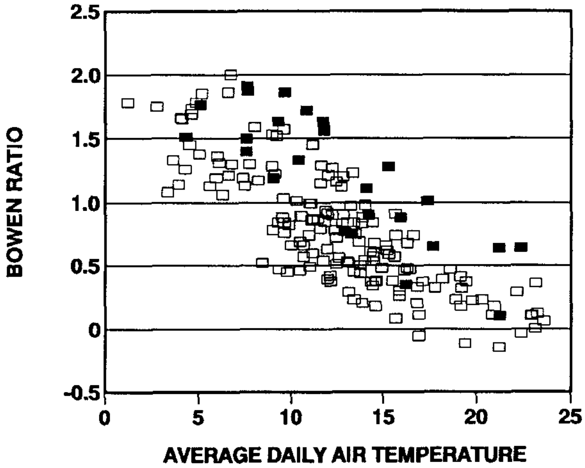

Figure 4
Bowen ratio as a function of air temperature. Solid symbols are Ekwan data and open symbols all the other James Bay and Hudson Bay data

were then applied to Ekwan. This weighting also agrees with the short-term measurements made during the 1988 growing season.

5. Data from southern James Bay and central Hudson Bay showed an empirical relationship between the Bowen ratio, β, and air temperature T (Figure 4) giving the linear relationship (Rouse et al. 1987).

$$\Delta\beta = 1.85 - 0.082\ T$$
$$r^2 = 0.64 \qquad (5)$$

in which r is the coefficient of determination. The Ekwan data have been added to Figure 4. With the exception of the Ekwan measurements, the data are for wet sites of various *Carex* species that were often standing in water.

6. Seasonal average data for $Q^* - Q_G$ combine data from southern James Bay and central Hudson Bay, averaged and presented as running means, in order to represent the long-term average at Ekwan for which no data are available.

7. Daily energy and water balances were calculated using $Q^* - Q_G$ as calculated above and Bowen ratios derived from the regression relationship in (5). Evaporation, E, is calculated as

$$E = Q_E/L\rho \qquad (6)$$

where L is the latent heat of vaporization for water and ρ is the density of water. The water balance, WB, is given by

$$WB = r - E \qquad (7)$$

where daily rainfall, r, is the average of the long-term records for Moosonee and Churchill. In this context WB does not include the soil moisture reservoir. Total water balance for the growing season, WB_{GS}, becomes

$$WB_{GS} = \sum^{n} WB \qquad (8)$$

where n is the number of days in the growing season (June 1 to August 31).

8. Energy and water balances were calculated, using daily totals for ice-melt delays of $m = 1, 2, \ldots, 30$ days.

Results

TEMPERATURE. Figure 5 shows predicted growing season temperatures arising from delayed sea-ice melt. A full 30-day delay leads to a predicted temperature decrease of 7°C. A 12-day delay would result in a 3°C cooling, which is more probable. Cooling would be large in June and early July when plants are growing most rapidly (Figure 6; Kadonaga 1989) and small in August when growth rates are small.

EVAPORATION. Because of the linear functional relationship with temperature, the Bowen ratio (β's) display a mirror image of the temperature plots. Present-day average βs during the growing season are large at 0.86. They are predicted to increase to 1.06, 1.24, and 1.41, with 10, 20, and 30 days delayed melt.

The predicted evaporation decreases by 19, 32, and 44 mm for 10, 20, and 30 days delayed melt. The decrease would be most strongly felt between June 10 and July 25, which at present coincides with the most active

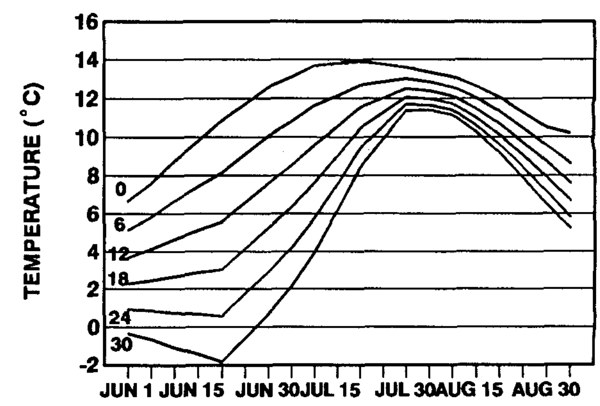

Figure 5
Seasonal temperature changes predicted for 0, 6, 12, 18, 24, and 30 days delay of sea-ice melt

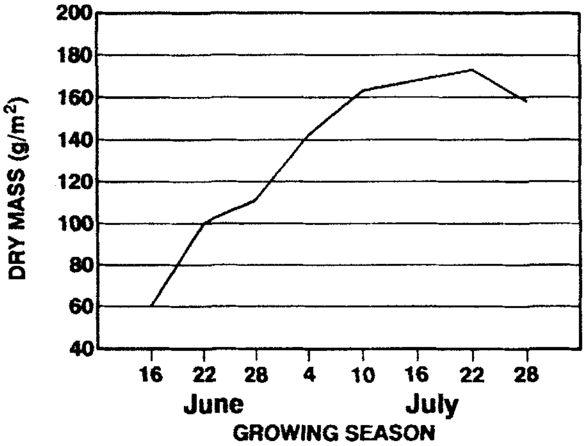

Figure 6
Above-ground dry-matter production of *Carex aquatilis* (after Kadonaga 1988)

part of the growing season (Figure 6).

WATER BALANCE. Figure 7(a) indicates a present-day water surplus of 9 mm. With later sea-ice melt, this would increase by the same amount that the evaporation is decreased. Figure 7(b) shows that seasonally there is a water surplus early in the growing season and a small deficit during the period of most rapid growth. With delayed melt, the former would increase substantially and the latter would disappear or become a surplus. The large surplus that occurs late in the growing season would increase only slightly with delayed melt.

Discussion

The usefulness of the Bowen ratio temperature relationship arises because of physical processes explored in Rouse and Bello (1985), Rouse et al. (1987) and Weick and Rouse (1990a, b). For the same values of $Q^* - Q_G$, vertical lapse rates, $\Delta T/\Delta z$, are greater and the vertical vapour pressure gradients, $\Delta e/\Delta z$, smaller when the atmosphere is cold than when it is warm. Thus in (3), Q_H and ΔT are large and Q_E and Δe are small for a cold atmosphere. The strong correlation shown in (5) indicates that the atmospheric temperature control on β is paramount. That, for the Ekwan experiment, this is occurring over a very dry measurement period, with a falling water table, indicates that transpiration in the stand of *Carex acquatilis* in this environment responds strongly to atmospheric control.

The reduced temperature that would result from later sea-ice melt has other ramifications. Delayed melt of 10 days is predicted to reduce average summer temperature (June, July, august) below that of Churchill. Churchill is underlain by continuous permafrost, as is Cape Henrietta Maria (200 km north of Ekwan Point). It is therefore reasonable to predict that continuous permafrost could readily develop in the Ekwan coastal area. The period of most rapid growth of *Carex acquatilis*, as shown in Figure 6, coincides with the greatest reductions of temperature and evapotranspiration. Undoubtedly later sea-ice melting, colder soil and air temperatures, and continuous permafrost would retard the rate of growth. *Carex acquatilis* would not disappear due to colder temperatures and

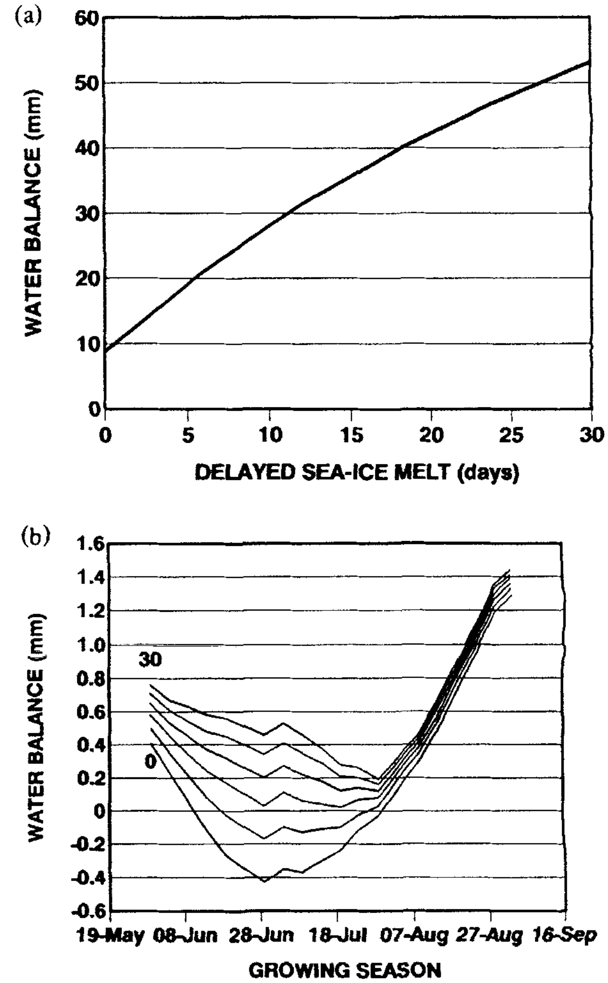

Figure 7
Calculated changes in the water balance due to delayed sea-ice melt showing (a) overall response and (b) seasonal patterns for 0, 6, 12, 18, 24, and 30 days delay of sea-ice melt

wetter conditions, alone, since it is ubiquitous in the north and survives at higher latitudes underlain by permafrost. However, in comparing Hannah Bay and Ekwan (Figure 1), Rouse et al. (1991) maintain the following. 'Species distributions in southern James Bay will be affected more by the anticipated decline in growing season temperatures than by the minimal changes in salinity predicted by the hydrology-salt flux model. Contrastingly, the more saline northern marshes (of northern James Bay) would be expected to undergo a complete replacement of all salt-tolerant species for freshwater taxa adapted to either very wet or even standing water conditions.' The hydrology-salt flux model is the topic of the second paper in this series (Price et al. 1991).

Other ecological responses can be postulated. Larger growth forms, especially trees, would feel the impact strongly and would be influenced by an ecological succession to species better adapted to cold and wet conditions. As a result, one would anticipate a shift of the boreal forest boundary away from the coast in the northwestern part of James Bay.

Conclusion

Damming of James Bay for the GRAND Canal diversion would have a major impact on coastal climate. The freshening of the Bay waters and disruption of the currents would delay spring sea-ice melt for an unknown period. The most likely delay is calculated to be in the order of 12 days. This would decrease temperature, increase Bowen ratios, and suppress evaporation. Water balance calculations show that the present water surplus would increase. The magnitude of these impacts depends on how long sea-ice melt is delayed. Further effects from colder temperatures could include a change in species composition of vegetation, movement of the boreal forest away from the coast, and the development of continuous permafrost.

Acknowledgments

This research was funded through a strategic grant from the Natural Sciences and Engineering Research Council of Canada and was partially supported by Northern Training Grants from the Department of Indian and Northern Affairs. The authors wish to thank Derek Carlson, Steve Hardill, and Lisa Kadonaga for their dedicated field assistance.

References

CLARKE, K.E., MARTINI, I.P., and GLOOSCHENKO, W.A. 1982 'Sedimentary characteristics of the coastal environment of North Point, Ontario' *Le Naturaliste canadien* 109, 385–97

EWING, K., and KERSHAW, K.A. 1986 'Vegetation patterns in James Bay coastal marshes I: Environmental factors on the south coast' *Canadian Journal of Botany* 64, 217–66

GAMBLE, D.J. 1987 'The GRAND Canal scheme: Some observations on research and policy implications' *Proceedings, Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada* (Canadian Water Resources Association) 71–84

GLOOSCHENKO, W.A., and CLARKE, K. 1982 'The salinity of a subarctic salt marsh' *Le Naturaliste canadien* 109, 483–90

HUTTON, C.L.A., and BLACK, W.A. 1975 *Ontario Arctic Watershed* (Ottawa: Environment Canada)

KADONAGA, L.K. 1989 'Stomatal response of *Carex aquatilis* to climate conditions' BASC thesis, McMaster University, Hamilton

KIERANS, T.W. 1987 'Recycled water from the north: The alternative to interbasin diversion' *Proceedings, Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada* (Canadian Water Resources Association) 59–70

PRICE, J.S., and WOO, M.K. 1988 'Studies of a subarctic coastal marsh: II Salinity *Journal of Hydrology* 103, 293–307

PRICE, J.S., WOO, M.K., and MAXWELL, B. 1989 'Salinity of marshes along the James Bay coast, Ontario, Canada *Physical Geography* 10, 1–22

PRICE, J.S., WOO, M.K., and ROUSE, W.R. 1992 'Damming James Bay: II. Impacts on coastal marshes' *The Canadian Geographer* 36

PRINSENBERG, S.J. 1982 'Present and future circulation and salinity in James Bay' *Le Naturaliste canadien* 109, 827–41

PRINSENBERG, S.J. 1983 'Effects of hydroelectric developments on the oceanographic surface parameters of Hudson Bay' *Atmosphere-Ocean* 21, 418–30

ROUSE, W.R. 1991. 'Impacts of Hudson Bay on the terrestrial climate of the Hudson Bay Lowlands' *Arctic and Alpine Research* 23, 24–30

ROUSE, W.R. and BELLO, R.L. 1985 'Impact of Hudson Bay on the energy balance in the Hudson Bay Lowlands and the potential for climatic modification' *Atmosphere-Ocean* 23, 375–92

ROUSE, W.R., HARDILL, S.G., and LAFLEUR, P. 1987 'The energy balance in the coastal environment of James Bay and Hudson Bay during the growing season' *Journal of Climatology* 7, 165–79

ROUSE, W.R., HARDILL, S.G., and SILIS, A. 1989 'Energy balance in the intertidal zone of Hudson Bay: II. Fast ice and floating ice periods and seasonal patterns' *Atmosphere-Ocean* 27, 346–66

ROUSE, W.R., WOO, M.K., KERSHAW, K.A., PRICE, J.S., and EARLE, J.C. 1991. 'Modelling the impacts of impoundment on the coastal marshes of western James Bay' *TASO Research Report* no 32 (Hamilton: McMaster University)

THOMAS, V.G., and PREVETT, J.P. 1982. 'The roles of James and Hudson Bay lowland in the annual cycle of geese' *Le Naturaliste canadien* 109, 913–25

WEICK, E.J., and ROUSE, W.R. 1991a 'Advection in coastal Hudson Bay: I. Surface energy balance' *Arctic and Alpine Research* 23, 328–37

— 1991b 'Advection in coastal Hudson Bay: II. Impact of atmospheric divergence on the energy balance' *Arctic and Alpine Research* 23, 338–48