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DAMMING JAMES BAY: II. IMPACTS ON COASTAL MARSHES

The damming of James Bay as proposed by the GRAND *Canal Scheme will influence the hydrology of the coastal marshes. The salinity regime of two James Bay marshes were compared to understand the processes that govern salinity in the zone near mean high water (*MHW*) and to predict changes that may result from this proposed impoundment. Data suggest that sites along southern James Bay would be minimally affected because of the current low level of salinity. The northern marshes would, however, experience significant changes, as their primary source of salt is from saline tidewater. A simulation of the vertical salt and water fluxes at a northern location predicts a rapid reduction in the chloride concentration at* MHW*, which should approach the present values for southern James Bay in about 10 years. Above* MHW*, the salt will be leached quickly, so that within four years the surface chloride concentration will be reduced to the level currently found in southern James Bay.*

*La construction d'un barrage dans la baie James selon la proposition du projet du Canal Grand influencera l'hydrologie des marais littoraux. La salinitié de deux des marais est comparée afin de comprendre les processus qui gouvernent la salinité dans la zone proche au niveau moyen de l'eau haute (*MHW*) et pour prédire les changements qui pourraient résulter de l'endiguement projetté. Les donnés suggèrent que les sites qui longent le sud de la baie James seraient aujourd'hui peu influencés à cause de la basse salinité de ces eaux. Les marais du nord, par contre, subiraient des changements importants parce que les eaux de la marée saline sont à l'origine de leur salinité. Une simulation du sel vertical et des fluxs d'eau dans un site du nord prévoit une réduction rapide de la concentration chloride à* MHW*. Les résultats seront proches des valeurs du temps présent pour le sud de la baie James dans à peu près dix ans. Au-dessus du* MHW *le sel sera rapidement filtré de telle sorte que dans quatre ans la concentration de la chloride de la surface sera réduit au niveau observé aujourd'hui dans le sud de la baie James.*

The proposed GRAND canal scheme, outlined in Paper 1 of this series (Rouse et al. this issue) involves the damming of James Bay. The large annual freshwater input of 317 km^3 a^{-1} into the Bay (Prinsenberg 1980) will transform it to a freshwater lake. One possible effect is cooling of the local climate due to a longer ice-covered season in the Bay caused by lower water salinity. The current water surplus of 40 mm during the growing season could rise considerably because of reduced evaporation rates. The enhanced vertical leaching of the salt, coupled with lower tide water salinity of the Bay, would alter the present distribution of vegetation.

The objective of this study is to predict the long-term changes in the gross salinity characteristics of marshes in the coastal zone of western James Bay. As the GRAND Canal scheme is a mega-project of a magnitude never before attempted in the littoral zone of the subarctic, prior assessment of the environmental impact is essential.

Study Area

The counterclockwise circulation of waters in James Bay is subject to constant dilution by freshwater input from rivers on its western flank. This is reflected by a gradient in tidewater salinity from 23 g/l in northern James Bay during summer to about 1 g/l in southern James Bay. Two coastal marshes were studied, one on the northwest coast near Ekwan Point (EKP), and one in southern James Bay (SJB) at Hannah Bay. In southern James Bay, relict salt from the postglacial Tyrrell Sea sediments imparts a high salt concentration in the substrate, ranging from 1–2 g/l (Cl) nearthe surface, and 14 g/L at depths of 3–10 m (Price and Woo 1988a). This is the principal source of salt at the surface because tidal inundation is infrequent, and is

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mostly <1 g/l (Cl) (Price and Woo 1988c). Diffusion of this salt toward the surface, coupled with the input of meteoric water, controls the surface salinity pattern in the absence of strong topographic gradients (Price and Woo 1988c). In contrast, northern James Bay marshes have large areas with high surface salinity (Price et al. 1989), which are covered by abundant salt-tolerant plant species.

Seasonal variations of salinity are small where the soil remains saturated (Price and Woo 1988c). This represents a significant portion of the marsh because the fine surface sediments near the coast maintain capillary saturation, while the organic mat that has developed at more inland sites has a higher moisture content. Nevertheless, James Bay marshes studied by Glooschenko and Clarke (1982) exhibit seasonal variation when their surface sediments are subjected to alternating wetting and drying. Price and Woo (1988c) noted seasonal changes in the electrical conductivity in ponded water, and demonstrated that it was a function of the water balance, rather than due to the variability of salt exchanges.

These sites have a regional topographic gradient of 0.001. The intertidal zone rises gradually to the low (0.5–0.6 m), broad, emerged beach ridges formed of reworked sand and silt (Martini 1981), which define the upper limit of this study (Figure 1). At each site, a transect was made perpendicular to the shoreline, from just below mean high water (MHW) to the first beach ridge. Five sampling points were selected along each transect to include different marsh environments – the inter-tidal zone, MHW, a hypersaline zone above MHW, the upper backshore, and the peat-covered first beach ridge (Figure 1).

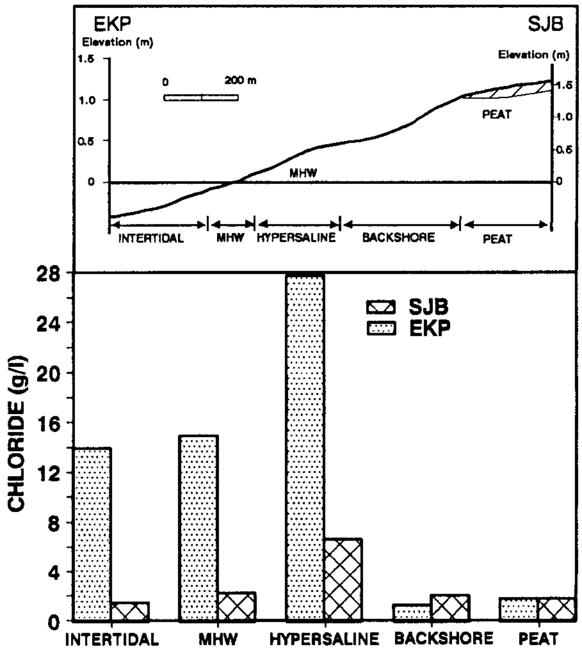

Figure 1

Topographic cross-section along transect (top), and chloride concentration (bottom) at five typical zones along each transect

Methods

At southern James Bay, soil cores were taken in July 1985 with an agricultural sampler, and pore water chloride[1] concentration at 0–0.05, 0.1–0.2, and 0.2–0.3 m depths was determined using a method described in Price et al. (1989). These concentrations were averaged to represent the 0–0.3 m depth range. At Ekwan Point, cores taken during July 1988 were analysed for chloride by this method, except that they were not sectioned as described above. Error analysis on 3 cores of various salinity indicates that the different sampling procedures yielded an error of <1 g/l (total salinity). Gravimetric soil moisture was also determined in the Ekwan Point samples. The intertidal zone chlorinity at Ekwan Point was also sampled from a piezometer slotted between 0.15 and 0.25 m. At Ekwan Point deep sampling was precluded by stony soil. However, a riverbank exposure along nearby Attawapiskat River had a similar facies to that of southern James Bay sediments, with Tyrrell Sea clay at about 3 m depth, compared to about 1.5 m in southern James Bay. At all sites groundwater wells were installed to monitor water table elevation.

Hydrological Processes and Salinity

Before considering the impacts of impoundment of James Bay, processes controlling water and salt flux in these coastal marshes must be understood. All points along a transect perpendicular to the coastline once occupied the MHW zone, and have emerged subsequently. All sites, therefore, once had a vertical chloride distribution similar to that at the present-day MHW. As a site undergoes emergence, it is gradually removed from tidal influence, and it experiences progressively longer periods of surface flushing and leaching by meteoric water. At southern James Bay, tide water is of low salinity, but a balance between upward salt transport by molecular diffusion and leaching by meteoric water has maintained a relatively

[1]Note that unless stated, all concentrations reported here are of chloride, not total salinity, because chloride has unambiguous and unique properties, which must be explicitly defined for modelling purposes.

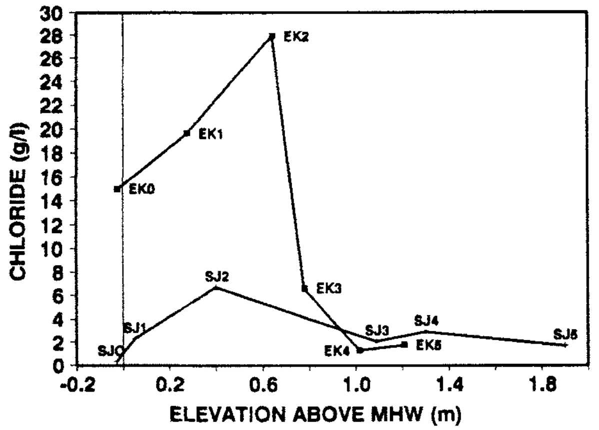

Figure 2
Chloride concentration at specified elevations at the Ekwan Point (EK) and southern James Bay (SJ) sites

uniform salt concentration in the upper 0.3 m of soil. At Ekwan Point, decreasing frequency of saline tide water inundation at a given site has resulted in a strong decline in salinity inland, as surplus water (precipitation excess over evaporation) leaches the salt downward or flushes it from the surface.

At both the Ekwan Point and southern James Bay marshes, there are similar trends of chloride distribution along the transect, except that values at Ekwan Point are much higher (Figures 1 and 2). Chloride concentration in the intertidal zone closely matches average values of local tide water. At MHW, there is a longer drying period between tides than in the intertidal zone, resulting in a slight increase in chloride concentration. The highest chlorinity at both sites occurs in a 'hypersaline zone,' which is at an elevation of 0.4 to 0.7 m above the MHW level (EK2 and SJ2 in Figure 2). The occurrence of this zone is characteristic of all James Bay coastal marshes and is easily recognizable by bare soil interspersed with salt-tolerant vegetation (Price et al. 1988). Based on a probability analysis of James Bay tides (Price et al. 1988), this zone has only a 0.5 to 1% chance of tidal inundation. Thus, the elevated salinities here are not due to salt import by tidal processes. However, the hypersaline zone (EK2 and SJ2) experiences the lowest water table during dry periods because (1) the zone up to and just above MHW is frequently recharged by tide water, and (2) positions inland of the hypersaline zone have developed an organic mat that retains more moisture. The depression in the water table profile causes saline groundwater to flow towards it from both landward and seaward sides (Price 1991). Removal of the stagnant water raises the salinity to the observed values. The backshore zone at both sites represent older (i.e., previously emerged) areas, and have developed an organic mat that is easily flushed by meteoric water, producing relatively low surface chlorinity (<2.2 g/l).

Short-term salinity fluctuations occur throughout the transect, but given the trend of increasing specific yield and moisture content with distance inland, the variation in salinity will decline (Price and Woo 1988c) (though it remains more variable near the coast (Glooschenko and Clarke 1982), where moisture content changes as a result of short-term atmospheric sources and sinks of water rather than variation in the salt flux through that zone (Price and Woo 1988c)). Long-term changes in salinity, however, do result from flux convergence or divergence, so it is important to determine the relative rate of the opposing tendencies operating there: leaching, which removes salt from the rooting zone, and molecular diffusion, which brings salt up from the substrate. These are the basic processes that must be simulated, so that we can predict the time required for a given site to desalinize if James Bay is impounded.

Modelling Impacts of Impoundment

Date from SJB and EKP represent the spatial heterogeneity that is typical of marshes of western James Bay. Short-term variability at a site results from a complex set of processes that are generally well understood (Glooschenko and Clarke 1982; Price and Woo 1988c), but whose data requirements make it impractical for a predictive model. However, the long-term change in gross salinity characteristics can be simulated so that one can obtain a general understanding of the fundamental changes that the marshes will undergo. The most likely operating strategy of the proposed GRAND Canal is to maintain a water level within the present-day tidal range. Impounded water will no longer be tidal, and given the large freshwater input from rivers that drain into James Bay, conversion to fresh water will not take long, at least at the surface of the new reservoir (density gradients may maintain higher bottom water salinities for a longer period).

The vertical salinity profile presently observed near MHW is a function of the rate of salt loss when the sediments were submerged, and this depends on the concentration gradient between the sediments and the Bay water. At southern James Bay, tide water is currently not saline (about 1 g/l), so that freshening of surface water caused by the Grand Canal project will not result in different conditions there. The present salinity profile at southern James Bay (Figure 3) already represents the extreme, and

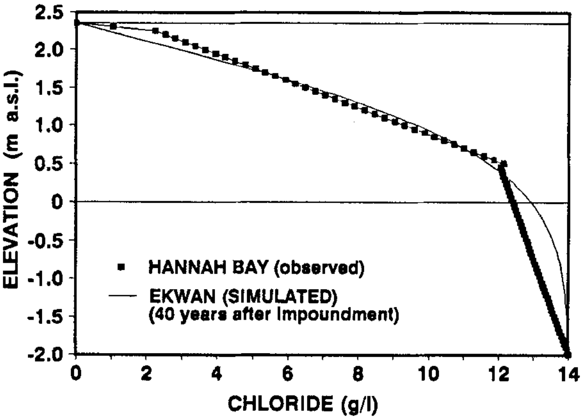

Figure 3
Vertical profile of chloride concentration measured at MHW at southern James Bay (Hannah Bay) and the simulated profile at Ekwan Point (Ekwan) after 40 years, given a starting condition of 14 g/l

other sites will gradually approach this after prolonged salt loss by diffusion.

With reference to the previous discussion, the objective of the model is to determine the time required for an initially saline site (such as Ekwan Point) to attain a condition in which the vertical chloride distribution approaches that of present-day southern James Bay. The model will simulate the vertical distribution of salt (1) at and below MHW, and (2) above MHW, where atmospheric processes must be considered.

Marsh at MHW

The model is a one-dimensional finite difference approximation of the molecular diffusion process. Diffusion is driven by the concentration gradient that will be created when Bay water becomes fresh and overlies sediments containing saline pore water, causing salt to migrate across the sediment surface into the Bay. Boundary conditions for the model can be expressed as follows:

$$C(z, 0) = C_0, \quad z \geq 0 \qquad (2a)$$

$$C(0, t) = 0, \quad t \geq 0 \qquad (2b)$$

$$C(z_m, t) = C_m, \quad t \geq 0 \qquad (2c)$$

where t is time, C is chloride concentration, and C_0 is the initial concentration. Depth (z) for this simulation ranges from 0 (surface) to $z_m = 4.35$ m. These boundary conditions assume (1) some initial concentration must be specified at all depths (2a); an instantaneous change to, and maintenance of, fresh water at the surface (2b); and steady concentration at some point deep enough not to be affected during the period of simulation (2c). The initial condition is assumed to be the present chloride concentration near MHW at the Ekwan site. Simulation will continue until the modelled chloride profile approximates the SJB condition.

Core retrieval at Ekwan was incomplete due to stoniness below 1 m, so the sampled chloride profile is also incomplete. Values for various depths and locations (Table 1) indicate 14 g/l (Cl) is typical. Depressed values (8 g/l) at 2.0 m for nearby locations may have been affected by local freshwater discharge from a creek (Price et al. 1989, 4). The problem of spatial variability is recognized, and further data would be valuable in assessing the range. However, commonly occurring concentrations of approximately 14 g/l (Cl) will be used as a first approximation of the chloride concentration in the vertical profile near MHW at Ekwan Point.

Table 1
Typical chloride concentrations for MHW at Ekwan

Location	Depth (m)	Cl (g/l)
Tyrrell sea sediments*	3–10	14
Ekwan MHW	0.15–0.25	15
Ekwan tides (average)	0	14
Near Ekwan†	0.75–1.25	17
Near Ekwan†	2	8

*Sample from SJB
†Data from Price et al.

The diffusion proces is simulated with a finite difference approximation of Fick's second law:

$$dC/dt = D^*(d^2C/dz^2) \qquad (3)$$

Where D^* is the molecular diffusion coefficient of chloride in a porous medium. A value of 7×10^{-10} m^2 s^{-1} was found to be satisfactory by Price and Woo (1988c).

Results (Figure 3) indicate that a good fit to the southern James Bay MHW chloride profile is achieved after 40 years. Thus, 40 years after impoundment, the model predicts that the MHW location at Ekwan Point will reach a condition similar to that which presently exists at southern James Bay. Perhaps more importantly, chloride *concentration* at a depth of 0–0.3 m is predicted to decrease exponentially, so that at MHW the full effect of lowered salinity will be felt by the vegetation within 10 years (Figure 4).

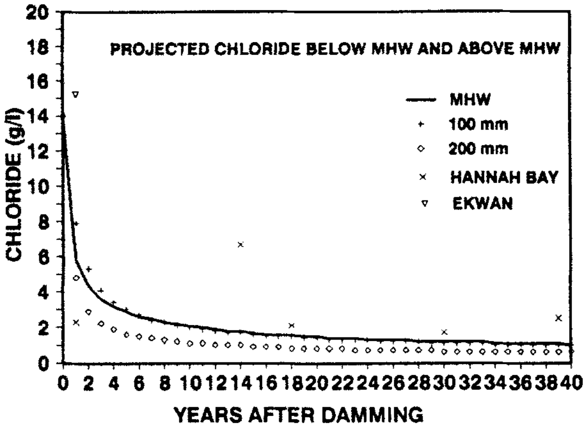

Figure 4
Chloride concentration in the 0–0.3 m zone: Predicted value at MHW (——), predicted value above MHW with *P-E* of 100 mm (+) and 200 mm (◇). Also shown are measured concentration values at southern James Bay (x) and Ekwan Point (∇), plotted at the estimated time since the sites were at MHW.

Marsh above MHW

At Ekwan Point sites above MHW (excluding the hypersaline zone), measured surface concentration ranged between 14 and 20 g/l, and declined with depth to about 8 g/l at 2 m (Price et al. 1989). For simplicity, the same initial condition of 14 g/l was selected. Soil conditions above MHW at Ekwan Point will likely remain at or near saturation, so the same diffusion coefficient was assumed. However, the constant zero-salinity upper boundary condition [eq. 2b] cannot be used. As there is no ponded water to receive the upwardly transported salts as in the previous simulation, a Neumann-type boundary condition (no flux) was employed (Wang and Anderson 1982). Furthermore, periodic recharge by rainfall reduces surface salinity over time. To represent this process, various levels of precipitation excess (*r-E*) were applied by assuming plug flow displacement in the 0–0.3 m zone occurred for 6 months in each year (during the other 6 months precipitation falls as snow and the meltwater runs off over the frozen soil with negligible infiltration). The depth of *r-E* was distributed evenly over this 6-month period by dividing the amount into equal portions for each iterative cycle (18 days) in the numerical model. This amount was expressed as a percentage of the soil water in the 0.3 m column, and directly replaced an equivalent amount of soil water at ambient chlorinity with fresh water. Results of the simulation show that with only 100 mm of precipitation excess, sediments at 0–0.3 m will experience a rapid decline in chlorinity (Figure 4).

The results of both simulations indicate a rapid change toward a less saline marsh environment under a cooler, wetter climate (Rouse et al., this issue), with a nontidal freshwater James Bay. The processes occurring at and below MHW, where freshwater will inundate the surface, are appropriately represented by the model. That the model indicates 40 years are required to produce a vertical chloride distribution similar to that at SJB is less important than the rapid change in the upper 0.3 m in terms of the ecological consequences. Above MHW, where there will be no further addition of salt by tidal action, the model crudely represents the leaching processes by displacing saline pore water, and this induces a concentration gradient, thus upward diffusion. The model clearly indicates that diffusion will not be able to sustain present-day salinity near the surface when relatively small amounts of freshwater are added. Given the rapidity of the predicted change in both zones, the spatial variation of the initial (i.e., present) chloride concentration becomes only a technical point and has little influence on the outcome. The magnitude of the changes predicted here are general rather than absolute, and provide an approximation of the scope of the change.

With a decline in rooting zone salinity, significant vegetation changes may occur at the Ekwan site (Earle et al. submitted), with a shift from halophytic *Puccinellia* and *Plantago spp.*, to salt-intolerant *Eleocharis, Juncus,* and *Potentilla* spp. However, the short-term variability not accounted for by the model may result in salinity peaks incompatible with salt-intolerant species. Furthermore, rooting zone salinity during the critical germination period cannot be predicted. While short-term fluctuations will be superimposed onto the general trends predicted here, their ecological consequences are less certain.

Conclusions

Coastal marshes of southern James Bay experience upward diffusion of relict salt from Tyrrell Sea sediments but weakly brackish tidal water maintains surface sediments at a low salinity. Over the short to medium term, damming James Bay with freshwater will have no noticeable consequences with respect to the time average soil salinity there, as the marsh salinity is already adjusted to an equivalent situation. At more northerly locations where offshore water is currently more saline, tidal inundation of the MHW zone controls its salinity, and the Tyrrell Sea salt influence is currently negligible. A change to freshwater will directly impact the MHW zone, as salt will begin to diffuse out of the sediments in response to the concentration gradient thus created. The response in the rooting zone will be very rapid, and salinity will match that at the southern James Bay site within 10 years. At sites above MHW, infiltrating rainwater will leach out the salt, so the salinity in the rooting zone will decline even more rapidly, probably matching that of southern James Bay in a shorter time. This will lead to a change in the marsh vegetation and the ecology of the coastal zone.

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'CANADA'S ALL RIGHT': THE LIVES AND LOYALTIES OF IMMIGRANT FAMILIES IN A TORONTO SUBURB, 1900–1945

Before World War II, many immigrant workers in North America lived in industrial and residential suburbs. The early history of a residential suburb of Toronto, Ontario, shows that, initially, homes were modest and public services were absent. Men worked long hours, commuted far and built the family home. Women strove hard to keep house and raise a family in unserviced homes. Children helped out, and played in the accessible bush. Self-provisioning was common, and early opportunities to acquire homes and establish businesses were good. Community-building created a strong neighbourhood identity. At first, settlers felt loyal to Britain, compared their experience with the situation back home, and concluded that Canada was 'all right.' The Depression brought working-class loyalties to the fore and prompted many to become more critical of the Canadian status quo. This

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