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TERRAIN STUDIES IN THE JAMES BAY DEVELOPMENT AREA

by

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TERRAIN STUDIES IN THE JAMES BAY DEVELOPMENT AREA

INTRODUCTION

The James Bay Development Corporation plans to develop hydo-electric power in a vast region east of James Bay, principally in the drainage basin of La Grande River (Fig. 1). This project, La Grande Complex, will eventually include the diversion of the headwaters of the Great Whale (Grande Baleine), Eastmain and Koksoak Rivers into La Grande River along which several dams will be constructed[1].

When a river is dammed for hydroelectricity, both permanent and short term changes occur in the river's character. Because a river's geomorphology and biology are, in part, a function of its hydrology it seems almost axiomatic that a change in the latter will lead to alteration in the former. Two inescapable consequences of dam construction are that they regulate flow in the river's lower courses and trap sediment in the newly created reservoirs. In addition, during construction and reservoir filling, sudden changes often occur in flow and sediment régimes, triggering geomorphological and biological changes that may or may not be permanent.

The present La Grande River is relatively clean. Like most Canadian rivers it exeriences a spring flood and a late winter drop in flow. Discharge measurements of the Lower La Grande are available from 1960 (Station #92704 of Quebec Hydrological Services). Figure 2 shows a mean monthly hydrograph for Station #92704, about 20 miles from La Grande's mouth. The highest recorded discharge is 237,000 cfs (May, 1973); the lowest is 11,800 cfs (April, 1965). The mean annual discharge is about 61,000 cfs. Apart from the spring peak flow peaks often occur from August to October.

Although the development plans are not yet final, based on volume 2 of the report the drainage area will be increased from 37,850 to 64,290 square miles and the proposed post-construction discharge at LG-2 (see Fig. 1) will be 110,000 cfs year round. Discussion of the repercussions of hydroelectric development must be based on this discharge.

In 1973 the Geological Survey of Canada carried out terrain investigations in La Grande basin including the following:

a) An assessment of the sediments and sedimentary processes of La Grande River downstream from the proposed LG-1 dam including study of the types and rates of erosion of bed and banks, the nature and distribution of sediment, and the nature and rate of sediment movement with particular emphasis on the immediate vicinity of Fort George in order to predict what changes, if any, will occur along this stretch of the river as a result of hydroelectric development.

b) A study of the relationship of sediment and vegetation of Goose Bay, a small bay and marsh and convenient goose hunting area 5 miles north of Fort George and the mouth of La Grande River. This phase of the project was in response to wildlife specialists' concern that vegetation in and around Goose Bay is controlled by sediment derived from La Grande River and that a change in the sediment régime of La Grande would affect vegetation and consequently geese habitats in the Goose Bay area. This study included a reconnaissance of part of James Bay's east coast to assess the distribution of eel grass with respect to sediment and coastal geomorphology.

c) Surficial geology mapping along La Grande River to the proposed LG-2 Reservoir (Fig. 1) and south along the new highway route to Eastmain River Crossing. This phase was carried out by J.S. Vincent. The objectives are to provide basic impact and terrain data along principal development corridors. Resulting maps at a scale of 1:50,000, with surficial geology as a base,

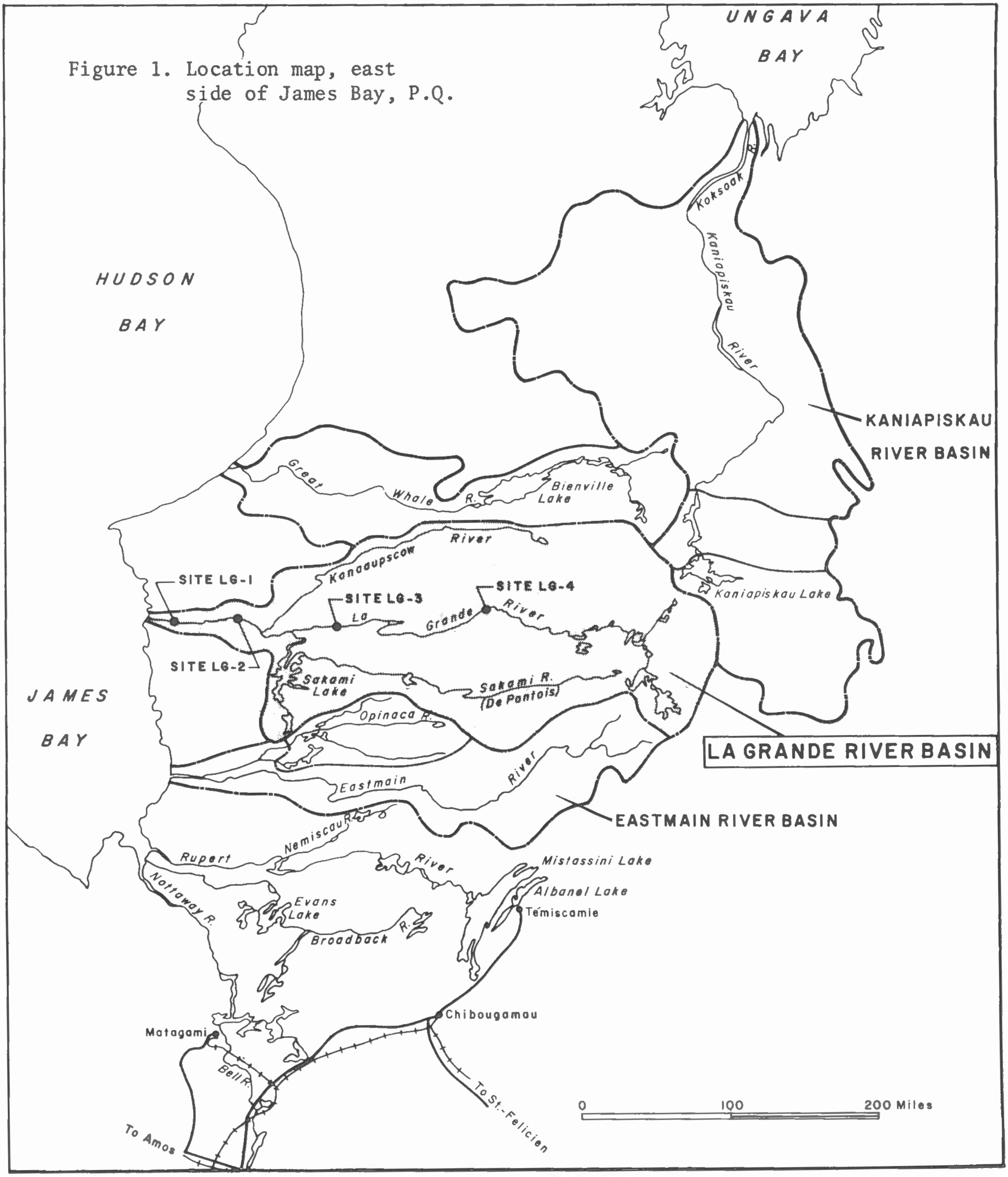


Figure 1. Location map, east side of James Bay, P.Q.

illustrate a variety of land use information including terrain unsuitable for transportation, sources of aggregate, permafrost features, and hazardous areas. These types of data are useful not only as an adjunct to smaller scale biophysical mapping programs but can be used as a basis for impact statements and terrain-use planning.

This report is organized into three parts dealing with each of the above sub-programs. Discussion of possible effects and a series of conclusions and recommendations are presented at the end of the report.

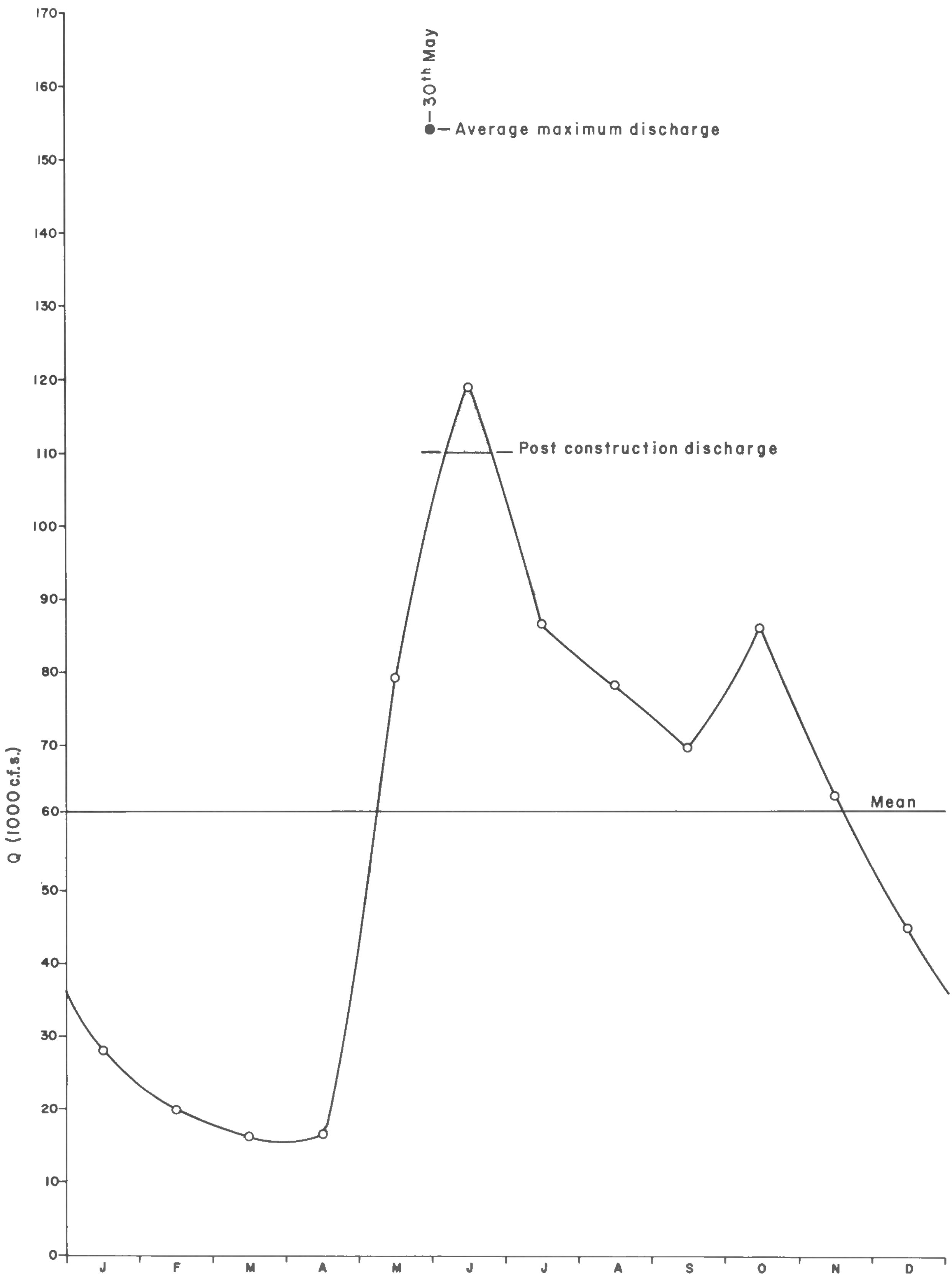


Figure 2. Mean monthly discharge, La Grande River, 1960-1973

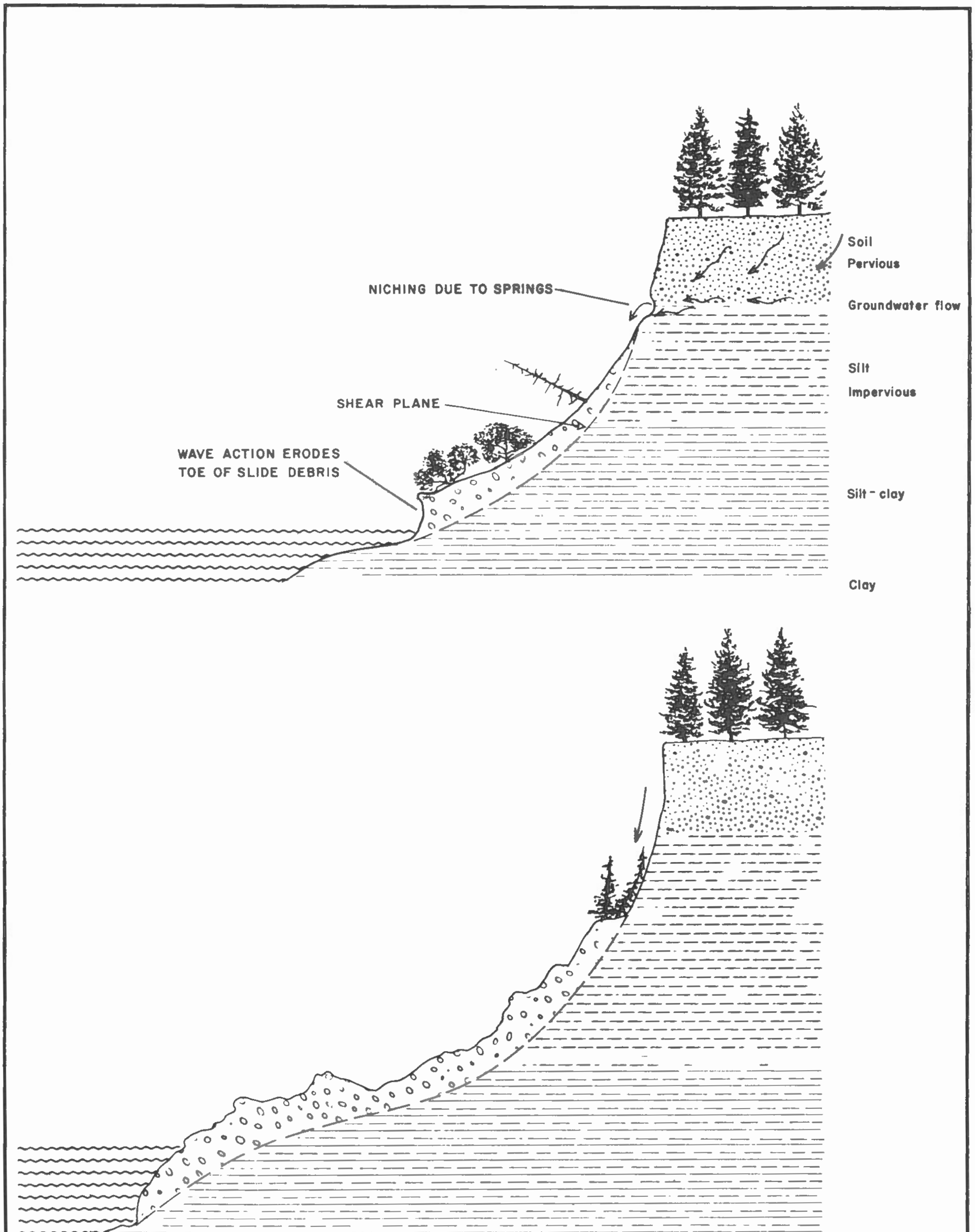


Figure 4. Bank erosion processes.

EROSION AND DEPOSITION ALONG LOWER LA GRANDE RIVER

Introduction

Various forms of erosion and deposition presently characterize lower La Grande River. Under new hydrologic conditions many of these geomorphic processes will differ in force and distribution. In order to predict what might happen it is essential to have at least an overview of the present fluvial geomorphology. Therefore, geomorphic features and processes were delineated on a 'dynamics' map (Fig. 3 in pocket). Most of the following discussion centres around this map.

Field work was carried out between July 16 and August 9, 1973. River banks and sand bars were examined from canoe, motor tricycle, and to a lesser degree, helicopter. Steel rods and wooden pickets were used to monitor bedform movement as well as to establish bank-erosion monitoring stations. The nature and distribution of bank materials and their relative stability were mapped. Historical markers were sought in an attempt to ascertain rates of bank retreat on Governor Island where Fort George is located.

The distribution of erosional and depositional processes along the lower La Grande is both a consequence and a continuation of these processes in the past. For about 7,600 years, since the last continental glacier retreated from this area, the land has slowly rebounded from the glacier's weight. Initially the Tyrrell Sea (ancient Hudson Bay) extended many miles inland and as the land rose the sea gradually retreated to its present position while the river formed sandy deltas at successively lower shore levels. Silt and then clay were deposited further out to sea. As sea level fell the river was forced to cut into its older deltaic sands, reworking them into new bars and spits on top of silt, and to re-activate silt deposited on the clay. Hence the present-day sandy delta surface is the equivalent of the sand facies seen capping the river bank all along La Grande. Abandoned, raised distributary channels occur along La Grande, analogues of the channels around Fort George and Governor Islands. As the river cuts deeper through the sand into its older deposits it encounters the silt facies, then clay. This relationship is illustrated on the inset, Figure 3. As will be shown, the distribution of erosional processes is a function of the degree to which the river has cut into this older sand-silt-clay stratigraphy.

Erosional Processes

At least four types of erosion were observed along La Grande River: wave, current, wind, and ice. Contributing to erosion by these means is mass movement, including retrogressive mud flows of sensitive marine clays, land slides, slumps or sloughs and particle creep; and frost action such as solifluction, diurnal frost wedging, icing, etc.

The distribution of erosional features along La Grande downstream from LG-1 is illustrated on Figure 3. Most erosion seems concentrated on the south bank of the river which is steeper than the north. The north shore commonly has a veneer of cobbles and slopes gradually up through an alder-covered floodplain.

Wave action, the most important process during the free-flow period, acts all along the southern, windward bank, but is most effective around Fort George Island where the sand facies is exposed at water level. The constant wave action through the tidal cycle over 3 or 4 feet of section results in steady erosion of the non-cohesive sands. Erosion of the sands is greatest where the bank is directly exposed to the longest fetch of waves and where the river current impinges against the bank. As the river level fluctuates with the tide the water table is left hanging and springs issuing from the sands aid erosion by piping and spalling the sand from the bank. Early in the summer when water levels are high the bank takes the full force of current and waves. Later, erosion is reduced because the beach at the toe of the bank and bars in the channel tend to dissipate some of the wave energy.

Further upstream where silt is exposed at water level, wave erosion is not as important in directly removing the bank; slumping of banks into the river provides sediment that is sufficiently disaggregated to be more easily removed by current and wave action.

Based on observations of slumps in various stages along this part of the river the following general sequence of erosional events is postulated (see Fig. 4). Starting with a debris-covered slope, wave and current action gradually remove the toe of the slide area while the porous debris further up the slope becomes saturated due to the impervious nature of the shear plane. Through rapid slumps, gullying and solifluction this mass of debris is gradually cleaned off the slope. Eventually, or before the face is cleared of old debris, a niche develops along the sand face where springs discharge because downward groundwater flow is impeded by the finer sediments. Soon the section, including the upper terrace sands, slumps, covering the whole slip surface with fresh, porous debris. Although there certainly are variations to this sequence it does explain in general the process of bank retreat observed along this middle reach of lower La Grande River.

In at least one locality along this reach of the river marine stratigraphy plays an important role in bank failure (Fig. 5). The section comprises 10 to 12 feet of coarse terrace sand overlying 6 to 10 feet of massive, saturated, grey odoriferous clayey silt that is very plastic at the base where it overlies three feet of extremely wet grey medium sand with a one-inch thick layer of organic debris and silt at the base. Beneath the organic zone the section grades from massive grey fine sand into fossiliferous clayey silt for about 30 feet to river level. The massive odoriferous silt is very wet and unstable and spalls off easily. In fact when cleared of debris with a shovel, a six-inch niche formed at the base of the unit within half an hour. The grey medium sand overlying the thin compact organic layer contains so much water that it too liquefies rapidly and a niche quickly forms. The alternating sand and silt sequence is responsible for much of the instability here. The coarser units act as aquifers; the finer units and especially the organic layer at the base of the lower sandy unit are impermeable, resulting in saturation and complete loss of strength to the overlying coarse units which erode back, undermining the section. The upper part of the section fails and slides to river level, wave action removes it, the lower silty part of the section becomes highly saturated and gradually slides, flows and slumps into the river. Debris on the surface of the lower silty-clay part of the section becomes dried and hardened. Water percolating through the coarser, upper part of this debris apparently builds up at the base of this dried crust of colluvium causing it to slide and flow when stepped on, jarred, or when wave action undermines the toe of the debris. In other areas it appears that vegetation growing on the debris helps retain water in this surface crust of debris; eventually the debris uncouples from the slope and slides down into the river. Whether there is a preferred time of year for slumping is unknown, but certainly during the spring melt and the fall rains there is an abundance of moisture to aid in this process.

Marine clay outcrops at river level further upstream toward LG-1 and between LG-1 and 2. Besides slumps and slides typical further downstream, there is a different type of mass-movement known as the retrogressive flow slide. This penomenon results from liquefaction of the lower silt-clay facies. These flows have all the characteristics of flows occurring in marine clays of the Ottawa - St. Lawrence Valleys. The retrogressive flow slide

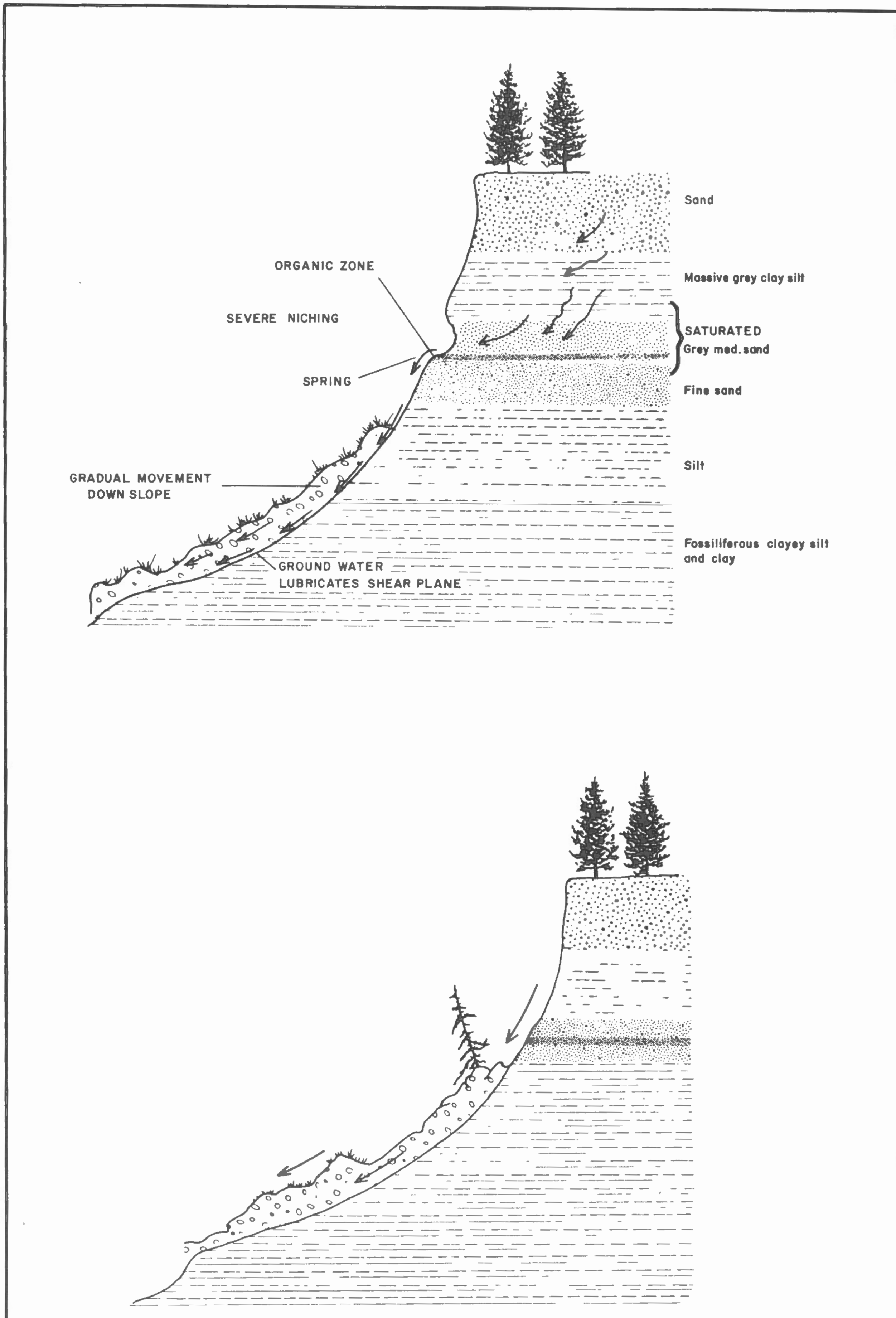


Figure 5. Stratigraphy of a slump-prone section.

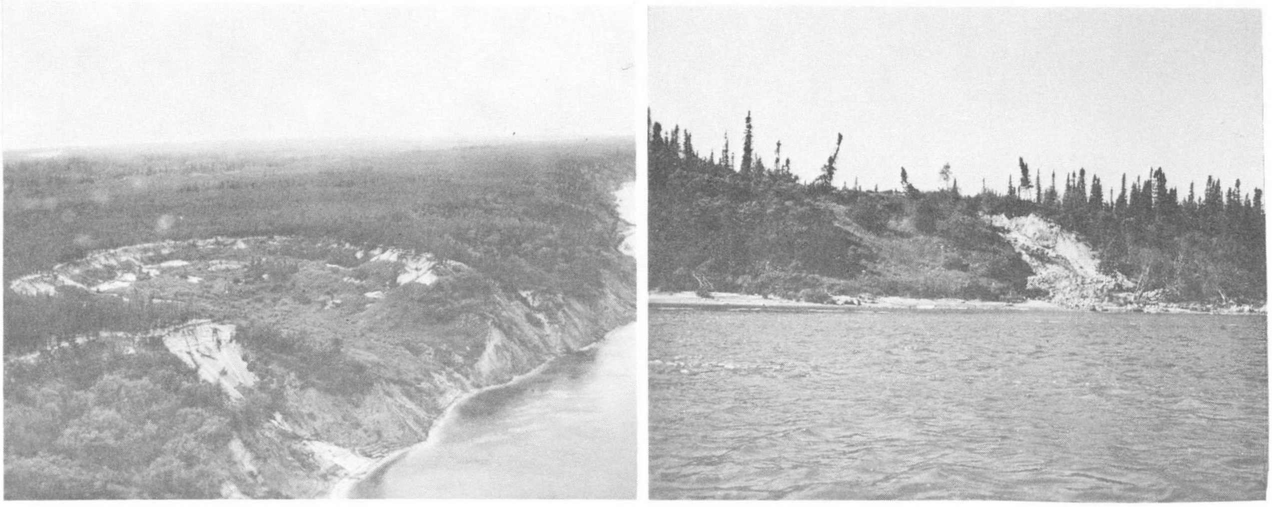


Figure 6. Retrogressive flow slide. (Geol. Surv. Can. photos 201915-F, left and 201915-V, right)

with its distinctive, crater-like, arcuate form, containing parallel, linear slump blocks is found on the north bank of the first island just downstream from LG-1 rapids (Fig. 6). Older flows are more common between LG-1 and 2, where the clay facies is exposed, especially between Longitudes 78°00' and 78°30' West. Basically, the lower silty-clay is in a 'sensitive' state likened to a 'house of cards'. It is believed that if pore-water pressure is increased the 'cards' or silt-clay fragments come apart and the silty clay behaves as a liquid. Often when this happens, blocks of overlying less 'sensitive' strata subside and are tilted and rafted on the fluid mud. The bank slumps back in successive blocks in a concentric pattern until stability, albeit temporary, is attained.

Erosion by wind is confined to a few areas of deflation on old beaches and on the downstream end of Fort George Island. Evidence of ice erosion, most significant during breakup, occurs on the upstream heads of islands and on low, alder-covered banks. Mounds of ice-transported sand and debris and toppled trees occur on the top of a 30-foot bank at the head of the first small island upstream from Fort George Island, attesting to the vertical extent and force of ice action.

In summary, there is a transition of erosional processes along the lower La Grande River which is controlled by the stratigraphy above river level. Wave erosion is very important, especially in sandy areas such as Fort George and Goat Islands. River current contributes to erosion at high discharge where it impinges on the unprotected sandy banks. Further upstream, landslides generated by a combination of many interrelated factors including groundwater, stratigraphy, vegetation, aspect (north-facing) and frost action make sediment available for transport by the river.

Rates of Erosion

Rates of bank retreat in the mouth area were estimated for selected locations by comparing low level areal photographs taken 15 years apart[2]. Estimates of the amount of erosion between 1954 and 1969 are shown on Figures 3 and 7. The concave bank paralleling the airstrip in the south arm of the river eroded at least 100 feet over the fifteen year period. Corresponding accretion of sand and vegetation is evident on the opposite, convex bank. Already, gullying has reached the side of the strip and unless remedial measures are taken the strip will erode away, perhaps faster than at the natural rate because of the absence of vegetation. A series of poles was placed along the ploughed field west of St. Joseph Mission in 1960-1961 (Fig. 7). On a 1972 areal photograph (scale 1:4,000, Q-72838), all are standing; in 1973, several were toppled into the river, attesting to a year of unusually bad erosion reported by local residents. Very high water levels (highest recorded discharge) and high winds were important factors resulting in severe wave action along the sandy banks.

Based on these few observations it appears that in the Fort George area retreat of long sections of the bank proceeds at about three to five feet a year but in any one year this average can be exceeded and perhaps doubled. Further upstream bank retreat is sporadic; the bank may be eroded back 30 or more feet in one event. In the area of flow slides, many acres can be removed in one event although the length of bank affected may be relatively short.

Sediment Movement

During the 1973 field season sand bars in La Grande's mouth were surveyed and sampled in an attempt to detect any trends in grain size or bed-forms that would help explain the sedimentological character of the river mouth.

It is likely that the peak sediment loads correspond with highest discharge in spring when the river's eroding and transporting ability is greatest and when mass movement processes are most actively supplying sediment.

The spring flood and associated high sediment discharge were not observed although evidence of this event was noted on the north side of the sand plain on the downstream end of Fort George Island. There, kettled sand dunes of coarse to very coarse sand and locally very fine gravel are distributed over an area that is only partially flooded during highest summer tide and then the currents are not strong enough to carry coarse sand and gravel. This 'kettled' area (Fig. 8) is typified by disconnected, isolated mounds of very coarse sand with seaward dipping primary bedding. Mounds of sand were also found on vegetated, relatively stable areas higher on the sand plain. Eye-witness reports indicate that break-up first occurs along the north shore of Fort George Island. This would be encouraged by uncoupling and weakening of the ice cover along the shore due to tidal action. A lead probably develops here and is subject to jamming at its downstream end resulting in flooding over the ice. Sediment-laden flood water spreads out over grounded ice on the sand plain. Later, once the ice melts, all that remains are the irregular, kettled mounds of sand.

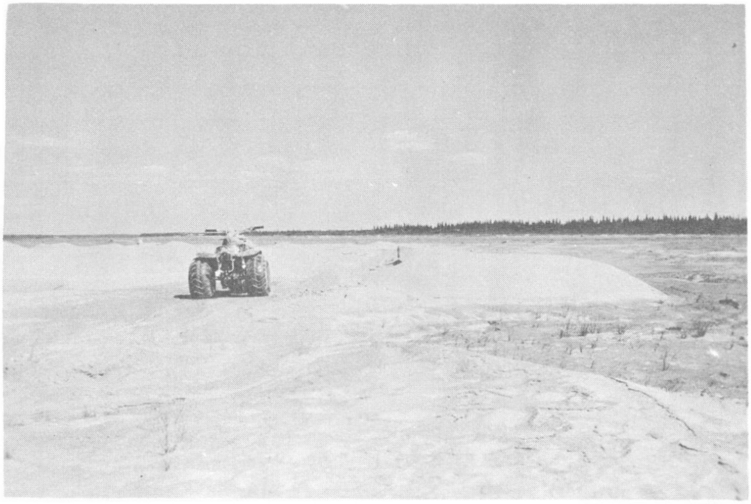
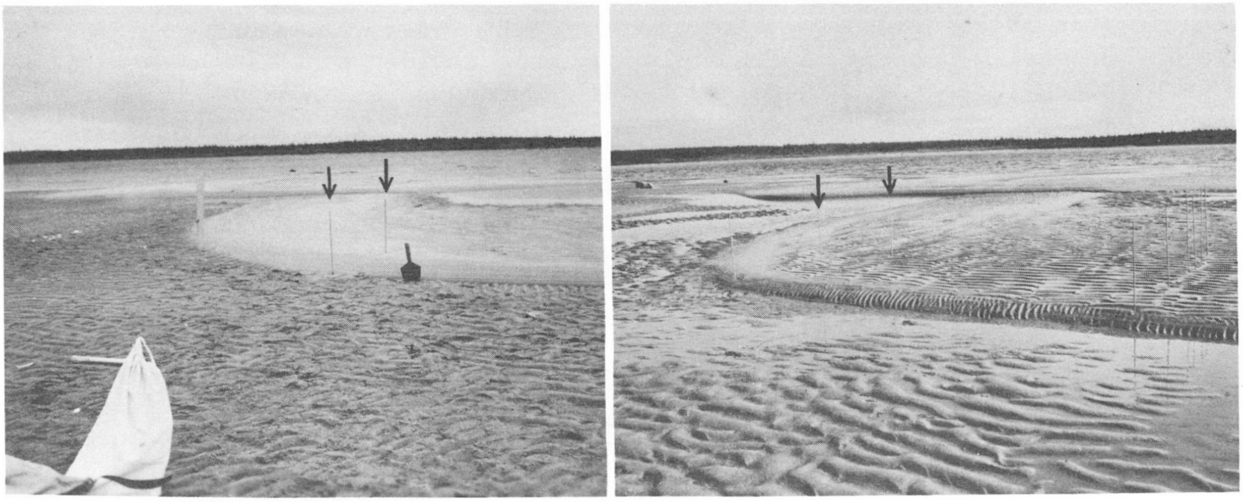


Figure 8. Kettled area, Fort George Island sand flat. (Geol. Surv. Can. photo 202278)



July 17, 1973, 0730 hours. Emplacement of steel rods. (Geol. Surv. Can. photo 201915-O)

August 8, 1973, 0800 hours (low tide). Toe of slip face of dune moved about 30 inches. (Geol. Surv. Can. photo 202278-S)

Figure 9. Migration of a current-generated dune on river bar out from Fort George, Québec.

As discharge decreases, as occurred through the observation period, suspended sediment transport diminishes as judged by the gradual clearing of the water. It is probable that net bed load transport decreases as well. Once the discharge drops to the point where sand bars are exposed at low tide, bed load movement on these areas is confined to the turn of high tide and early ebb tidal periods. Movement of a current-generated dune on the upstream end of a relatively low sand bar out from St. Joseph Mission was monitored for 22 days (July 16 - August 8, 1973). Steel rods ($\frac{1}{4}$" diam.) were inserted along the toe of the slip face, on the crest of and towards the upstream edge of the dune (Fig. 9). The level of the sand surface was recorded on the rods, the sand surface movement monitored, photographs taken and new rods placed as the dune migrated.

The dune moved a total distance of 75 cm (Fig. 9 A, B). The average rate of migration for the slip face was about 3.4 cm/day or 1.7 cm per tidal cycle. Stakes inserted at the toe of the migrating slip face during this period hinted that the rates of migration changed. Although the data are few, apparently the rate increased when tides (which control depth) were lower and the ebb flow (velocity) higher even though discharge was falling. Figure 10 illustrates these relationships. Essentially, during lowest tides, the difference in elevation between the sand bed and sea level is greatest and the river reduces this difference by scouring its bed. At high flood tide and very low discharge it is conceivable that flow in the river mouth is in an upstream direction. Hence as discharge decreases, sediment movement in the mouth becomes periodic contributing to a build-up of bars and islands.

Other processes contribute to the accumulation of sand in the mouth and help account for the pattern and characteristics of the sand bars. The river mouth is best described as an estuarine delta. Distributary channels are separated by intertidal sand bars and flats. Waves acting on the sand modify sand dunes formed by the above-mentioned current action. Hence, the windward perimeters of bars are beached with low-crested wave-formed dunes. This outer rim of dunes encloses a lower, central, rippled sand plain that is relatively stable during the summer, receiving only a mantle or 'skin' of silt and fine sand from suspended load. Current-generated dunes appear to be confined to the lower flanks and the upstream ends of bars and to small interbar channels (Fig. 11).

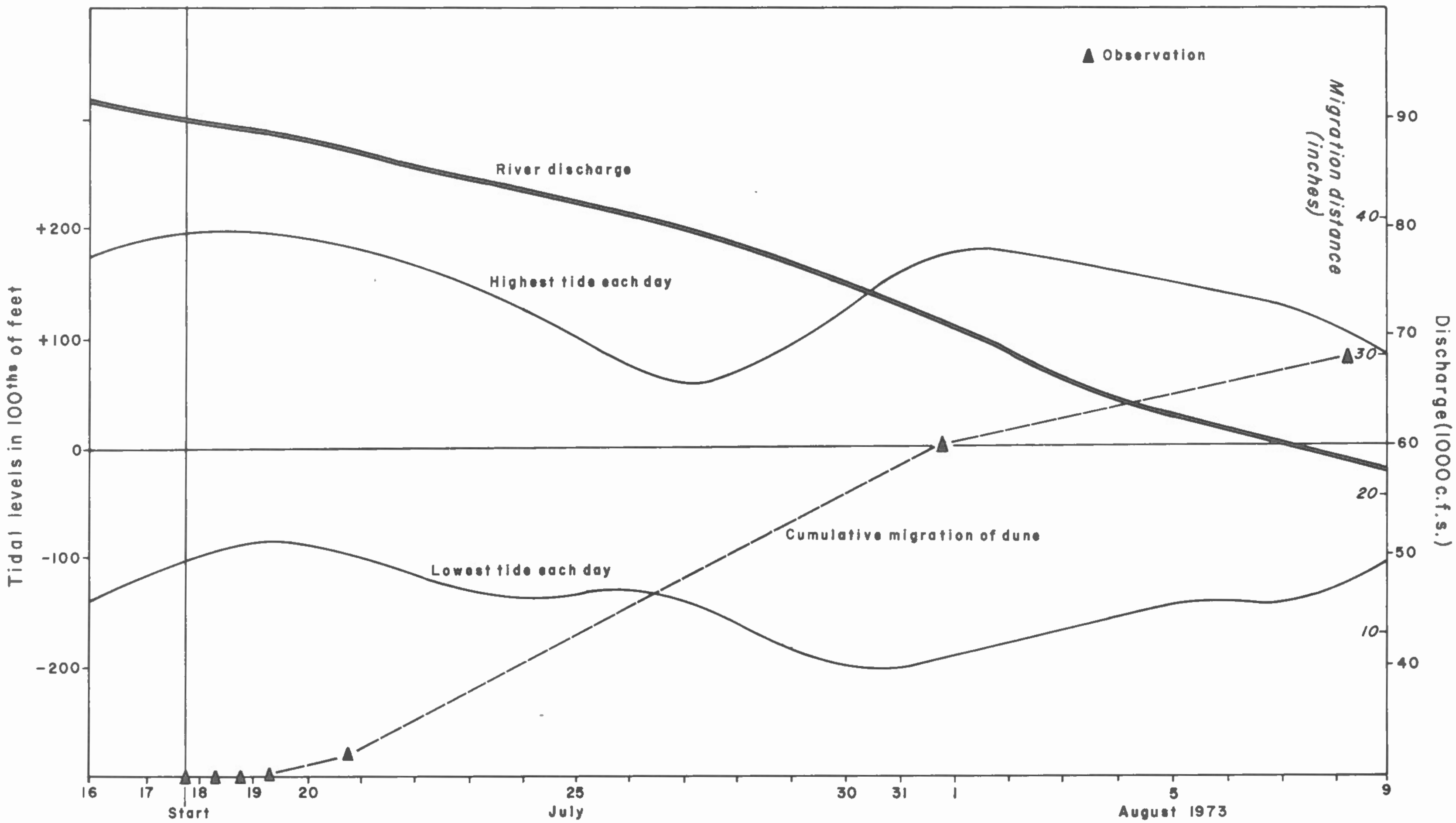
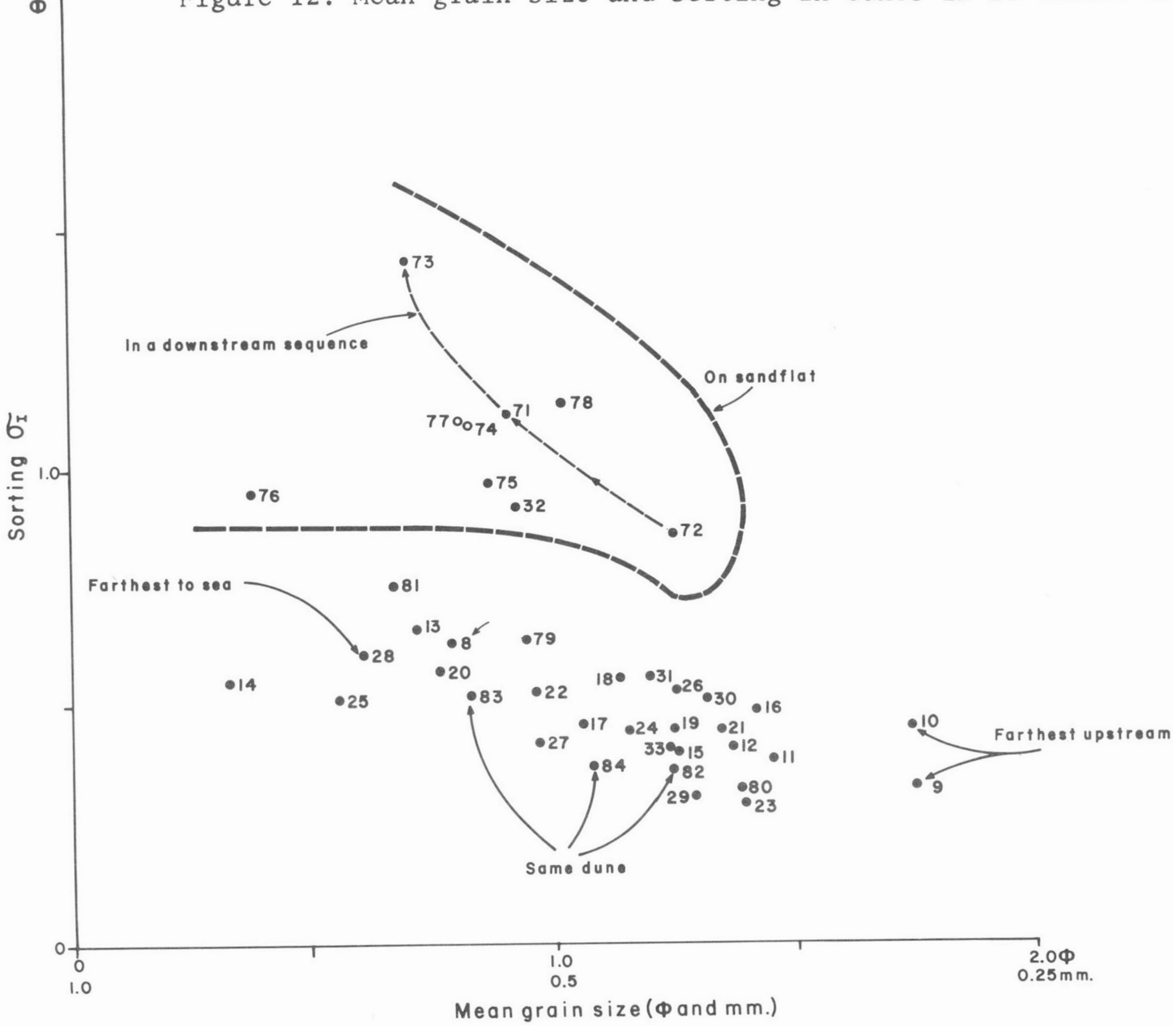


Figure 10. Relationship of discharge, tides and dune migration.

Figure 11. Current-generated dunes, St. Joseph bar. (Geol. Surv. Can. photo 202278-B)

Figure 12 shows the distribution of mean grain size and sorting of 40 samples from the crests of dunes on bars in La Grande mouth (Fig. 13) without regard to probable origin. In general, grain size increases and sorting decreases toward James Bay. Sample 8, farthest upstream ($M_z = .80\phi$; $\sigma_I = .64\phi$) is relatively coarse-grained which is perhaps explained by its location on the upstream (higher current energy) edge of the bar. Similarly sample 14 was taken on a current-generated dune on the upstream edge of the 'St. Joseph bar' (Figs. 11, 13). Samples 82, 83 and 84 were

Figure 12. Mean grain size and sorting in dunes in La Grande mouth.



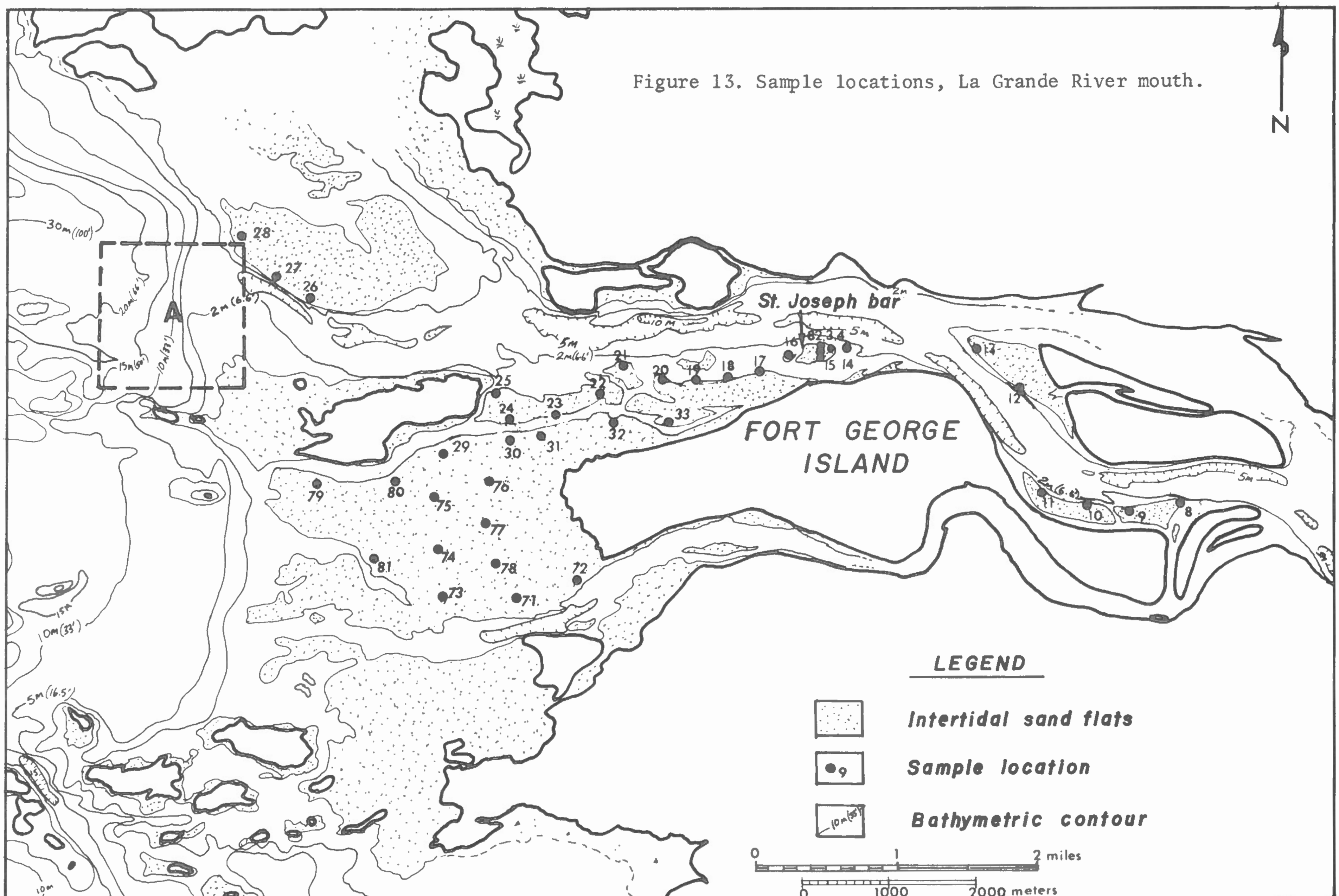


Figure 13. Sample locations, La Grande River mouth.

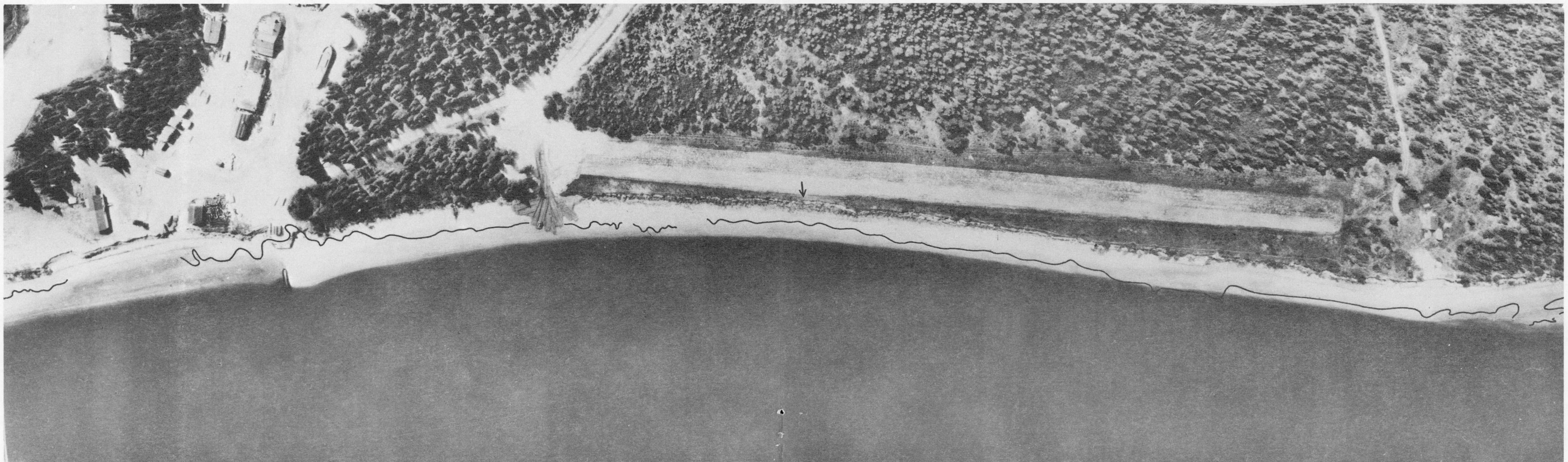


Figure 7. Erosion, St. Joseph Mission, Fort George Island, 1954 - July 1972. The solid line marks the approximate position of the bank in 1954. Note fenceposts between the bank and the airstrip, some of which had fallen by 1973. (Min. des Terres et Forêts de Québec, photo Q-72838-63)

taken from the same dune on this bar (monitored for 22 days) and display considerable variation in grain size emphasizing that only gross trends should be considered from these data.

Samples from the sandflat on the seaward tip of Fort George Island are characterized by poor sorting and relatively coarse size. This is thought to reflect the many processes active on this part of the delta. As noted earlier, this is an area of spring flood when abundant sediment of wide size range is delivered. Wind, ice-rafting, and to a lesser degree, wave action each produces a grain size mode which when combined results in poor sorting. A silt component is present in this area in the form of silt skins. Remnant skins have been observed buried by wind-blown and water-laid sand and in sparsely vegetated and protected parts of the sand flat. Wind tends to remove this silt as it dries, cracks and crumples. On dry windy days silt and sand can be seen blowing across the sand flat, concentrating behind pieces of debris and ice-rafted boulders or building up in accumulations held by 'goose grass' (Agropyron sp.). One of these areas of wind-blown sand accumulation had a relief of about ten feet.

Although some fine sediment is deposited on flood plains, and the coarse sand accumulates on bars and the edges of islands in the mouth, much sediment is carried out to sea as suspended load which drops to the ocean bottom, particularly on the delta front. A rough estimate was made of the rate of growth of part of this delta front. Figure 13 shows the bottom topography off the mouth and the general outline of the delta. Area A on 1961 and 1972 bathymetric charts was selected for measurement and comparison. The 1961 data are relatively few and scattered but an operator from that project put the positioning accuracy to within ±100 feet (John O'Shea, pers. comm.). Figure 14 illustrates the area versus height relationship for the 2 chart years. From this the volume of sediment between 1961 and 1972 was calculated as a little over 1,250 x 10^6 cubic feet. Using a figure of 7.0

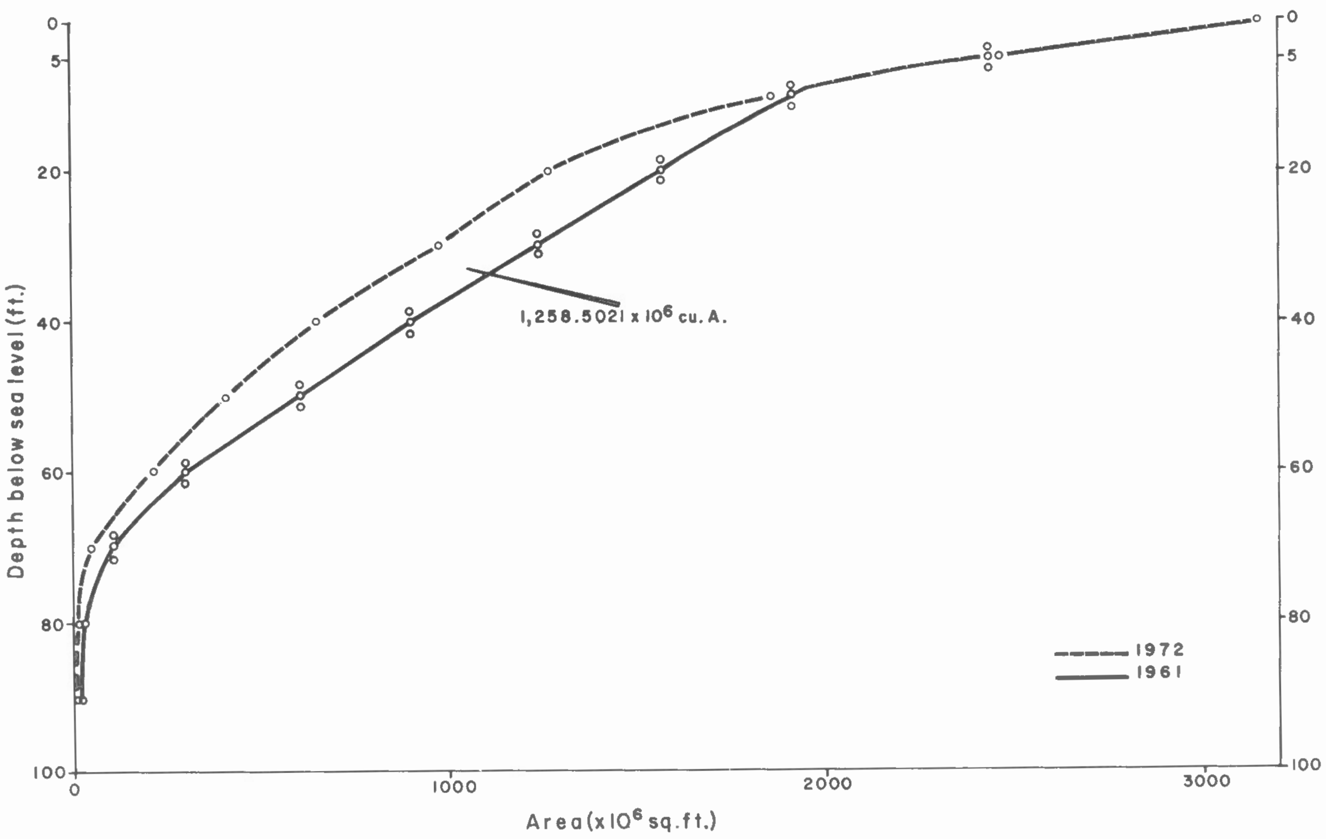


Figure 14. Hypsographic curves, La Grande River delta, 1961 and 1972.

lb./cu. ft. for submerged sand, silt and clay[4] this works out to about 4×10^6 tons of sediment per year deposited on area A. This part of the delta front is off the main channel so presumably receives the most sediment and therefore progrades most quickly. Contours along this part of the delta on the 1972 chart indicate a relatively steep cone of sediment just off the main channel, suggesting relatively rapid accumulation. The figure, 4×10^6 tons/year, does not apply across the whole delta front. Also, this sediment represents unknown portions of suspended and bed loads so cannot be used to estimate total sediment loads for La Grande.

The above estimate could be off by as much as 100% but the important point is that it gives some relative impression of sediment load. Even if the total annual load is 10×10^6 tons it still does not approach the loads of many other major North American Rivers. For example, the Colorado with twice the drainage area but about the same peak discharge used to carry 180×10^6 tons; the Missouri, 200×10^6 and the Mississippi 700×10^6 tons a year. The Fraser River carries 25 to 30×10^6 tons a year[5] and the Mackenzie River about the same (C.P. Lewis, pers. comm., 1974). Despite their turbidity, the Fraser and Mackenzie are considered clean rivers. La Grande River is apparently a much cleaner river than the Fraser. Calculations of sediment load, based on discharge and suspended sediment load measurements at the nearest upstream gauging station, should be done by qualified people when sufficient data are available. In addition, analyses of sediment load of portions of La Grande's plume in James Bay should be done at various discharge levels. Salinity, veolocity and temperature determinations should be made at the same time.

Summary

The nature and rate of sediment movement in La Grande mouth are complex. Fine sediment is trapped on flood plains, in small channels between islands where flow decreases, but mainly is distributed at sea. In some intertidal areas of the main channel downstream movement of sand due to current is later countered by beach drift which tends to move the same sand back upstream. In other areas, sand apparently moves downstream only when a critical water depth is attained, such as towards the end of ebb-tide. This discontinuous and ratchet-like sediment movement leads to bar-formation and shoaling around the river mouth.

SEDIMENTOLOGY OF GOOSE BAY AND SOME GEOBOTANICAL FEATURES OF THE EAST COAST OF JAMES BAY

Goose Bay

Introduction

Goose Bay is situated about five miles north of the mouth of La Grande River. Personnel of the Canadian Wildlife Service report that Goose Bay and Dead Duck Bay (15 miles south of Fort George) are important staging grounds for geese during the spring and fall migrations. Apparently the marshy meadows of the former and the abundant sub-tidal aquatic plant, "eel grass" of the latter offer attractive forage to geese, at least during the fall migration. Because these bays are located near the mouth of La Grande River, concern was expressed over the possible effect on sediment-nutrient supply in these bays due to hydroelectric construction on La Grande. The objectives of this summer's field work were (a) to gather an overview impression of the nature of sediment movement in Goose Bay, (b) to examine the relationship between sedimentological processes and flora, and (c) to make general predictions as to the effect of hydroelectric construction on the bay and foreshore marsh of Goose Bay and on other bays such as Dead Duck Bay.

Areal photographs and observations and ground traverses including sampling and trenching were carried out. During lowest tide, August 3, 1973, 33 samples were taken on the tidal flat in order to detect any trends in grain size. During the field season liaison was maintained with Canadian Wildlife Service botanists studying the flora of Goose Bay.

This section summarizes the 1973 observations and offers some preliminary impressions concerning the dynamics of sediment in Goose Bay and the eventual effect of hydroelectric construction on the bay and on eel grass in bays along the coast, in general.

Description and Observation

Goose Bay consists of an outer, subtidal bay with the Guillaume River entering from the northeast corner, and an inner, intertidal bay surrounded by grassy meadows. Extensive meadows to the east are crossed by three small creeks that diffuse before reaching the tidal flat. Drumlinoid, boulder-mantled shoals form a natural sill between the inner and outer bays (Fig. 15). The bays are oriented west-north-west parallel to the regional structure. The outer bay is bounded on the north and south by two bedrock ridges that jut out into the sea. Topographic maps indicate that part of the outer bay is intertidal; however, this area did not emerge completely during low tides in early August. At low tide the depth of water is less than 10 feet in the outer bay.

Boulders are scattered on the surface of the tidal flat and bay bottom. They are most abundant in the eastern extremity of the inner bay toward high tide limit and, of course, on the drumlinoid points between the bays. In some bays around the perimeter of Goose Bay and in other bays, there is a zone of boulder-free mud or sand-flat at or above high tide limit. Around the mouth of the Guillaume River there are flats of rippled sand with scattered boulders. The muddier portion of the inner bay contains many depressions where ice pans were grounded and either melted or were re-mobilized. There is abundant evidence of ice-push in the form of long linear grooves terminated by large boulders and mounds of boulders, mud and sand, mantled with this year's settling of mud. The stratigraphy in the base of an ice-pan depression adjacent to an outcrop in the inner bay comprises an upper 5 to 10 centimeters of soft, horizontally laminated sand

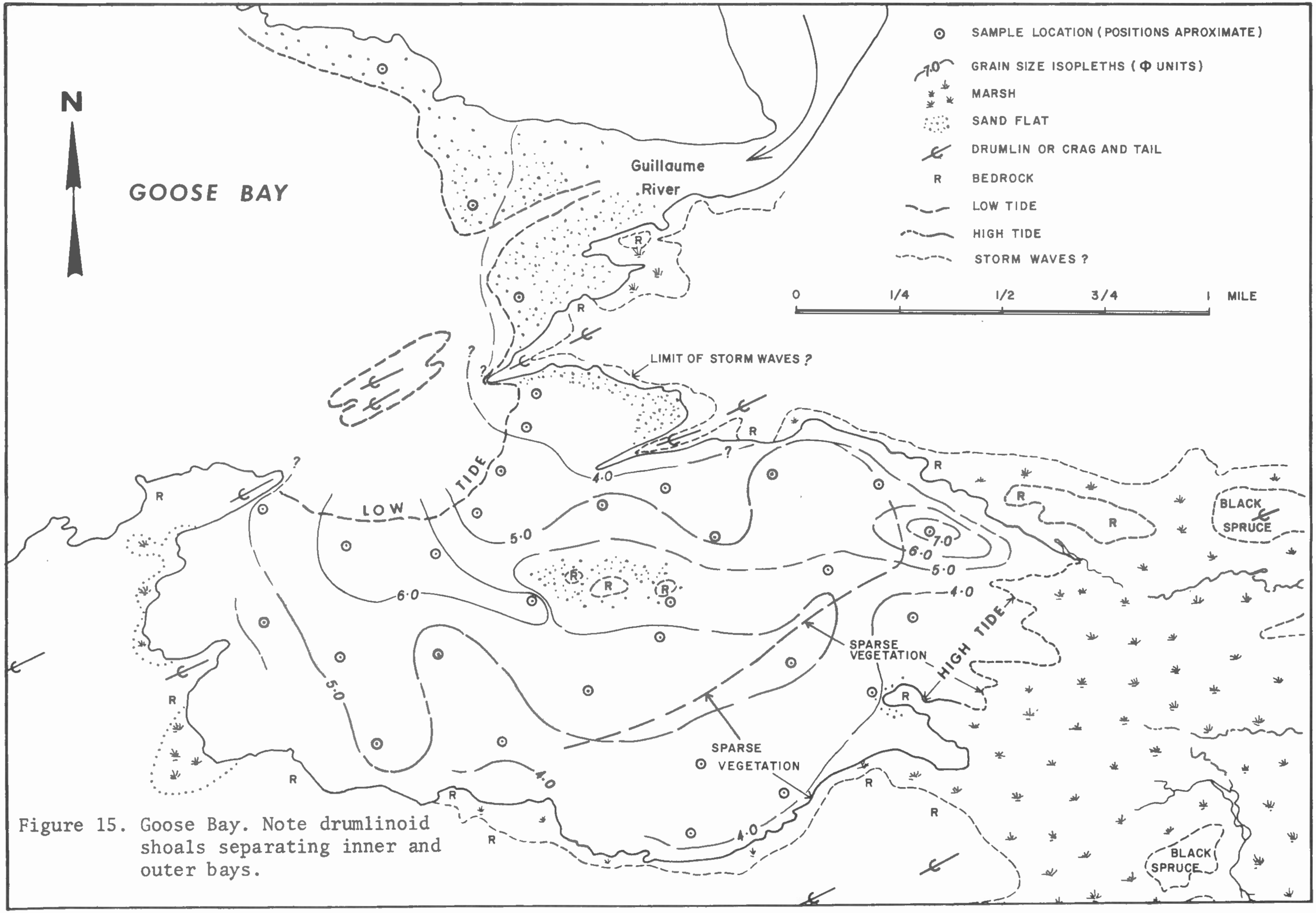
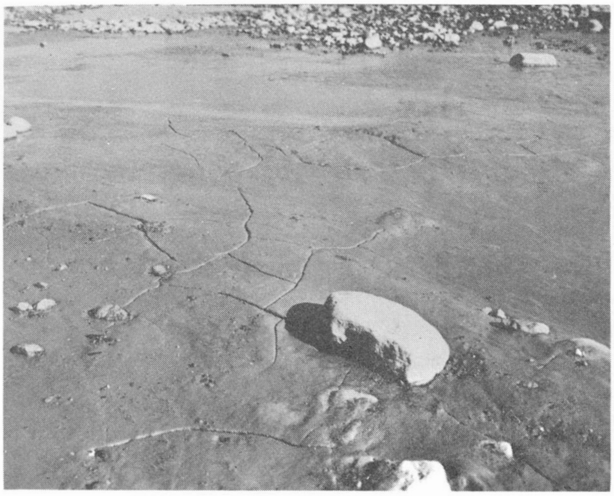


Figure 15. Goose Bay. Note drumlinoid shoals separating inner and outer bays.



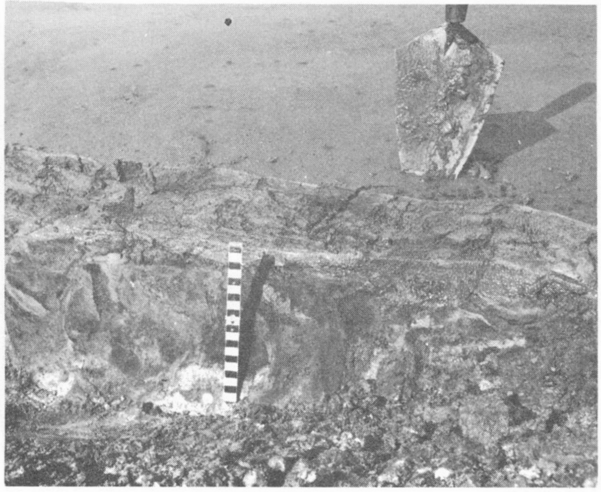


Figure 16A. Ice-pan depression and mud cracks. (Geol. Surv. Can. photo 202278-E)

Figure 16B. Stratigraphy of ice-pan depression. (Geol. Surv. Can. photo 1-3-73)

overlying compact, contorted sandy mud (Fig. 16). The soft upper layer represents the net accumulation since the depression was last occupied by ice. That was probably spring 1973 which indicates a very high rate of sedimentation locally; however, one should not extrapolate this rate over several years because the soft sediment is reworked throughout the summer, during the autumn storms, and over the winter drift-ice period. The very compact, highly contorted sediment underlying the soft mud would not easily be reworked by water but ice would likely scrape it up, especially if boulders were imbedded in the ice. It is probable that sediment spends several years in transit in the bay before it becomes permanently compacted in the bottom. The net effect of these processes would be to smooth out any trends that are solely a reflection of sediment supply. Grain size analyses of 33 samples of soft mud from ice-pan depressions indicate that grain size decreases away from the mouth of the Guillaume River and away from drumlin islands and points (Fig. 15).

Sources of Sediment

Possible sources of sediment to Goose Bay include La Grande River _via_ James Bay, the shores of Goose Bay, and tributary streams into Goose Bay. During the 1973 observations, no great influx of sediment from any of these sources was observed. It is believed that the annual period of major sediment supply had already occurred in the spring. The only sediment movement observed was due to wave action reworking the soft muddy bottom sediment into suspension which was carried back and forth in the bay with the tide. Figure 17 illustrates sediment streaming out of the bay with ebb-tide. It is unknown whether there is a net outflow of sediment in the bay although sediment probably settles out on the inner, vegetated parts of the tidal flat, especially at the turn of high tide.

Figure 18 shows the Guillaume's clear, brownish freshwater plume at flood tide in late summer looping back into the inner bay. If this plume contained sediment, some would be deposited in the inner bay. It is believed that the Guillaume River carries abundant silt and clay during the spring flood and that this amount, anomalous for rivers of its size along the east coast of James Bay, may be due to its basin's location in the fine-grained facies of ancient stages of La Grande delta. The silt-mantled basin is an excellent source of mud to the Guillaume River, the major sediment supplier to Goose Bay. Because of its situation with respect to

Figure 17. Ebb tide, Goose Bay. (Geol. Surv. Can. photo 201915-G)

Figure 18. Guillaume River plume entering from right. (Geol. Surv. Can. photo 202278-D)

La Grande River, the Guillaume has developed a geomorphology unlike that of rivers of comparable size along the east coast. It meanders in a deeply incised, well defined flood plain covered with Equisetum and alder bushes (Alnus), both considered to be pioneer species able to grow and regenerate in such a hostile environment.

The modern La Grande is probably not as important as the Guillaume although ERTS photos reveal that La Grande's sediment plume passes in front of and therefore probably enters, Goose Bay. The absence of extensive beaches and mud-choked embayments along the south shore of Goose Bay indicates that a large volume of sediment is not now coming from La Grande into Goose Bay and would,in any case, probably be masked by the abundant sediment from the Guillaume.

The general pattern of sedimentologic and geomorphic processes appears to be: a) a large influx of sediment from the Guillaume river during spring, associated with b) the grounding of ice-pans and the consequent disturbance and mixing of sediment, and the rafting of cobbles and boulders followed by c) the ice-free period during which wave and tidal action rework and move fine-grained sediment back and forth between the inner and outer bays and away from wave-washed areas.

Phytogeography

As noted above, Goose Bay's muddy tidal flats are surrounded by grassy marshes, thinning where they meet the tidal flat. On the mud flat, the rims of ice-pan depressions, at most one foot higher than the bottom of depressions, are the first areas colonized by vegetation (Triglochin palustris, Potamogeton sp., and algae). Closer to high tide limit these plants occur in depressions as well and additional species grow on the higher areas. The pattern of rims and depressions becomes less distinct as the soft muddy layer thickens. Apparently the vegetation helps trap sediment in this high tide zone.

Near and above high tide limit, a few elongate relic ice-pan depressions exist, devoid of vegetation or nearly so. It appears that some of the deeper depressions, once above high tide, are self-perpetuating. During winter, standing water in them freezes right to the bottom killing any vegetation that may have taken root in the bottom during summer. One summer is insufficient time for plants to permanently colonize the depression and the depression is too shallow to prevent winter-kill. Sediment no longer reaches these depressions and they slowly fill in by vegetation encroaching from the edges.

Consequently, the action of floating ice on the tidal flat results in a micromorphology that controls the pattern of vegetation, for a while at least, once the tidal flat emerges above high tide. In time a hydrosere relationship is set up; the halophytic vegetation gives way to freshwater species, including the sedges, then mosses, then assemblages of willow and larch, larch and black spruce to pure black spruce. Where the gradient is steeper, and there is no standing surface fresh water, as on the flanks of the drumlin points, Triglochin palustris and Potamogeton sp. are joined by T. maritima, Festuca rubra (a grass), Potentilla anserina, Hippuris tetraphylla (tidal limit) then a tall grass (Agropyron sp.) common in windblown sands of the area, mixed with a low vine of the pea family (Lathyrus sp.), and wild phlox (Epilobium angustifolium)[6].

Summary

It appears that the initial vegetation patterns in Goose Bay are a function of micromorphology and position relative to high tide. Only in the grossest sense does grain size appear to control vegetation and that is, as indicated, on the better-drained, sandier supratidal flanks of drumlin points. Isostatic uplift apparently is the critical factor in raising the mud-flat above the influences of salt water and high sediment flux. Above high tide, vegetation flourishes.

Based on these limited observations it is tentatively concluded that sediment from La Grande River does not play a major role in the vegetational sequence of Goose Bay and that hydroelectric development of La Grande will not seriously affect the sediment budget of Goose Bay. Goose Bay is considered by the author to be a harsh environment by virtue of the high sediment flux resulting in substrate instability and therefore poor for development of vegetation. If anything, a decrease in sediment to Goose Bay would be beneficial.

East Coast, James Bay

Introduction

On August 4, 1973, a reconnaissance flight was made to Paint Hills 50 miles south of Fort George in order to view the distribution of mobile sedimentary features and the general geobotanical features of bays and river mouths along this part of the coast. The following discussion summarizes this reconnaissance survey and examines some of the factors controlling growth of eel grass.

Factors Affecting the Distribution of Eel Grass (Zostera marina)

Figure 19 indicates areas of eel grass and the location of sand beaches and spits. It is not surprising that deposits of mobile sediment should occur near river mouths. Eel grass was absent near river mouths and very abundant in bays which no significant streams entered. It is not yet possible to say how large a stream must be to preclude the growth of eel grass in the area of its mouth. Some indication is given in Dead Duck Bay which is entered by two small streams, yet eel grass occurred in great abundance in the outer, shallower subtidal parts of the bay, suggesting that these streams are not so large as to prevent eel grass growth. Larger streams like the Beaver (Rivière au Castor) and Maquatua have no eel grass near their mouths.

Eel grass apparently does not grow on the western side of James

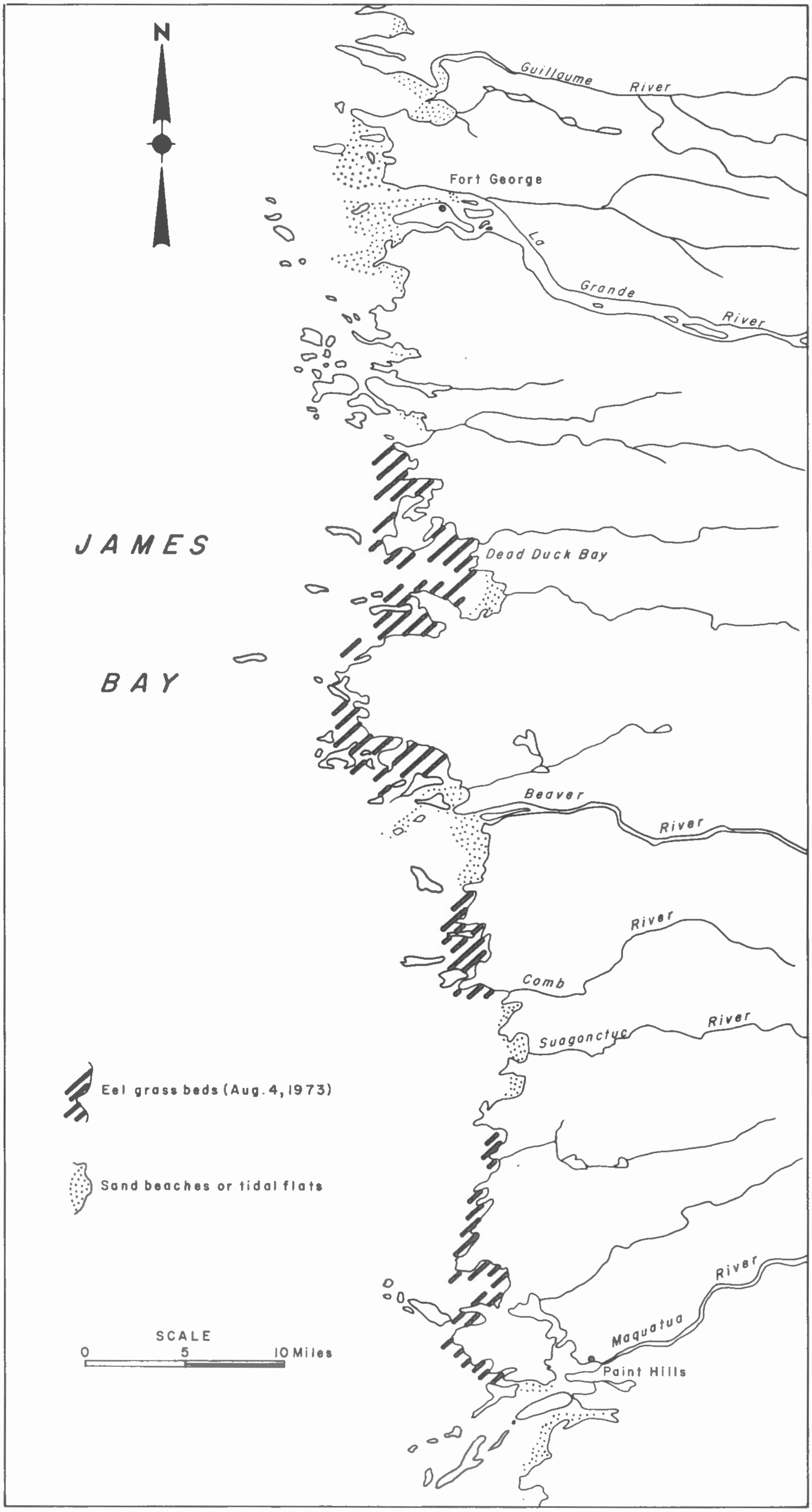


Figure 19. Eel grass distribution, east coast of James Bay.

Bay except on intertidal shoals around Akimiski Island[7]. ERTS linage E-874-15492-5, August 1, 1974, shows plumes of sediment, presumably reworked by waves and tidal action, around Akimiski Island. It appears that turbidity alone does not prevent eel grass growth.

In a comprehensive study in Alaska, McRoy[8] revealed that "temperature is of prime importance to the growth and morphology of eel grass." According to data from McRoy's study (p. 146) eel grass thrives in water temperatures of 10 to 20^{o}C. Furthermore, no evidence was found that temperatures around 30^{o}C destroy eel grass. Temperature determinations in the small bays along James Bay are not available but temperatures in James Bay may exceed 10^{o}C[9]. The highest temperature recorded in 1973 in La Grande River mouth was 21^{o}C on August 19th, in fresh-water (B. Kidd, D.O.E. pers. comm., 1974). Besides temperature, salinity certainly controls eel grass growth. Other factors such as depth, wave energy, and nature of substrate help determine the distribution of eel grass.

Summary

There are no eel grass beds within 10 miles of the mouth of La Grande River. Although the waters would be relatively warm in this area, they would also be turbid and have a low salinity; it seems therefore that more than temperature controls eel grass growth along the east coast of James Bay. Based on the absence of eel grass around the mouth of La Grande River, it appears that the river has some control on eel grass, and therefore a change in the river may affect local eel grass beds. This will be examined later when potential effects of hydroelectric development are discussed.

SURFICIAL GEOLOGY MAPPING AND TERRAIN USE

J.S. Vincent undertook surficial geology and terrain mapping at a scale of 1:50,000 along La Grande River and south along the highway route. As of January, 1974 NTS Sheets 33E/10, 11, 14 and 15 and a comprehensive legend had been released as Geological Survey of Canada Open File Report 178. The self-explanatory maps and legend are useful to a variety of disciplines. They convey to land-use planners what is revealed on air photographs, as interpreted by a geologist: basic terrain data such as the nature and origin of landforms, slopes, erodibility, potential for aggregate and suitability for foundation. Road engineers can easily locate possible routes because sources of gravel, sensitive marine clays, swampy areas and relief are shown on the map. Wild life specialists interested in locating beaver, areas of high or low water fowl potential, or likely caribou migration routes, can delineate low swampy areas and high, sandy, well-drained areas. Archeologists may be interested in the location of raised beaches and spits where evidence of past cultures might be found. Town planners can use the maps as a basis for site selection. The maps can also be used to delineate areas of potential erosion in future reservoirs or along diversion routes.

EFFECTS OF HYDROELECTRIC DEVELOPMENT ON LA GRANDE RIVER AND AREAS NEAR ITS MOUTH

Introduction

The following discussion is based on construction plans of January 1, 1974 when it was assumed the following plans were being followed (see Fig. 1) :

a) The Eastmain, Koksoak and Great Whale rivers will be directed into the La Grande system.

b) LG-1 will be constructed approximately twenty miles from the river mouth.

c) The south arm of La Grande River around Fort George Island is to be bridge or dyked.

d) The post-construction discharge down from LG-1 will be 110,000 cfs.

e) There will be virtually no flow downstream from LG-1 for approximately one year to permit reservoir filling.

It is necessary to make these assumptions in order to avoid unnecessary comment based only on hypothetical "ifs". Because only the general construction plans are assumed, the possible ramifications that can be isolated are necessarily simplified. As much as possible, suggestions of possible effects on biological features, excepting coastal vegetation, are avoided in this discussion. Finally, conclusions are made, recognizing that they are based on very few data and that much more research and monitoring are required in order to state unequivocally the effects of hydroelectric development on this region.

Effects

Lower La Grande

As stated earlier two inescapable consequences of dam construction are that they regulate flow in the lower courses of the affected rivers and that sediment is trapped in the newly created reservoirs. A river attempts to achieve an equilibrium in which its eroding ability is adjusted to, among other factors, its sediment load. Obviously if a river's substrate is resistant bedrock it will not erode much regardless of how little sediment it carries. If a river flowing on an erodible bed is deprived of its sediment load it compensates by picking up more sediment. Erosion downstream from dams is a common phenomenon. It has been systematically monitored downstream from the Hoover Dam where the river bed nearest the dam has degraded over 20 feet since construction. The amount of erosion tapers off downstream.

The bed of La Grande River will likely be eroded downstream from LG-1. The river bed is composed of bedrock for the first several hundred meters so erosion here will be prevented. As indicated in the inset on Figure 3, clay is present at the base of the section for the next few miles grading into silt then sand. The sand is the most vulnerable to erosion; however, in this case it is so close to the river mouth that the tendency for the river to degrade will be less than if the sandy bed were closer to the tail race, as would be the case if LG-1 were built at the 'first rapids' (mile 10). It is expected, then, that channel enlargement will take the form of widening through bank failure. Many boulders derived from drumlins exposed alongthe north bank downstream from LG-1 are armouring the bed, further encouraging lateral rather than vertical channel migration at least as far downstream as the 'first rapids' (Fig. 3).

As well as erosion due to a change in sediment load it is expected that the channel will erode in response to new discharge characteristics, including an increased mean annual discharge, due to diversions. A river's depth, width and velocity are a function of its discharge. There may be a critical discharge above which erosion of bed and/or banks begins. It is important to know the erosion potential of the post-construction discharge. Will it be high enough to seriously increase erosion along the lower part of the river? It is likely that erosion as a result of scouring will be increased locally due to the new, steady discharge of 110,000 cfs.

The steady discharge will be accompanied by water levels higher than at present during the bulk of the open water period. As stressed earlier wave action is an important eroding agent in the sandy regions of the mouth. Because the water level in the river will be fairly constant, wave action will be concentrated at the same level, perhaps increasing the rate of erosion, especially in the Fort George area. The effect of waves should decrease as the bank material at wave level changes up-river from sand through silt to clay.

The water table in the banks should change in response to the new water levels. How critical this will be in terms of triggering landslides is unknown.

Sediment patterns in the mouth now depend on an annual supply of sediment. It appears that most of this sand is reworked from sandy banks in the mouth region. If these banks are protected against the potential increased erosion mentioned above, the bars may gradually disappear. This would likely benefit navigation in the river mouth area. In some cases, bars in the mouth protect adjacent banks by acting as wave-breakers. If the bars are removed, coupled with the higher water levels, stretches of bank on Fort George Island not now eroding may begin to erode.

The prospect of bridging the south arm around Governor Island poses some engineering challenges. The most likely spot is at the southeast tip of the island where the south arm is narrowest (Fig. 3). There, the concave (south) bank of the stream is resistant bedrock. However, the opposite point on the tip of the island is sand and is eroding, perhaps due to deflection of flow from the opposite resistant bank and/or the convergence of flow of two channels around a small island. The island-based abutment will be unstable and will have to be protected upstream and downstream.

A dyke, which has been suggested as an alternative, would cause a diversion of flow at the entrances to the small channels between the islands, leading to eventual erosion of the heads of the islands and the build-up of bars across the entrances. Because more flow would be going through the main, northern channel between Fort George and Goat Islands, it is expected that this channel would deepen and/or widen. One can speculate that such a diversion in flow will lead to the eventual choking up of the south arm of channel with sediment over the long term and weeds each summer. It would be similar to the channels south of islands just up river, that fill with weeds in the summer during relatively low flow. The source of sediment to the south arm would probably be from around the seaward end of Governor Island. The south arm would essentially act like a cut-off meander in a delta, catching sediment only during flood periods. Perhaps the absence of flow would create new habitats leading to a local change in aquatic life. The in-filling presents obvious potential problems to the sea-plane traffic in the south arm. It would be many years, however, before the arm would fill enough to preclude seaplane traffic. Erosion of the bank adjacent to the airstrip would decline, perhaps reducing the necessity of bank protection there. It should be stressed, however, that this south arm carries a large volume of water and that a dyke would act like a dam directing more water down the main channel, perhaps leading to serious erosion and flooding problems along the main channel and on Fort George Island. Even if the south channel conducts as little as 5% of La Grande's total flow it is naïve to expect no consequences in terms of erosion and changes in sedimentation patterns.

During discussions of proposed plans for La Grande development it was indicated that total stoppage of flow would occur for one year during filling of the LG-2 reservoir. This approach seems unprecedented in dam construction techniques and several repercussions can be foreseen. Drinking water for Fort George is taken from the river. This supply will probably become salty because the freshwater discharge at the mouth will be insufficient to counter the push of denser sea-water into La Grande's mouth. Either an alternate temporary water supply will have to be provided or, more realistically, the construction schedule changed to provide a minimum flow to ensure freshwater at Fort George. Below which discharge, if any, in the past has the drinking water been salty? The answer to this question might provide some basis for estimating a minimum discharge. Whether this would be sufficient to offset serious deleterious effects of a flow cut-off to fish and other biological components of the river ecosystem is unknown to this author. 'No-flow' would also result in temporary changes in sand bar morphology and the pattern and timing of freeze-up and break-up.

Goose Bay

Because the sediment of Goose Bay is derived mainly from the Guillaume River basin, changes in the sediment regime of La Grande will have little effect on the sediment patterns of Goose Bay. The development of significant stands of vegetation in Goose Bay is precluded by a high sediment flux. The vegetation on which geese feed develops when the mudflat is isostatically raised above high tide. If anything, a decrease in the supply of sediment to Goose Bay may result in an increase in the area covered by vegetation.

Eel Grass

After construction, the freshwater plume out from the mouth of La Grande will be relatively stable in extent throughout the year. One major difference in the future will be during late winter when the discharge will be about ten times what it is now. Preliminary investigations have indicated that the freshwater rides out over the salt water with very little mixing taking place (F.G. Barber, pers. comm., 1973) not unlike what Walker[10] reported from the Colville delta of Alaska. The height of water on James Bay at the mouth of La Grande River varies with discharge and tide; the higher the discharge, the higher the water level. This water surface eventually reaches sea level out from the mouth. Presumably, the higher the head of water at Fort George, the further out to sea the fan of freshwater extends. Therefore in the future, the fresh-water sheet will extend further up and down the coast from the mouth during late winter but not as far as at present during spring floods.

It seems likely that a sessile organism's distribution will be limited by the short term extremes in the range of that organism's critical conditions. Eel grass presently does not extend any closer to the mouth than about ten miles and is probably in balance with the average spring limits of critical salinity and turbidity up and down the coast from La Grande. If it is assumed that the present spring conditions of high discharge and high turbidity, leading to moderate temperatures, low salinity, high substrate mobility, and low photosynthetic potential are controlling eel grass limits, then it is possible to foresee an encroachment of eel grass toward the mouth. As pointed out earlier, the future summer discharge will not be much different from the present one; therefore there will be no interference with the eel grass growth period. If winter salinity conditions are important in maintaining dormancy and if the new winter discharge flowing out under sea ice mixes less than under open water conditions it is conceivable that the fresh-water could reach more distant points along the coast, increasing winter mortality of eel grass rhizomes. However, in view of present day peak discharges' often being more than twice the post-construction discharge this author tentatively predicts an encroachment of eel grass toward La Grande's mouth. Meanwhile, a survey of eel grass and further research on the growth requirements of eel grass along the James Bay Coast are needed.

Other Areas of Concern

The old retrogressive flow slides between LG-1 and 2 are apparently stable now. They failed probably several hundred or perhaps two or three thousand years ago. It is tempting to speculate that they failed at a time when the river was not as deeply incised as it is now and when the ground-water table intersected the bank higher up, perhaps at a critical stratigraphic level in terms of silt-clay content. If the sensitivity was a function of grain size affecting the structure of the clay and pore water pressures it is worth considering whether these critical sensitive conditions will be reached again when this valley becomes the reservoir for LG-1.

The estuaries of diverted rivers will undergo an increase in salinity as well as experiencing increased difficulty in flushing sediment from their mouths although a new equilibrium will eventually be attained. The eventual loss of sediment and nutrients to the mouths is also foreseen.

Streams used to divert waters will undergo erosion along those stretches of the river banked and underlain by unconsolidated sediments. New deltas will be built where diversions enter reservoirs.

Conclusions and Recommendations

Lower La Grande

The banks of La Grande River have been eroding under natural conditions. They are experiencing increased local erosion due perhaps to tree clearing. The will continue to erode unless protected. In the Fort George area increased erosion is foreseen because water levels will be higher and constant, concentrating wave action at the same level through-out the open water season; furthermore, the eventual loss of sediment to the river mouth will result in the loss of protection to some banks from wave action. On Fort George Island protection of some banks will be necessary. A dyke is not recommended to bridge the south arm. A minimum flow at Fort George should be maintained during reservoir filling. Finally, construction activity near the edge of the bank should be avoided along the south bank for the first few miles down from LG-1 and along either bank up to well above LG-2.

The sediment and nutrient supply to La Grande mouth will eventually diminish. It is not known what the present sediment load is, what it will be and whether the loss will have a deleterious effect on the biology of the mouth.

However, if nutrient supply is a direct function of sediment load it is not unreasonable to predict the decline of certain species. Sand bars in La Grande mouth are mobile features that depend on a supply of sand for their continued existence. The eventual lack of sediment may result in a change in the bar and channel configuration, perhaps improving river navigation. In the extreme long term, loss of the sand flat and erosion of the seaward tip of Fort George Island is foreseen.

Goose Bay

The sequential development of vegetation in Goose Bay's supratidal marshes is primarily a function of isostatic uplift. Detailed vegetation patterns reflect micromorphology developed initially by the action of floating ice. Hydroelectric development of La Grande River and the attendant decrease in sediment load at the mouth will have little effect, if any, on the sedimentology and vegetation of Goose Bay.

Eel Grass

Eel grass beds along the east coast of James Bay are presently absent near major river mouths. A smoothing out of flow of La Grande and the increase in salinity around the mouth of the Eastmain will encourage the expansion of the James Bay eel grass community. Because temperature is an important factor controlling eel grass growth the net warmer future water temperature around the mouth may alter the eel grass community still further. It is unknown what the new temperature range will be but it is unlikely to exceed limits critical to eel grass.

For the future, rates of erosion should be monitored. Spring breakup and ensuing high discharge periods should be observed and sediment discharge measured. The spring flood is probably the critical time for sediment movement and maximum extent of La Grande River plume in James Bay. The effects of change in the extent and temporal characteristics of the plume can best be assessed with some knowledge of the present plume and its effect. An oceanographic study out from the river mouth is required. Salinity, temperature, depth, current, and suspended sediment determinations at various discharges and tidal stages would prove invaluable in understanding the present physical character of the freshwater plume. Thus one could predict in a semi-quantitative way what the configuration of the plume will be at 110,000 cfs.

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