MINISTRY OF FORESTS/

DEPARTMENT OF FISHERIES AND OCEANS

SHORELINE PROCESSES AND SEDIMENT DISPERSION IN ROBSON BIGHT, JOHNSTONE STRAIT

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EXECUTIVE SUMMARY

In December 1990 the Ministry of Forests and Fisheries and Oceans Canada retained Hay & Company Consultants to undertake a study sufficient in scope to render an informed opinion on:

- the geomorphic character of rubbing beaches frequented by killer whales;
- the potential for changes in water quality in the area and changes in rubbing beach characteristics due to any increased sediment loads from the Tsitika River and Schmidt Creek.

Two site visits were made to collect data and record the geomorphic characteristics of the shoreline between Schmidt Creek and the Tsitika River on the south shore of Johnstone Strait. Discussions were held with DFO staff familiar with the whales' use of the beaches, and analytical techniques were employed to assess the wave climate in the Strait.

The water quality portion of the study was aimed at quantifying the dispersion of suspended sediments emanating from the two streams in relation to the stream input concentration. The assessment of absolute sediment concentration in the streams was outside the scope of the study. A computational model was developed and used to predict the dispersion in Johnstone Strait using published data on tidal currents.

The study conclusions are as follows:

- The rubbing areas used by killer whales between Schmidt Creek and the Tsitika River are within high inshore wave energy environments and bed characteristics are typically a clean relatively uniform gravel with the absence of cobble, boulder, bedrock or vegetation. The gravels used by the whales are either in the active transport zone along the nearshore edge of the sub-tidal bench or on the beach faces where they are well churned during storms.
- Suspended sediment which enters Johnstone Strait at the Tsitika River and Schmidt Creek is flushed out of the Strait by the net westward tidal flow within two days of cessation of the inflow.
- The coastal processes along the study shoreline are unaffected by upland developments and an increase in the sediment load of the streams will not alter the processes but rather the processes will have more material upon which to work. The geomorphic character of the

beaches and sub-tidal bench will not change unless there is a dramatic change to the character of sediments delivered to the foreshore, eg. by becoming all sand or all cobble.

1 INTRODUCTION

The Tsitika River drains through Robson Bight into Johnstone Strait on the northeast coast of Vancouver Island about 35 km east of Port McNeill, B.C., Figure 1. Schmidt Creek drains a small catchment about 6 km east of the Tsitika River. From May to October, pods of killer whales feed in the area and utilize the gravel beaches for rubbing and socializing. The existence of these unique rubbing beaches on the south shore of Johnstone Strait from Schmidt Creek to Robson Bight led to the establishment of an ecological reserve in the early 1980's which includes land and water in the vicinity of Robson Bight.

In 1978 the Tsitika Watershed Integrated Resource Plan was established to, among other things, monitor the logging activity in the Tsitika watershed. In recent years concerns have been raised regarding the potential effect, if any, of the contribution of any sediment generated by logging activity on the beaches and water quality as it relates to the use of the area by killer whales.

To assist in addressing these concerns, the Provincial Ministry of Forests and the Federal Department of Fisheries and Oceans (DFO) retained Hay & Company Consultants to contribute to a study to assess the effects of forest harvesting activities on killer whales in the Robson Bight region of northeastern Vancouver Island. The terms of reference for Hay & Company's input were to establish the geomorphic characteristics of the rubbing beaches, including an assessment of the source of the beach sediments, and to assess the effect of fine sediment inflow from the Tsitika River and Schmidt Creek on local water quality and on the rubbing beaches.

The study was limited to providing an informed opinion on the processes based on:

- photographing geomorphic features,
- characterizing beach sediments including grain sizes, armouring and indications of transport directions,
- identifying possible sediment sources including a lithological analysis should sediments be ambiguous,
- tracking drogues to characterize nearshore tidal current patterns in Robson Bight

- assessing wave exposure along the shoreline,

- analysing sediment dispersion within the Strait using a computational model assuming a simplification of the physical processes.

The principal thrust of the modeling was to predict sediment concentrations in the receiving waters relative to inflow concentrations and thus allow potential impacts to be assessed in terms of stream flow sediment yield. It was beyond the scope of the study to determine sediment concentrations in the inflowing streams and the effects of water borne sediment on killer whales. The scope of the study also did not allow for comprehensive data collection and analysis, but was only sufficient to support an opinion on the shoreline processes.

Time constraints for completing the draft report required the site be visited in January 1991 when daytime tides are high and weather conditions often adverse. Two staff from Hay & Company visited the site January 28 to 31, utilizing a charter vessel from Telegraph Cove. Strong southeasterly winds were blowing at the time generating seas up to 1.5m in the Strait.

Subsequent to review of the draft report, an additional site visit was made September 9, 1991 with Mr. G. Ellis of Fisheries & Oceans to discuss and view the specific areas known to be used by the whales for rubbing.

2 LOCATION

Robson Bight is located on the northeastern end of Vancouver Island on the south shore of Johnstone Strait, Figure 1. Johnstone Strait is a deep narrow channel, approximately 3 to 3.5 km wide by 100 km long linking Queen Charlotte Strait to the west with Discovery Passage to the east. In the mid 1970's it was discovered that the area around Robson Bight was of special significance to killer whales resident in the general area, Karanka, 1990. The killer whales were found to utilize a few gravel beaches in the area for rubbing and socializing. The rubbing activity has been observed at only one other location in Alaska and it is generally thought by biologists that killer whales rub to rid their bodies of dead skin and/or parasites, for pleasure, or for socializing.

The southern shoreline of Johnstone Strait on Vancouver Island is mountainous with peaks rising to above 1500 m. The region is very rugged and access to the shores of Robson Bight is essentially restricted to water or air transport. The north side of Johnstone Strait at Robson Bight is made up of a series of large relatively low relief islands which form the outlet of Knight Inlet and the start of Queen Charlotte Strait.

3 OCEANOGRAPHIC CONDITIONS

A study of the oceanographic conditions in Johnstone Strait is essential to understanding the geomorphic development of the shoreline and for assessing potential changes and impacts. The wave climate and tidal flow patterns in Johnstone Strait near Robson Bight were characterized through analytical procedures and from published studies.

3.1 Wave Climate

The south shoreline of Johnstone Strait near Robson Bight has exposures to the west and east along the axis of Johnstone Strait. Wind frequency data were obtained from the Atmospheric Environment Service at Alert Bay, about 30 km west north west of the site. Winds from the east typify the fall, winter and spring seasons while westerly winds are common in the summer. East to southeast winds predominate overall and have higher speeds than westerly winds, Figure 3. The open water fetch lengths at the site are 45 km to the east and 30 km to the west.

Wave generation by wind blowing over open water was calculated with the Alert Bay wind data using the SMB hindcast method as outlined in the U.S. Army Corps of Engineers Shore Protection Manual (1984). Wave events with annual and ten year return periods were determined for both westerly and easterly directions. The predominant wave energy is developed across the slightly longer fetch length with higher winds to the east. The typical deep water wave conditions in Johnstone Strait offshore at Robson Bight are shown in Table 1.

Table 1: Deep Water Wave Climate at Robson Bight

Frequency of Occurrence	Westerly Waves		Easterly Waves	
	Wave Height (m)	Wave Period (sec)	Wave Height (m)	Wave Period (sec)
Annual	1.8	5.0	2.9	6.3
Ten Year	2.3	5.5	3.6	6.8

Johnstone Strait is very deep and narrow with charted depths in excess of 500 m and widths of 3 - 3.5 km. Sub-tidal slopes are very steep leaving little scope for refraction or shoaling of the waves along the shores of the strait. The wave characteristics listed in Table 3 can be considered to apply to all open coastline areas in the vicinity of Robson Bight.

Easterly waves entering Robson Bight from Johnstone Strait will reduce in height as they diffract around Critical Point spreading their energy into the sheltered area of the Bight. Critical Point, protects the east shoreline of Robson Bight to the mouth of the Tsitika River from easterly waves. Some of the small pocket beaches along the strait are partially sheltered in a similar manner.

3.2 Tidal Flow Patterns

Johnstone Strait, even though it is part of the Pacific Ocean, has been described by Thomson, 1976 as a 'moderately stratified' two layer estuary. The top layer is less saline than the bottom layer and is characterized by a net westward flow of water on the order of 1000 m^3/s. An equivalent net eastward flow occurs in the lower layer. The top layer occupies about 100 to 120 m of the 450 to 500 m deep western portion of the strait, which is confined by two sills or shallow areas near Alert Bay and Kelsey Bay. The interaction of the tidal currents and the sills has been found to create internal gravity waves in the lower layer.

The tidal currents in the top layer, measured by Thomson, 1976 near Kelsey Bay, are nearly uniform with depth, even though wind and estuarine circulation influence the flow regime. The phase lag between Robson Bight and Kelsey Bay both at slack water and at peak tidal velocity varies by a maximum of 10 minutes. The hydrodynamics in the westernmost region are complicated by a number of significant flows, such as Weynton Passage, which interact with the waters of Johnstone Strait. The resulting phase lag between Robson Bight and Alert Bay differs significantly with a negligible lag for maximum velocities but up to 2 hours for slack water, Fisheries & Oceans, 1990.

The surface tidal flow rates in Johnstone Strait were measured at a number of locations in the 1970's and tidal current tables are available which predict currents at various locations throughout the Strait. The closest location where tidal currents are predicted is about 9 km east of Robson Bight at Forward Bay, Figure 1.

Characteristics of the surface currents measured near Robson Bight are as follows (Thomson, 1977 and Thomson and Huggett, 1980):

- A net westward drift of about 0.15 m/s

- A net northward drift of about 0.02 m/s.

- A very flat tidal current ellipse with maximum cross channel currents of about 0.04 m/s and maximum along channel currents of about 0.8 m/s.

- A relatively uniform velocity profile in the top layer to a depth of about 100 m.

An illustration of the net flows in Johnstone Strait is given in Figure 4.

The Tsitika River discharges directly into Robson Bight rather than into Johnstone Strait while the dispersion model assumes a discharge directly into the Strait. Any delays in tidal exchange between the Bight and the Strait may impact the dispersion and to characterize the tidal flows local surface currents were tracked within the Bight.

Measurements were made during a mean to large tide on January 29, 1991 using two floating drogues deployed on both ebb and flood cycles to determine the general current patterns in Robson Bight. The drogues consisted of a weighted sail set 5 m below the water surface and attached to a spar buoy fitted with a radar reflector. The charter vessel was securely moored in a protected cove on the east side of the Bight and the drogues were tracked by radar.

Except for drogue 1 on the ebb tide which snagged the seabed, the tracks all indicate an exchange of surface water between the Bight and the Strait with an outflow into the Strait on both ebb and flood tides, Figure 5. The ebb tidal current was observed to flow out of the Bight along the western shoreline into Johnstone Strait, whereas the flood current was observed to flow out of the Bight into Johnstone Strait along the eastern shoreline. Once in the Strait the tracks confirmed the net westerly tidal flow. Eddy gyres likely to trap surface water within the Bight over several tidal cycles were not indicated by measured current patterns.

There are no tide level records available at Robson Bight however the most applicable recording station is at Port Harvey, located approximately 26 km east north east of the site. Pertinent tidal levels are given in Table 2.

Table 2: Tide Levels at Port Harvey

Tide Level	Height above Chart Datum (m)
Extreme High Water	5.9
High Water Large Tide	5.4
High Water Mean Tide	4.3
Mean Water Level	2.8
Low Water Mean Tide	0.9
Low Water Large Tide	0.0
Extreme Low Water	-0.2

Tides are primarily created by the gravitational interaction between the earth, moon and sun. Springs or larger tides occur during full and new moons when the gravitational pull is greatest while the narrower range of neap tides coincides with the partial moon phases. Both neap and spring tidal ranges are amplified along coastlines such as British Columbia with its many islands and channels. Tidal currents respond to the tidal range and the shape of the coastal waterway and are thus amplified through narrow passages, being greatest during spring tides. The tides in the Johnstone Strait are classified as mixed, predominantly semi-diurnal with two high tides and two low tides in a 24 hour period.

4 SHORELINE GEOMORPHOLOGY

The south shoreline of Johnstone Strait between Schmidt Creek and the Tsitika River is characterized by a generally steep bedrock backshore which extends to below the low tide level. A number of small pocket beaches formed between spurs of bedrock dots the shoreline. The beaches are founded on a sub-tidal bench of varying slope and width and three alluvial fans are also evident along the shoreline, Figure 2. The alluvial fans have formed at the mouths of the Tsitika River, Schmidt Creek and an unnamed stream which will be referred to in this report as Middle Creek.

Alluvial fans form along coastlines at the mouths of streams which carry sediment. All three streams carry a wide range of sediment sizes into Johnstone Strait, most of it during rainfall runoff events. Illustration of the sediment size range in the Tsitika and the Schmidt stream beds is shown in photos 1 and 2 respectively. The maximum size of sediment evident in both streams was observed to be about 1 m.

The bed-load sediment in streams is transported to the coastline by the high energy environment of river flood flows. On reaching the tidal waters, there is a dramatic drop in velocity and the sediments are deposited forming a conical shaped alluvial fan. The wave energy, an order of magnitude less than the stream flow, then works the sediments on the shoreline of the fan producing a net transport in the direction of the predominant waves. The stream delivers a wide range of sediment sizes to the coastline, however the wave energy can only transport the smaller fraction of sediments, leaving the larger sizes behind.

As the smaller surface sediments are transported downcoast, in this case to the west, the remaining coarse fraction knits together into an armouring layer protecting the underlying matrix of sediments from further erosion. The littoral drift or wave transported sediment becomes separated into its various size fractions through the mechanics of the transportation process. The finer and hence lighter material is transported at a faster rate than the heavier coarse sizes. This process of sorting results in a distribution along the beach of coarser material to finer material in the direction of net sediment transport. The initial sorting of fresh sediment deposits on the fan is stream and tide dependent and often results in bars of relatively uniform sized material forming at distinct tide levels.

4.1 Schmidt Creek Alluvial Fan

The Schmidt Creek fan, photo 3, has developed over the years with the sediment delivered into the open coastline wave energy environment of Johnstone Strait. The fan is composed of a beach along the shoreline and a relatively flat upland area behind the beach which is covered by mature trees and other vegetation.

Just upstream from the mouth, the fan is contained between bedrock outcrops and has a width at its narrowest point of about 50 m. A low flow channel of about 15 m width cuts through the fan down to the mid tide level. Numerous relic overflow channels are evident through the upland area, and these channels may only be used during periods of flooding.

Recent flood deposits were evident at the mouth where sediments ranged from gravels to small boulders. Older armouring is evident from the east of the stream mouth to the edge of the fan, Photo 4, where the surface comprises a stable, well knit layer of 100 to 200 mm sized cobble interlaced with the occasional 300 to 500 mm boulder embedded into the surface. To the west of the stream mouth the beach face is characterized in a similar manner but with an armoured layer of smaller, 50-75 mm sized material on a flatter slope, Photo 5. The tapering in armour size from west to east across the fan is a reflection of the net wave induced transport to the west.

Evidence of the matrix of sediment sizes protected by the armouring can be seen in Sample 1, Figure 6, which was extracted from a shallow hole excavated through the single layer of armour material on the fan. Geomorphic features of the transport process can also be seen in the upper foreshore berms of coarse sand and fine gravel lying to the west of the stream mouth. Sample 2, Figure 6, taken from a berm at the downcoast or west end of the fan clearly demonstrates the rapid sorting under the influence of the predominant easterly waves. The lack of fine sand and silt sizes in the samples confirms the harsh wave environment. Such material is either carried into the Strait as suspended load during the flood or transported offshore by wave action shortly thereafter.

Sediment samples were collected as grab samples from geomorphic features to indicate the characteristics of the features in support of an opinion on the coastal processes rather than to quantify any processes.

4.2 Beaches

The rubbing beaches are components in a string of pocket gravel beaches extending along the south coast of Johnstone Strait from Schmidt Creek to the Tsitika River, Figure 2. Sediment samples were taken from a number of the beaches to characterize the coastal processes. Photographs of the samples and their locations are shown in Figure 6 and details of the samples including lithology, median sediment size and uniformity coefficient are included in Table 5.

At the mouth of Schmidt Creek a rapid sorting of the wide range of sediment sizes takes place under the influence of the wave and current regime. Fine sand and suspended sediments are washed immediately offshore at the stream mouth while the bedload sediments become sorted into groups with the finer material traveling quickest alongshore.

Sand and fine gravel are initially transported up the beach and then alongshore forming upper foreshore berms. Sample #2, taken from the upper foreshore berm at the east end of Beach #1 consists of a coarse sand intermixed with a separate population of medium gravel. Sample #3 taken from the west end of Beach #1 likewise consists of two size fractions but the sand component is finer. The difference in the upper foreshore surface texture of Beach #1 from the east to the west is illustrated in photos 6 and 7. There is visually more sand at the east end of Beach #1. Sample #4 on the upper foreshore of Beach #2 contained only gravel with no traces of sand.

Calm seas, clear skies and a low tide during the followup site visit in September, 1991 permitted a visual inspection of the nearshore sediments on the sub-tidal bench extending west from Schmidt Creek. The sand fraction which disappears from the upper foreshore between Beaches #1 and #2 would appear to be transported offshore and deposited onto the flatter sections of the sub-tidal bench. Visual observation of the bench indicated a sandy surface colonized by patches of eel grass where the bench was wide and relatively flat and a gravel surface adjacent to the shoreline and on the steeper and narrower sections. Outcroppings of boulder and bedrock could also be seen, although bull kelp had heavily colonized these coarse areas.

The alongshore sorting process which characterizes the beach faces is evident in the increased uniformity of sediments from sample 1 at the mouth of the creek to Sample #5 downcoast at Beach #7. (An increase in uniformity is indicated by a decrease in the uniformity coefficient.) The classic gradual reduction in median grain size downcoast is, however, not as evident and anomalies may be explained in the variation in beach geometry and orientation. Additional fine material is introduced to the alongshore sediment budget at Middle Creek, Beach #13, sample #10.

The pocket gravel beaches along the coastline to the west of Schmidt Creek have formed at indentations within the shoreline bedrock. Gravels, transported by wave action along the bench have filled each indentation at a stable slope to a point where additional material bypasses the beach travelling further downcoast. Some sediments likely entered the beaches directly from upland erosion as indicated by the presence of occasional cobble and boulder. The general uniformity of the beach sediments is, however indicative of a longshore sorting process.

The bedrock forming either side of the indentation acts as an anchor supporting the trapped sediment. Each beach is unique with a differing bedrock geometry and in several cases the beach is supported by a spur of rock extending out from the shoreline. These variations have allowed some beaches to form with an easterly exposure whilst others face west. Although each beach has developed to a stable equilibrium, minor fluctuations in alignment and profile to reflect variations in the quantity of sediments delivered alongshore can be expected.

Gravel is transported between the beaches along the nearshore edge of the sub-tidal bench at the toe of the steep bedrock shore. Waves reflected from the bedrock face essentially double the application of wave energy applied to the bed adjacent to the rock. The increased macro turbulence from the combination of the incident and reflected waves results in a rapid transport of sediments along the bench. A clear narrow gravel strip devoid of vegetation was observed along the rock face between beaches during the September site visit.

Beaches #2 to #9 are made up of various gravel sizes depending on the orientation of each beach with respect to the predominant waves. In general, beaches facing directly at the predominant easterly waves are comprised of medium sized gravel while beaches in the lee of bedrock structures with a westerly aspect are characterized by coarser gravels. For example beach #5, sample 7, which is east facing is finer than beach #8, sample 6, which faces west. This apparent contradiction can be explained in terms of the wave dynamics around the rock spurs and points.

Easterly waves diffract around the bedrock points or spurs anchoring west facing beaches and although the wave height is reduced the oblique approach to the beach results in a strong alongshore component of the energy. The beaches facing east, although exposed to more energy from direct wave attack, are not affected by as strong an alongshore component of wave energy and will therefore trap a smaller sized gravel, albeit on a flatter beach gradient. The beach faces are all supported on the sub-tidal bench. One anomaly occurs in the set of samples at Beach #9, which contains small sized gravel on a narrow beach facing to the west. A long finger of bedrock with a low profile supports the beach on the upcoast or the northeast side. The geometry allows little scope for diffraction of easterly waves and the beach face may have been developed by the more direct westerly wave climate.

The gravel beaches along the coastline are formed by a combination of alongshore and onshore transport and such beaches are commonly referred to as shingle beaches, Muir Wood, 1970. Due to the permeability of the gravels, there is very little offshore transport of the gravels under wave action as the downrushing wave energy is dissipated in percolation through the gravels. The resulting beach has a steep gradient (1V:5H), a uniform gravel size, clean of sand, barnacles and detritus and with a high energy wave climate is frequently turned over and vertically sorted.

An additional small alluvial fan has formed at Middle Creek and the fresh inflow of finer material is evident in Samples #12 and #13. The sediments are distributed westwards to Beach #14, the last gravel beach in the series. The foreshore steepens west of Beach #14 to Critical Point with very few indentations where beaches might develop. The few indentations that were observed were characterized by cobble and boulder derived from local upland bedrock erosion.

The Tsitika River alluvial fan has formed in a manner similar to the Schmidt. The Tsitika fan is more extensive, reflecting the larger catchment area and has been filling Robson Bight since the last glaciation. The Tsitika fan is somewhat protected by Critical Point from easterly waves at its present location in Robson Bight. The lower wave energy combined with the shoreline geometry of the Bight results in the bedload Tsitika sediments being trapped within the Bight. A narrow beach, Beach #15, extending to the west of the fan, is evidence of the predominant easterly waves. Beaches further to the west in the outer portion of the Bight and west of the Bight are formed by local upland erosion and sediment inflow from local streams. These beaches vary in size and sediment composition depending on the feeder stream, and are also characterized by the presence of the sub-tidal bench.

A visual lithological identification of the gravels on the beaches was undertaken, Appendix A. In general, the gravels found in all the beaches from the Schmidt Creek to Middle Creek are mostly Basalt and Greenstone whereas the beach to the west of the Tsitika River is composed mostly of Quartz Diorite.

5 RUBBING BEACHES

The sketches provided by Fisheries and Oceans Canada at the start of the study showed that the two principal rubbing beaches for investigation were located between the Tsitika River and Schmidt Creek. According to our guide on the field trip, Mr. W. Mackay, the most popular rubbing beach areas utilized by the killer whales are locally referred to as 'Main Rubbing Beach' and 'Strider Beach'. Mr. Mackay has observed the killer whales in the area for many years.

Observation and discussion of the area with Mr. G. Ellis of DFO during the followup site visit in September, and review of the Japanese underwater video obtained by DFO, provided a clearer understanding of the specific beach characteristics preferred by the whales. The animals would appear to glide along clear patches of the gravel bed rubbing their sides or bellies. The nearshore edge of the sub-tidal bench is the most frequented zone with the inter-tidal beach used at higher tide levels.

The main rubbing beach faces to the east and is directly exposed to the predominant waves. The beach is approximately 30 m wide and the face is well indented between bedrock points to the west and east. The offshore beach slope is shown in Figure 7. The beach was visited during an evening low tide and the following characteristics were noted: the beach slope was measured at 1V:5H; the surface material was uniform 10-20 mm gravel over the exposed portion of the beach; some shallow excavation indicated no change in the sediment characteristics; the beach exhibits the classic features of a shingle beach. On the followup visit it was evident that the surface texture extended onto the sub-tidal bench.

Strider beach differs from the main rubbing beach being only 7 m wide, facing west and comprising finer sediments, Photo 8. The 5-10 mm sized sediments are contained by a steep bedrock wall in the backshore and a sloping bedrock finger parallel to the shoreline on the east. Some boulder and cobble is evident around the lower part of the beach and onto the adjacent sub-tidal bench. The area utilized by the whales at Strider is apparently the sub-tidal zone along the bedrock finger containing the beach rather than the beach face or toe of the beach. The gravels along this clear narrow strip were visually coarser than the beach material.

In viewing the two main beaches and other less frequented areas, the rubbing zones are within high inshore wave energy environments and bed characteristics are typically a clean relatively uniform gravel with the absence of cobble, boulder, bedrock or vegetation. The gravels used by the whales are either in the active transport zone along the nearshore edge of the sub-tidal bench or on the beach faces where they are well churned during storms. The constant movement and washing of the gravel would prohibit marine growth and infiltration by sand and detritus.

Although there is potential for the desired physical attributes for rubbing beaches to exist elsewhere along the shoreline west of Robson Bight, tradition and social structures may influence the whales highlighting the uniqueness of the Robson Bight to Schmidt Creek area.

The coastal processes along the study shoreline are well established and an increase in the sediment load of the streams will not alter the processes but rather the processes will have more material upon which to work. The geomorphic character of the beaches and sub-tidal bench will not change unless there is a dramatic change to the character of sediments delivered to the foreshore, eg. by becoming all sand or all cobble. The greatest potential change would be to the alluvial fans themselves where the sediments are initially deposited. Due to the steep bed on which the Schmidt Creek fan is formed there would have to be massive increases in sediment delivered by Schmidt Creek before changes to the growth of the fan could be observed.

6 HYDROLOGY

Northeast Vancouver Island has a mean annual precipitation of between 1400-2000 mm, Ministry of Environment, 1981. The steep local topography produces orographic rainfall, with rain on snow pack in the October to February period often generating the highest run off events. The rainfall events are generated by cyclonic low pressure disturbances which travel from west to east across the northern hemisphere. Individual disturbances typically have short rainfall periods on the order of a day or two.

The two main drainage basins in the area of the killer whale rubbing beaches are Schmidt Creek and the Tsitika River, Figure 2. Schmidt Creek is a small ungauged stream and although the Tsitika River supports a Water Survey of Canada Gauging station, the site is at the Catherine Creek junction, located about 6 km upstream from the mouth.

Modelling the potential for dispersion of suspended sediments in the Strait requires flood flows for each stream. Since the Schmidt catchment is an order of magnitude smaller than the Tsitika a multivariate regional hydrology analysis was carried out to obtain an estimate of the annual and 1 in 10 year flood magnitudes. Area, median basin elevation, and mainstem channel length were chosen as independent variables thus requiring five streams to perform the analysis.

The five streams were selected from the Water Survey of Canada data based on having a location in northern Vancouver Island and a similar mountainous setting. There are only a few gauged streams in the region and it was necessary to include two large streams, one with a lake and the other with regulated flow.

The Consolidated Frequency Analysis Package (CFA), developed by the Water Resources Branch (Inland Waters Directorate) of Environment Canada, was used to obtain the annual and 1 in 10 year flood flow estimates for each stream. Maximum daily rather than instantaneous flows were used to represent the potential for sediment to be carried into Johnstone Strait during a flood event.

The regression was run in a stepwise fashion and the highest multiple correlation coefficient, r^2 was obtained using all three independent variables. An r^2 value of greater than 0.9 was obtained in all cases and the results are shown in Tables 3 and 4, for the annual and 10 year flood estimates respectively. Although the analysis is based on poorly matched streams the derived Schmidt Creek flows are greater than those obtained by simply factoring the Tsitika flows based on areas. The dispersion modelling assumes sediment inflow concentrations are directly proportional to stream flows and a further level of conservatism was employed by rounding the flow values upwards for use in the model.

Table 3: Annual Flood Estimates
(Maximum Daily Flows)

Station	Name	Qest m^3/s	Qmes m^3/s	Area km^2	Elev m	Length km	
8hf004	Tsitika	124	112	360	750	31	
8hf001	Kokish	52	47	290	600	37	
8he006	Zeballos	87	105	181	610	25	
8hf002	Nimpkish	202	257	1760	700	103	lake
8hd006	Salmon	233	186	1200	650	85	regulated
	Schmidt, mouth, 1 yr	21		35	490	11	
	Tsitika, mouth, 1 yr	127		399	690	37	

Note: Qmes from WSC data, A, El & L from 1:50,000 mapping

Table 4: 10 Year Flood Estimates
(Maximum Daily Flows)

Station	Name	Qest m^3/s	Qmes m^3/s	Area km^2	Elev m	Length km	
8hf004	Tsitika	459	417	360	750	31	
8hf001	Kokish	251	226	290	600	37	
8he006	Zeballos	453	547	181	610	25	
8hf002	Nimpkish	1024	1295	1760	700	103	lake
8hd006	Salmon	1422	1140	1200	650	85	regulated
	Schmidt, mouth, 10 yr	118		35	490	11	
	Tsitika, mouth, 10 yr	571		399	690	37	

Note: Qmes from WSC data, A, El & L from 1:50,000 mapping

A brief review was made of previous flood flows calculated for the Tsitika River. Karanka, 1987 reported that a 409 m^3/s instantaneous flow had a return period of less than 2 years although no reference was made to maximum daily flows. A comparison between recorded maximum daily and maximum instantaneous flow records on the Tsitika reveals an average ratio of 1.64 for the maximum instantaneous to maximum daily flows. Applying this ratio to the maximum daily flood flows calculated above results in the maximum instantaneous flows for the Tsitika of 208 m^3/s for the annual flood and 936 m^3/s for the ten year flood.

7 SUSPENDED SEDIMENT DISPERSION

Suspended sediment dispersion within Johnstone Strait was analyzed with the aid of a computational model developed for the study. Assumptions were made to simplify the physical processes and allow an opinion to be rendered on the bounds of sediment concentrations in the Strait in terms of concentrations at the mouths of the streams. The model was structured as a rectangular grid representing the western portion of the Strait. Inputs to the modeling were stream flows for annual, and 1 in 10 year floods coupled with the set and strength of tidal currents. Outputs were a temporal and spatial relationship between concentrations in the Strait in terms of concentrations in the streams.

7.1 Dispersion

On the basis of the hydrodynamics of Johnstone Strait described by Thomson, the dispersion of sediments are primarily longitudinal under the influence of the net westward flow in the top layer of the Strait. Sediment inflow events were assumed to be related to the peak flow events which occur in the winter months from October to February.

Data presented in Thomson 1981, for the surface waters of Johnstone Strait at Robson Bight, give the salinity variation between 30.7% and 31.5% and the temperature variation between 7.2°C and 9.1°C during the winter. The salinity and temperature differences between the Johnstone Strait waters and the stream water create density differences, the stream water being lighter. Thus inflowing stream water will spread over the surface of Johnstone Strait, acting like a buoyant plume. As the plume spreads out into the Strait the fresh water will mix into the waters of Johnstone Strait by the process of dispersion and under the influence of wind and waves.

Modeling of the dispersion in Johnstone Strait assumed that the sediment enters the Strait from the streams as a buoyant plume of constant thickness and without vertical mixing. This assumption is correct near the inflow points, however it becomes an increasingly conservative estimate further and further away from the source as the fresh water becomes mixed into the Strait waters.

The spreading of the buoyant plume depends primarily on two processes: advective transport by the tidal currents and dispersion of the plume under the influence of its own buoyancy. The advective transport is modeled by using the predicted tidal flow data in Johnstone Strait. Modellng the spread of the plume by the process of dispersion, requires a dispersion coefficient to be assigned. Measured dispersion coefficients for real estuaries vary between 10 and 1500 m^2/s, Fischer 1979. Since no field measurements of dispersion coefficient were viable at this level of study, a dispersion coefficient was estimated from theory, Fischer 1979, and from observations by other field workers that the plume typically spreads across the strait. A final value of 40 m^2/s was chosen.

7.2 Numerical Model

The numerical model is based on the Monte Carlo Simulation technique as described by Koutitas, 1988. The model tracks individual particles across the model grid subjecting them to the advective tidal velocities and the effect of dispersion. The model grid is presented in Figure 8.

The following assumptions were used for the numerical model:

1. Johnstone Strait be analyzed as a straight channel of constant rectangular cross section.

2. The predicted currents near Robson Bight at Forward Bay (Fisheries and Oceans, 1990) are applicable over the length of the Johnstone Strait modeled from Alert Bay to Forward Bay.

3. The longitudinal surface velocities were varied across the Strait according to the measurements of Thomson, 1976 as presented in Figure 4.

4. Cross channel velocities were set to zero.

5. Fresh water at about 5°C was assumed for the stream inflow.

6. Sediment inflow was set constant for 1 day.

7. Annual and 10 year stream inflows were used as calculated by the regional analysis.

8. It was assumed that sediment concentrations do not affect the hydrodynamics of the Strait and that a linear relationship exists between the sediment concentration and the stream inflow.

Both a neap and a spring tide were used as input to the model for comparison, Figure 9. A spring tide was chosen with the largest flood tide velocities to the east and a neap tide was chosen with the smallest ebb tide velocities to the west. The complex flow patterns through Weynton Passage have not been studied and were not included in the model.

Cross channel velocities were reported by Thomson 1976, to be very small with net drift to the north. In order to simplify the model, this small drift to the north was neglected. This assumption will result in a bias towards slightly higher sediment concentrations along the south shoreline.

Variations in wind speed and direction contribute significantly to the dispersion and these effects are implicitly accounted for through the dispersion coefficient and the mean estuarine circulation which is accomodated in the predicted currents.

7.3 Model Results

Inflow of suspended sediment from the Tsitika River and Schmidt Creek was found to be moved primarily to the west under the influence of the net westward flow in the top layer of Johnstone Strait. The sediment dispersed completely across the Strait as observed in the field and after cessation of inflow, the majority of sediment was traced westward off the model grid, 26 km away, within 2 days.

The model results are presented graphically as a distribution of the individual particles used to run the model and as a plot of concentration vs. time at two selected locations. The particle distributions are shown plotted on the grid after cessation of inflow, 1 day later and 2 days later. Outputs for the annual and 10 year floods are shown on Figures 10 and 11 respectively. The results for the neap tidal currents are not markedly different from those of the spring tidal currents. The sediment disperses widely and travels rapidly to the west under the influence of the net tidal currents. Within 4 days of cessation of inflow all sediment will have passed Alert Bay.

Relative concentration plots are also included to demonstrate the potential impacts on water quality in the strait. Two locations were chosen: one near the inflow of the Tsitika River close to the south shoreline at station (50,2) and the second 5 km to the west closer to the centre of the strait, station (40,4). These two stations were chosen to characterize the spread of the sediment plume in the strait close to Robson Bight. Model runs for the relative concentrations were executed using all the available computer memory to maximize the accuracy.

The relative concentration that is presented is the ratio of the particle concentration (particles/cu.m.) in the selected station grid to the total inflow particle concentration of the streams. The results from the annual and ten year floods are shown in Figures 12a and 12b respectively. The results convey the plan view picture presented in Figures 10 and 11. Concentration rises rapidly as the sediment plume approaches each station and tails off to zero within 2 days. A maximum relative concentration of about 0.7 was recorded at the point closest to the inflow. Each plot shows a series of peaks and troughs superimposed on the general rise and fall trend. These peaks are related to the tidal flow patterns which have periods of about 12 hours. Peaks occur on the maximum ebb flows and troughs occur on maximum flood flows as the centroid of the plume cycles back and forth along the Strait.

It is important to note that the inflow period for the model runs shown in Figure 12 is 24 hours. Testing with the model has confirmed that the 24 hour period is sufficient to establish equilibrium conditions in the Strait and that a longer flood does not result in higher relative concentrations. Some additional sensitivity testing on cross channel velocities and dispersion coefficients did not alter the fundamental effect of the net westward flow.

8 CONCLUSIONS

The study conclusions are as follows:

- The rubbing areas used by killer whales between Schmidt Creek and the Tsitika River are within high inshore wave energy environments and bed characteristics are typically a clean relatively uniform gravel with the absence of cobble, boulder, bedrock or vegetation. The gravels used by the whales are either in the active transport zone along the nearshore edge of the sub-tidal bench or on the beach faces where they are well churned during storms.

- Suspended sediment which enters Johnstone Strait at the Tsitika River and Schmidt Creek is flushed out of the Strait by the net westward tidal flow within two days of cessation of the inflow.

- The coastal processes along the study shoreline are unaffected by upland developments and an increase in the sediment load of the streams will not alter the processes but rather the processes will have more material upon which to work. The geomorphic character of the beaches and sub-tidal bench will not change unless there is a dramatic change to the character of sediments delivered to the foreshore, eg. by becoming all sand or all cobble.

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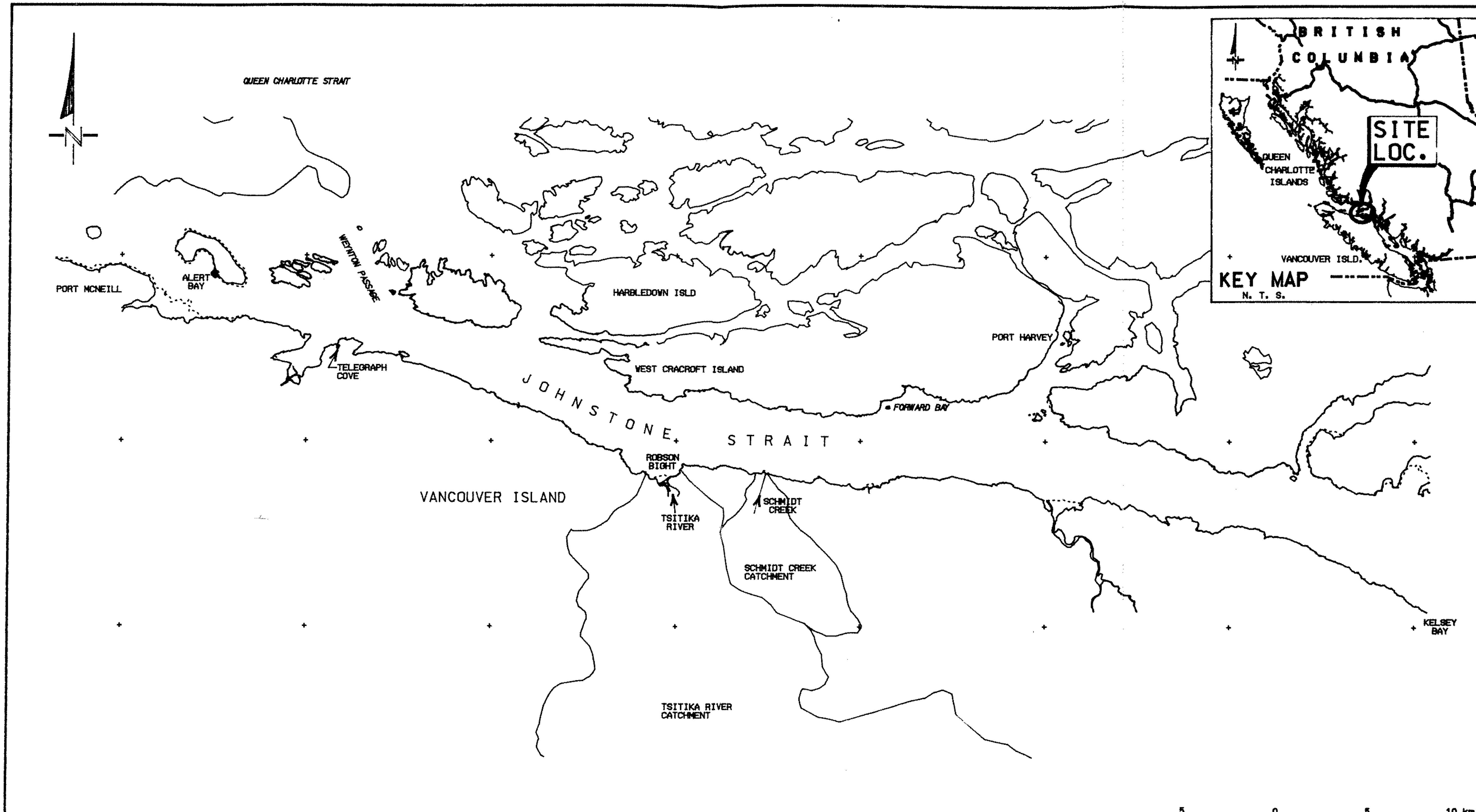
FIGURES



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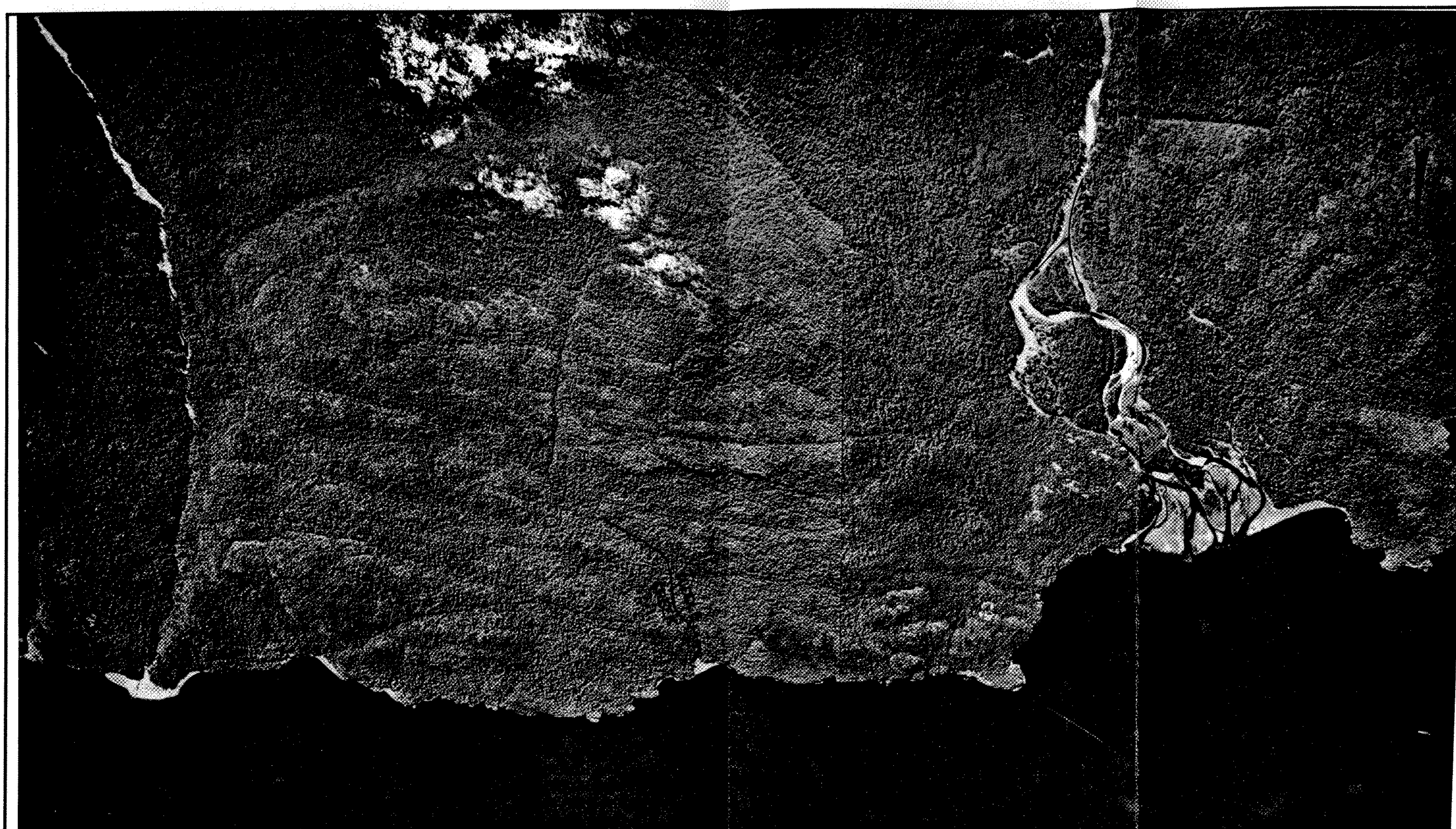
SEDIMENT STUDY

SITE PLAN

FIG. 1

MFOR-002/BFIG-1.DGN/RF=PLAN.DGN/91-03-28



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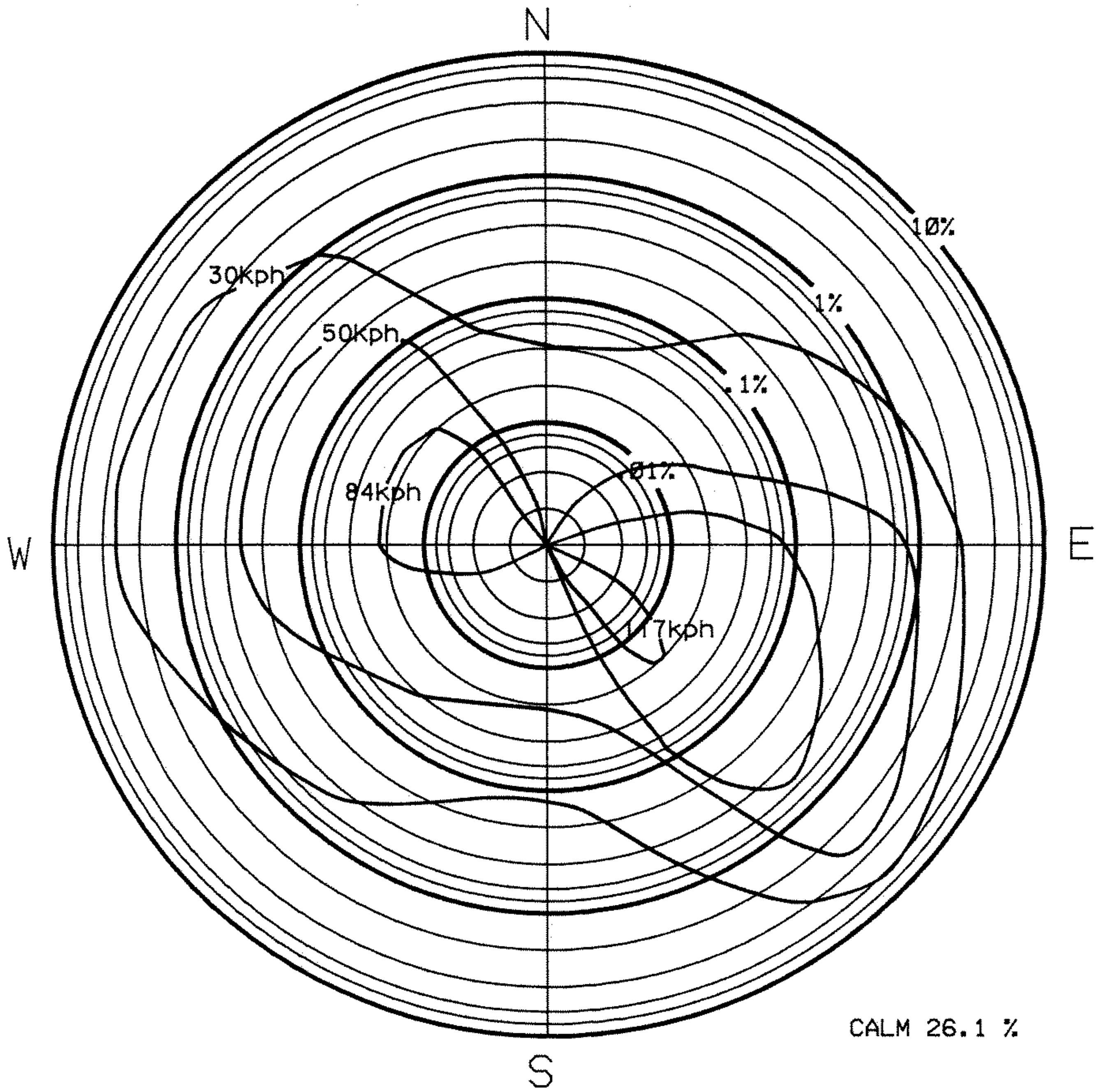
SEDIMENT STUDY

SHORELINE FEATURES

FIG. 2

MFOR-002/FIGURS.DGN/91-03-26



FREQUENCY OF OCCURRENCE (%) OF WIND SPEED (KPH)
33 YEARS OF RECORD, 1954 TO 1987
ALERT BAY, B.C.

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WIND ROSE ALERT BAY

FIG. 3

MFOR-002/WINDROSE.DGN/91-03-27

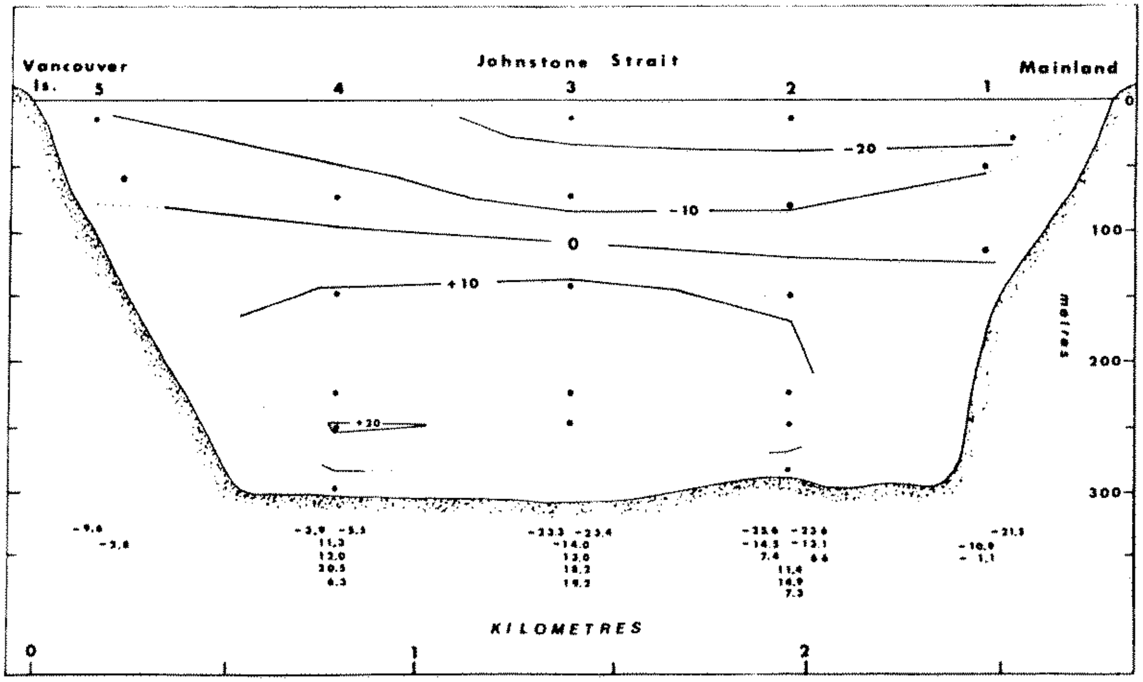

FIG. 3. The time averaged along-the-channel current structure across the central portion of Johnstone Strait. Speeds are in centimetres per second, negative values indicate a seaward (westward) flow and positive values an inward (eastward) flow. The channel is oriented at −10° to the eastward direction. Observed values are listed below each mooring location. Dotted lines represent uncertain interpolated values.

FROM THOMSON, 1977

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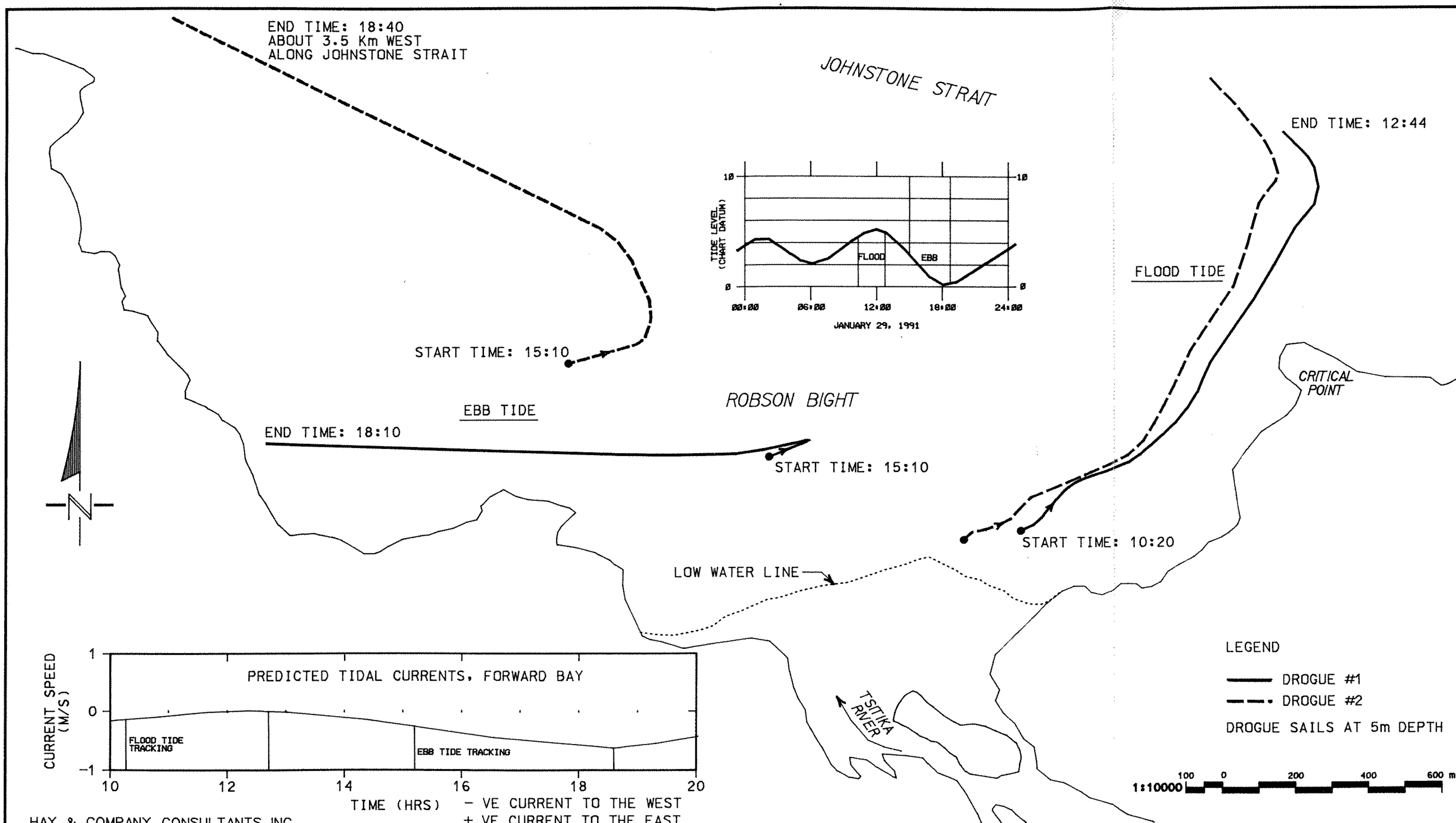
NET TIDAL FLOWS IN JOHNSTONE STRAIT

FIG. 4

MFDR-002/FIGURS.DGN/91-03-26



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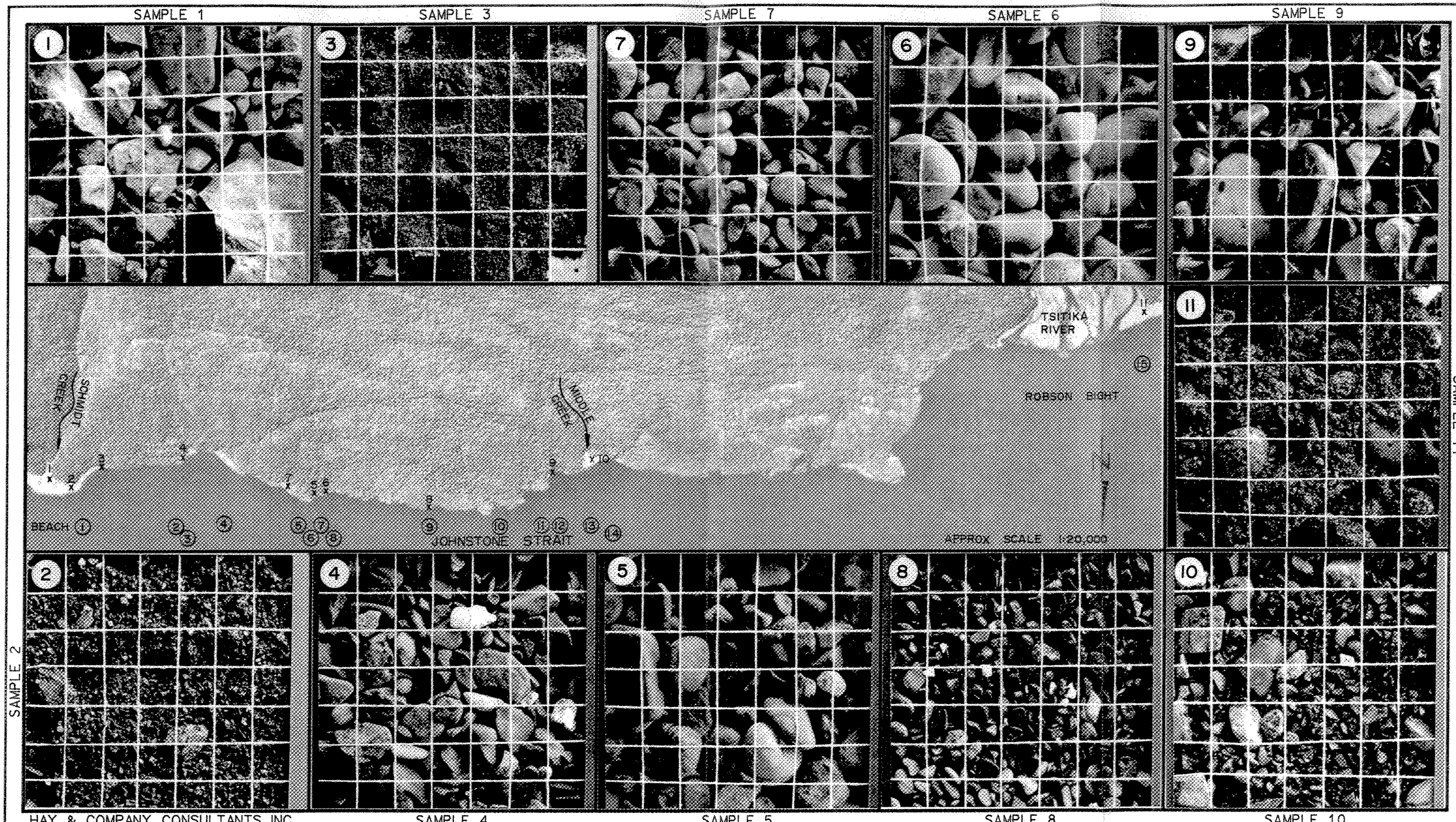
DROGUE TRACKING IN ROBSON BIGHT

FIG. 5

MFOR-002/FIGURS.DGN/91-04-25



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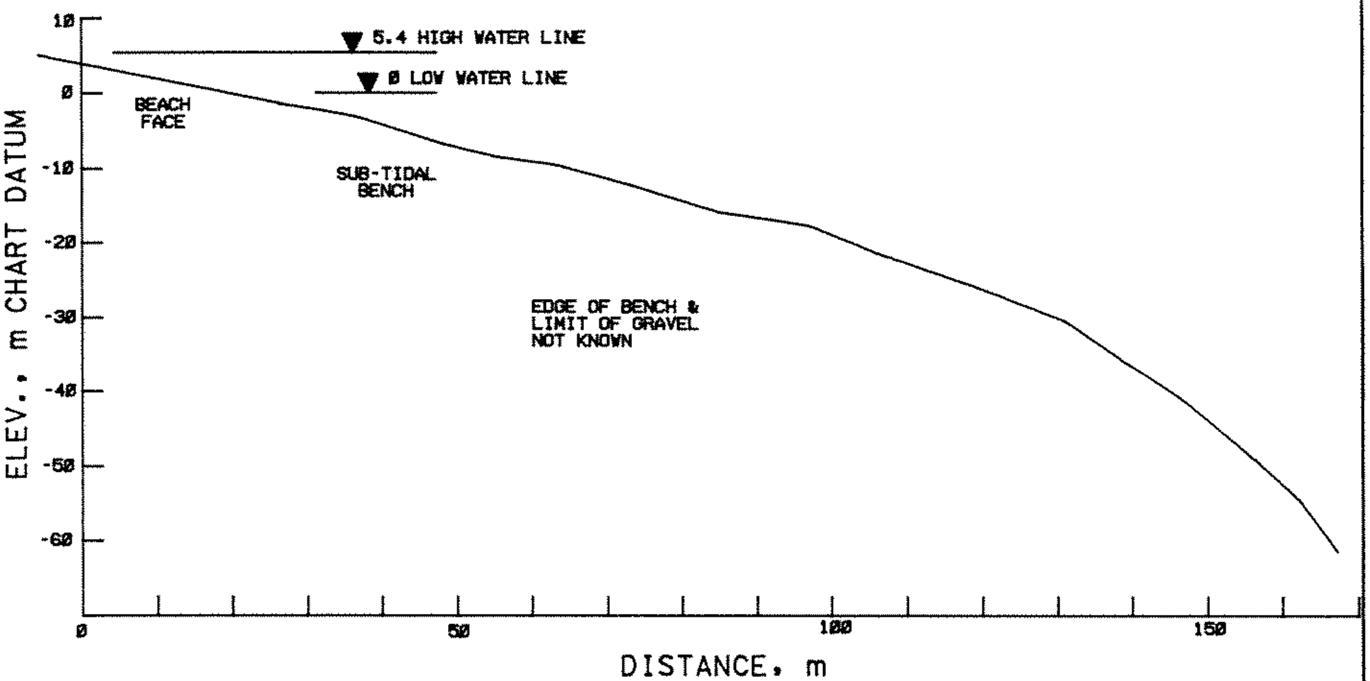
ROBSON BIGHT SEDIMENT STUDY

NOTE:
GRID SIZE ON SAMPLE
PHOTOS = 2 CM

SEDIMENT SAMPLES

FIG. 6

MFOR-002/FIGURS.DGN/91-03-26



NOTE : PROFILE SOUNDED BY MV GIKUMI. FEB 1991

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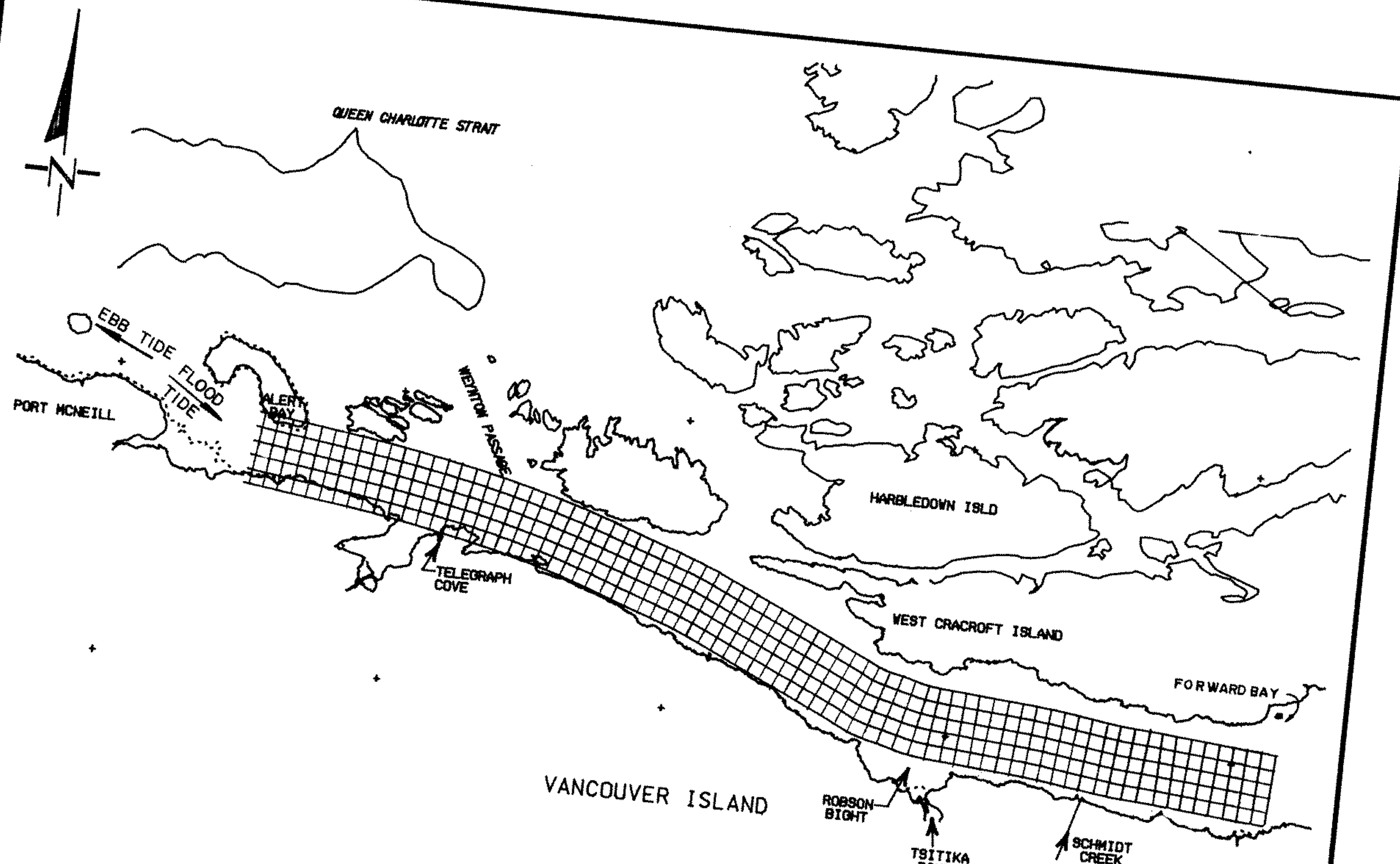
RUBBING BEACH PROFILE

FIG. 7

MFOR-002/PROFIL.DGN/RF=BCHPROF.DGN/91-04-09



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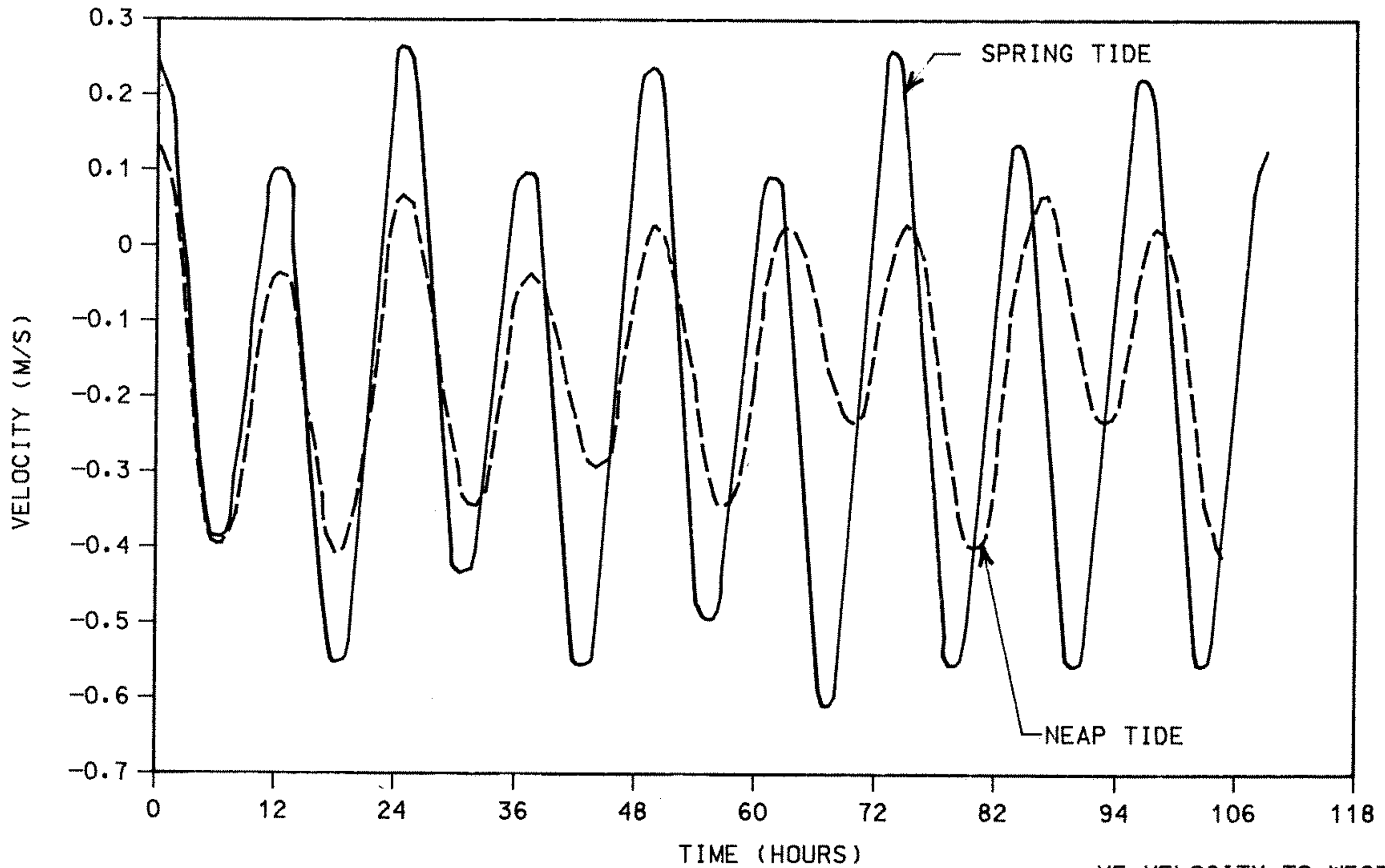
MFOR-02/BFIG-2/91-04-03

MODEL GRID

FIG. 8



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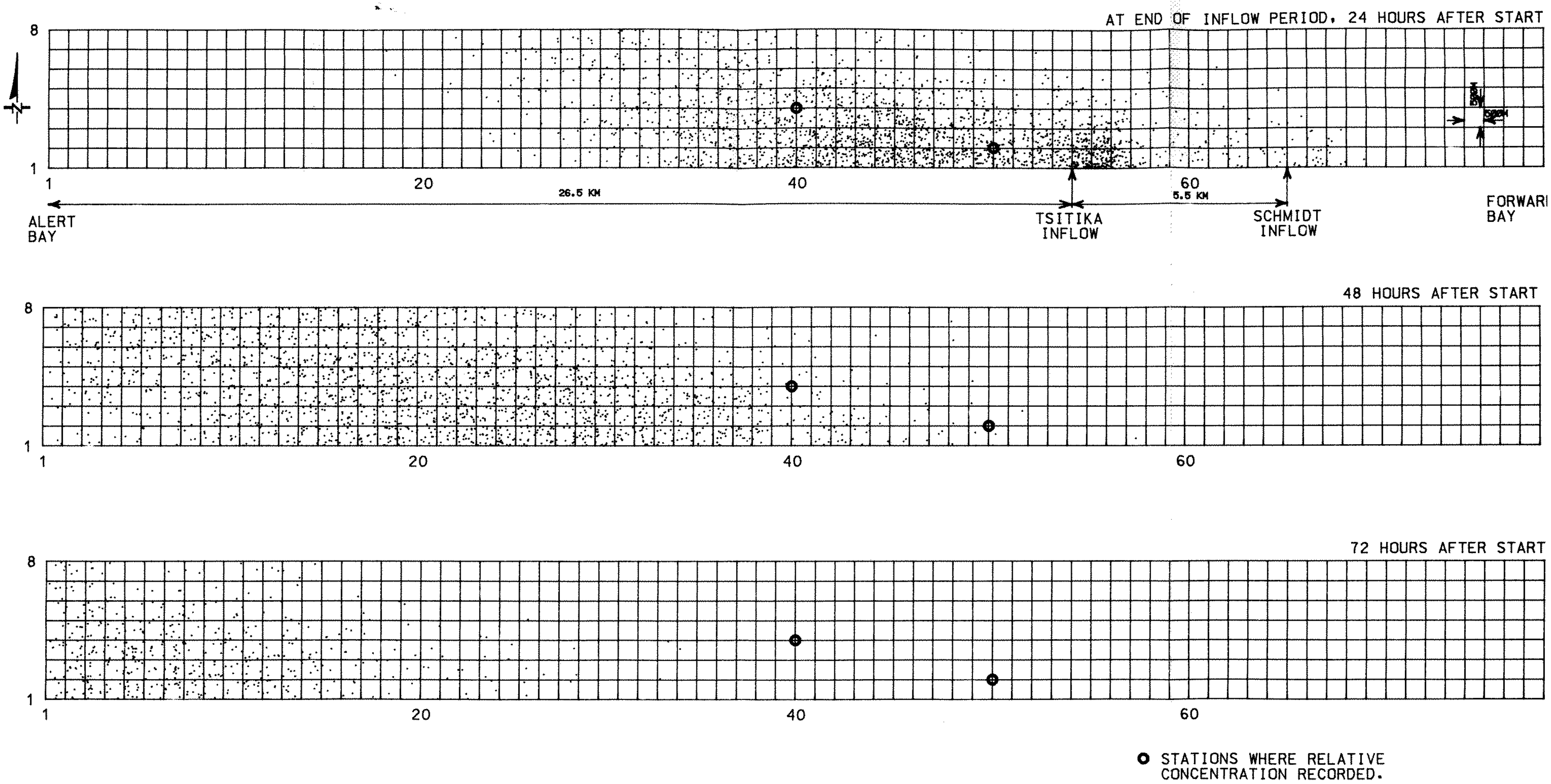
NEAP AND
SPRING TIDE

FIG.
9

MFOR-002/FIG11.DGN(RF=FIG11P.DGN)/91-04-10



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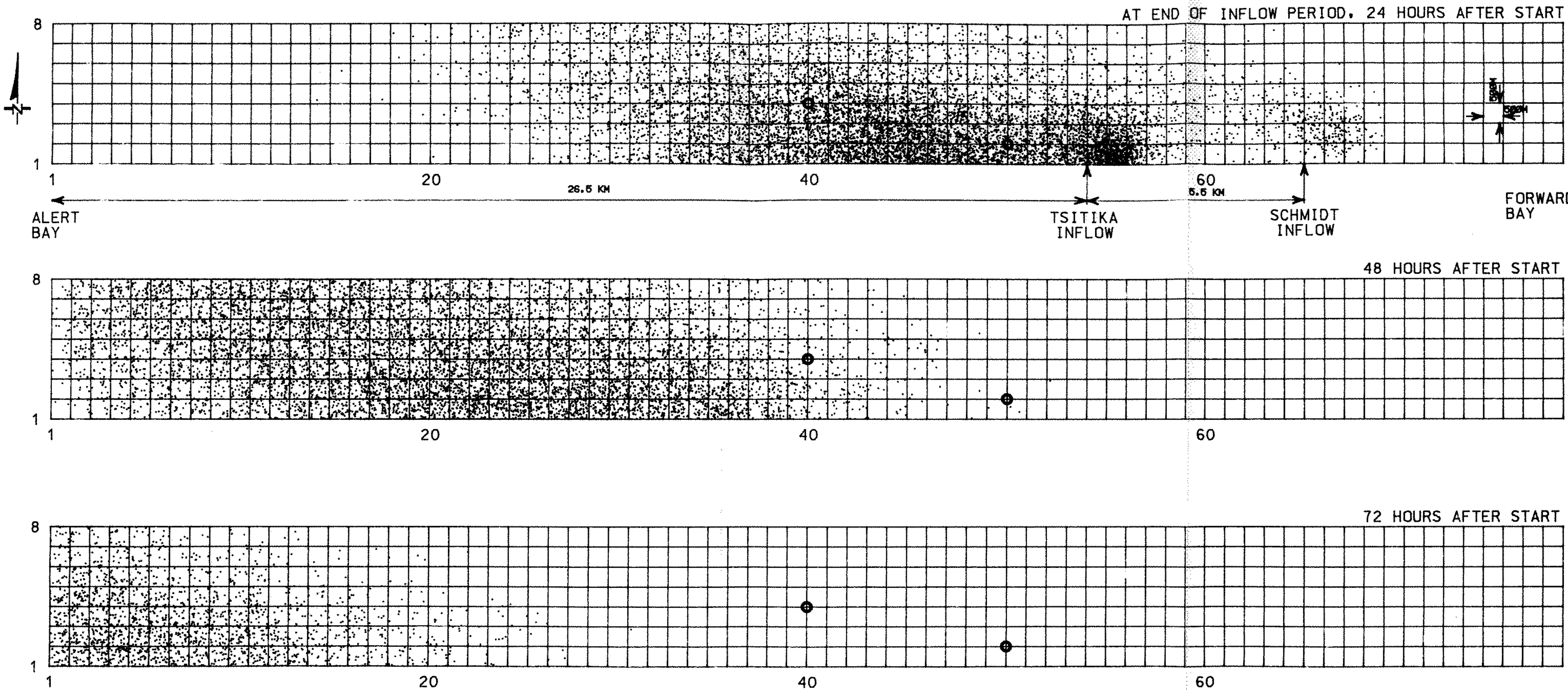
ROBSON BIGHT SEDIMENT STUDY

ANNUAL FLOOD SEDIMENT DISPERSION

FIG. 10

mfor-02#fig8.dgn, rf=1yr 24hr, 1yr 48hr, 1yr 72hr, vl=grid



NOTE: - 24 HOURS OF SEDIMENT INFLOW
- SPRING TIDE

o STATIONS WHERE RELATIVE CONCENTRATION RECORDED.

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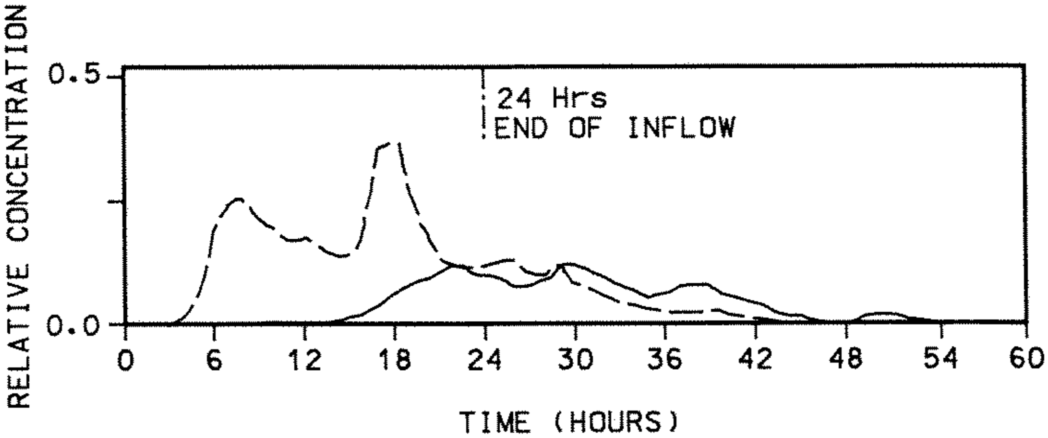
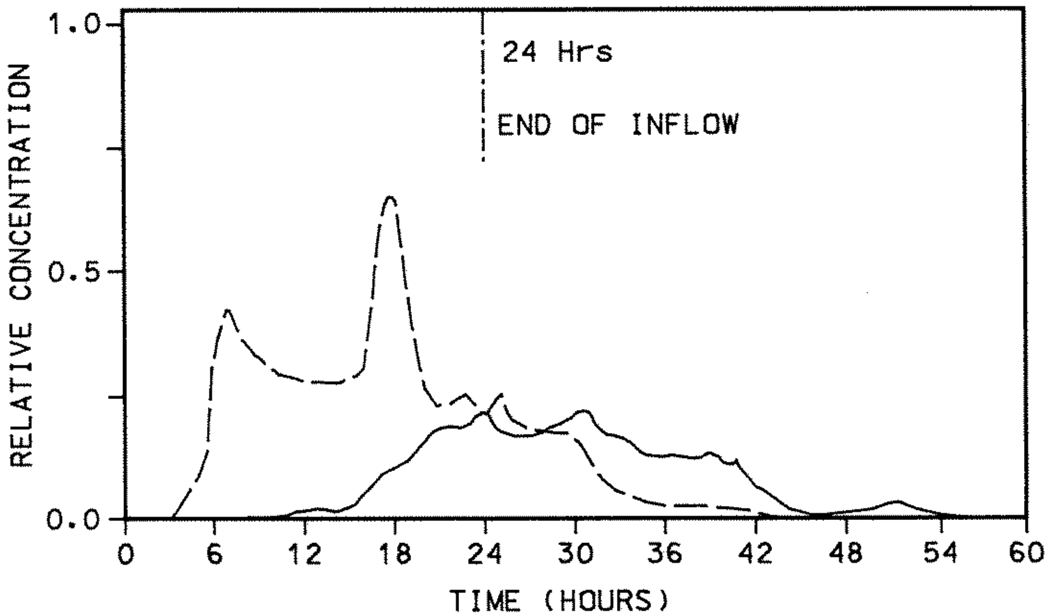
TEN YEAR FLOOD SEDIMENT DISPERSION

FIG. 11

MFOR-02#FIG9.DGN, RF=10YR 24H, 10YR 48H, 10YR 72H, VI= GRID



A. ANNUAL FLOOD



B. TEN YEAR FLOOD

NOTE : RELATIVE CONCENTRATION IS EQUIVALENT TO THE RATIO OF SEDIMENT CONCENTRATION OF THE PLUME IN THE STRAIT TO SEDIMENT CONCENTRATION AT THE MOUTH OF THE STREAMS

LEGEND

– – – POINT (50,2 SEE FIG 10)

——— POINT (40,4 SEE FIG 10)

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ROBSON BIGHT SEDIMENT STUDY

RELATIVE CONCENTRATION

FIG. **12**

MFOR-002/FIG12.DGN(RF=FIG12P.DGN)/91-04-10

PHOTOGRAPHS

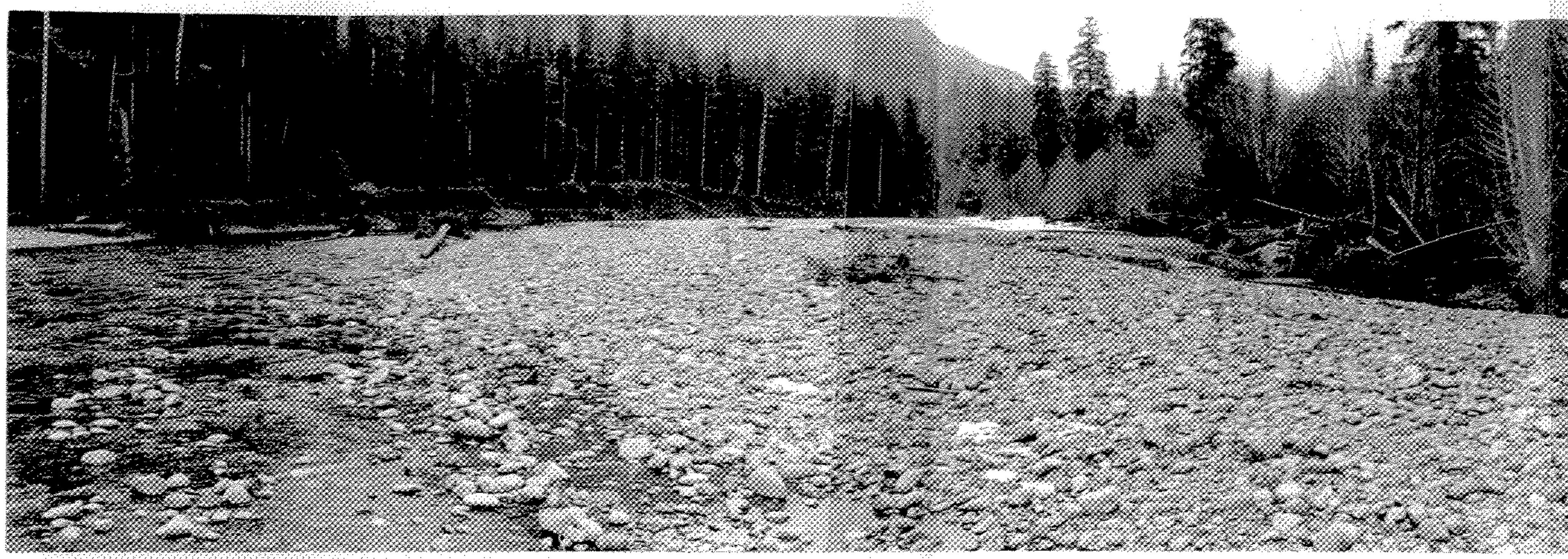

PHOTO 1 : TSITIKA RIVER BED ABOUT 1 KM UPSTREAM FROM THE MOUTH, JAN. 1991

PHOTO 2 : SCHMIDT CREEK BED ABOUT 100M UPSTREAM FROM THE MOUTH, JAN. 1991

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PHOTOS 1 & 2

MFORT-002/PHOTOS.DGN/91-03-26

PHOTO 3 : LOOKING TO THE WEST OF THE MOUTH OF SCHMIDT CREEK, JAN. 1991

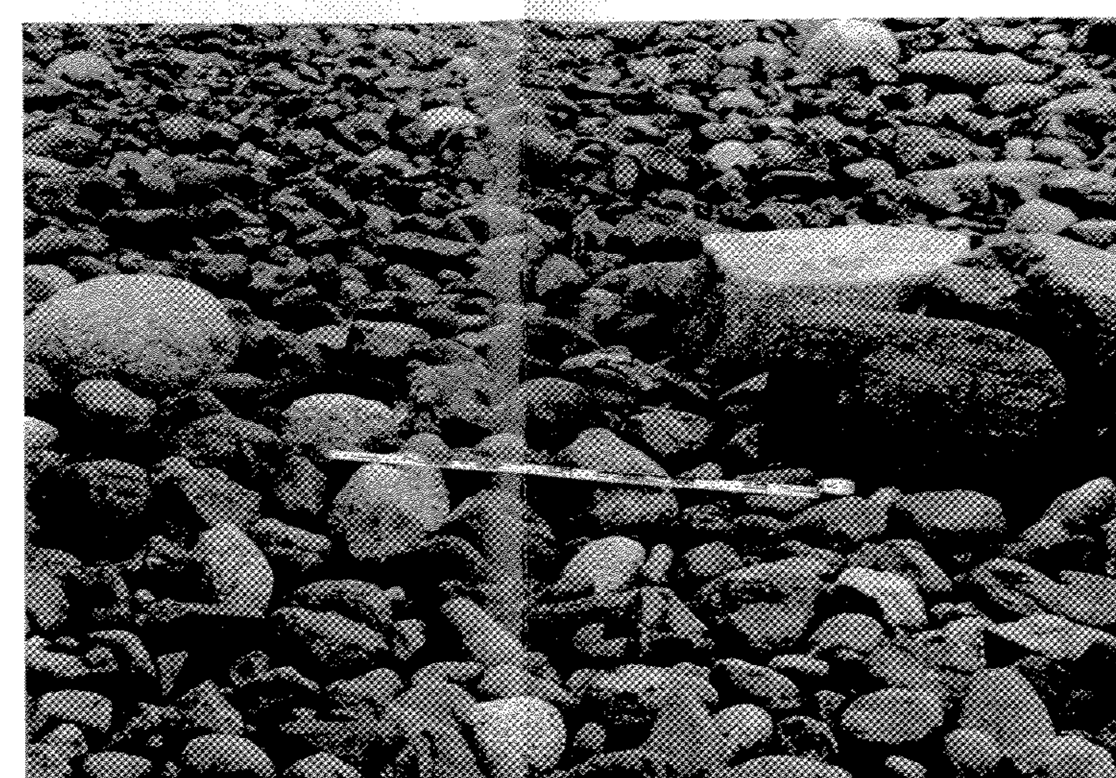

PHOTO 4 : SURFACE OF BEACH TO THE EAST OF SCHMIDT CREEK MOUTH, JAN. 1991

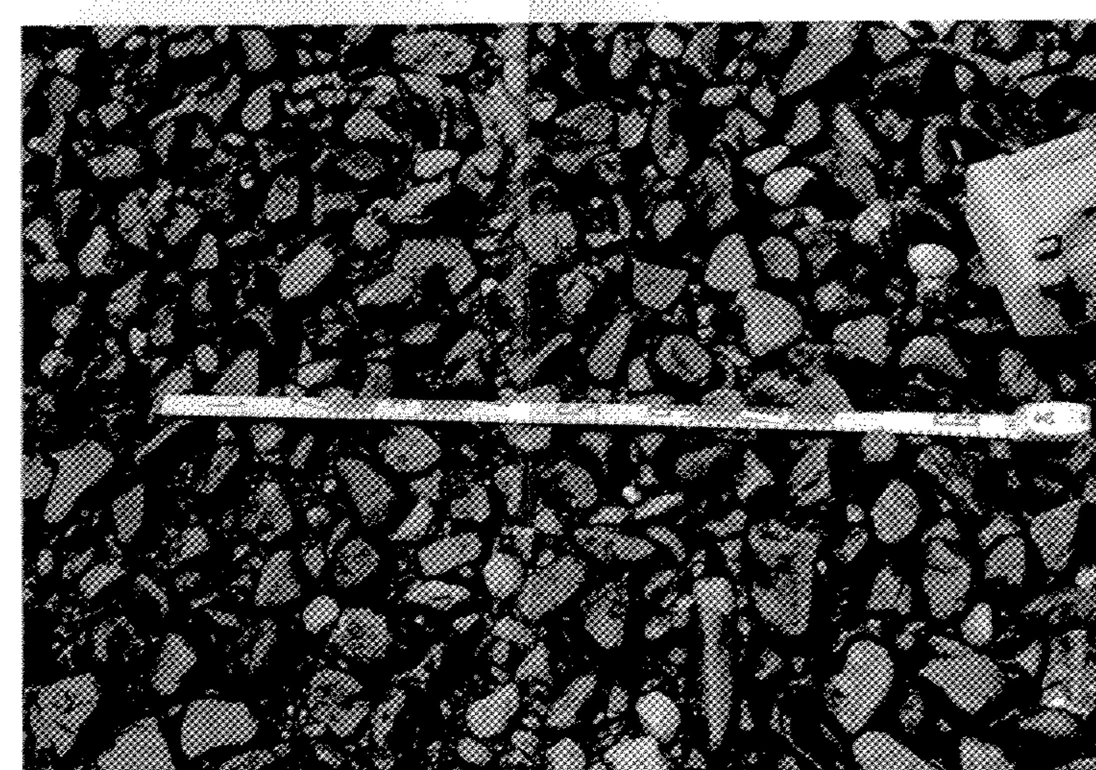

PHOTO 5 : SURFACE OF BEACH TO THE WEST OF SCHMIDT CREEK MOUTH, JAN. 1991

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SEDIMENT STUDY

PHOTOS 3 , 4 & 5

MFORT-002/PHOTOS.DGN/91-03-26

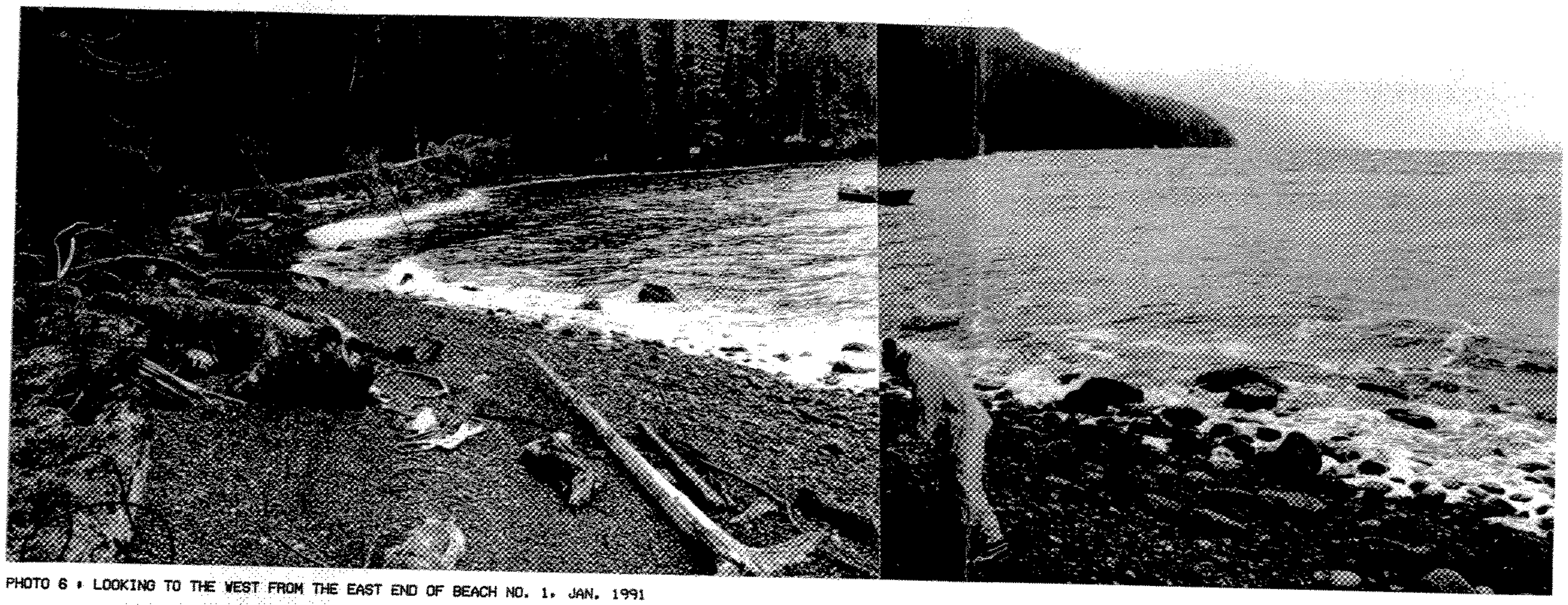

PHOTO 6 : LOOKING TO THE WEST FROM THE EAST END OF BEACH NO. 1. JAN. 1991

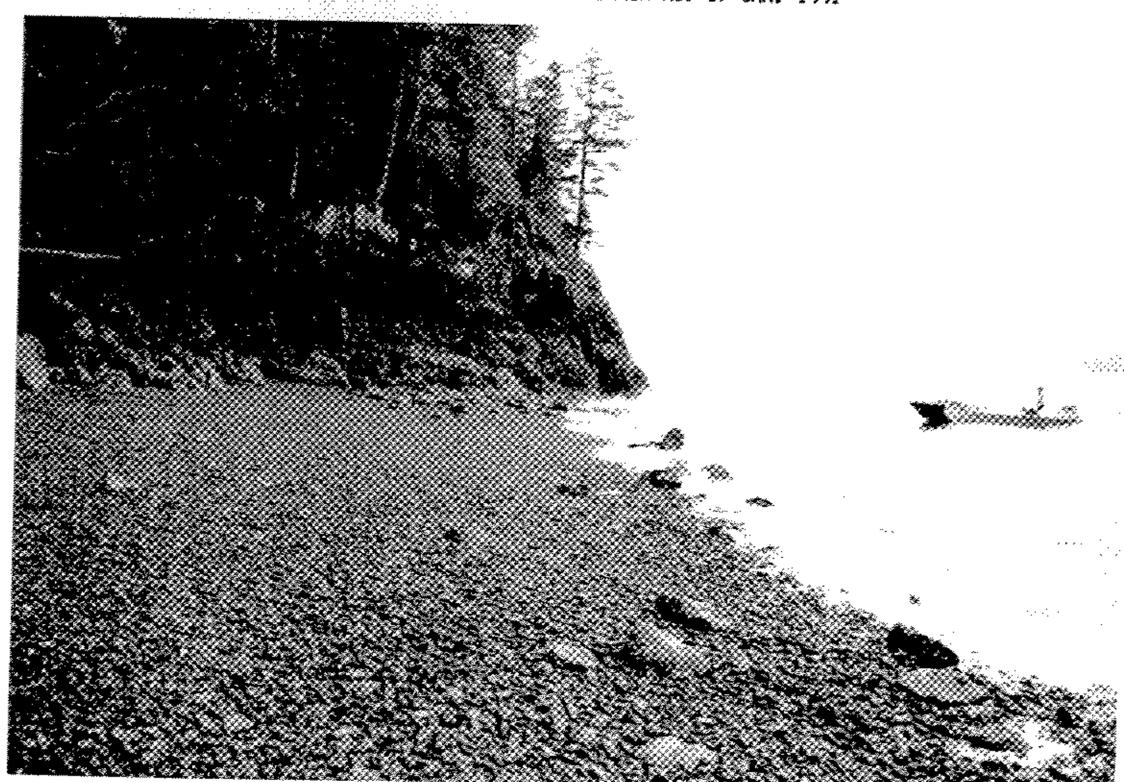

PHOTO 7 : BEACH NO. 1 AT THE WESTERN END. JAN. 1991

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ROBSON BIGHT
SEDIMENT STUDY

PHOTOS 6 & 7

MFORT-002/PHOTOS.DGN/91-03-26

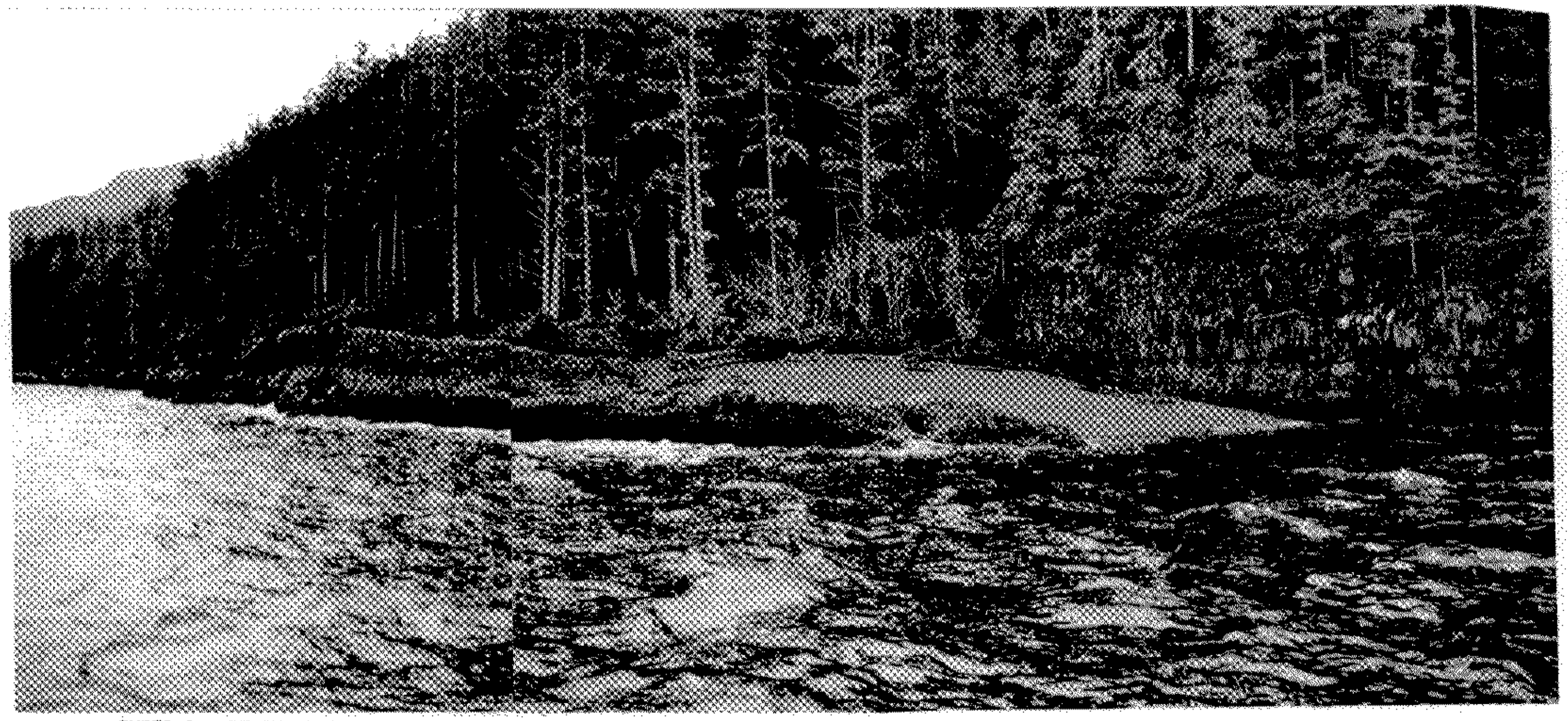

PHOTO 8 : BEACH NO.9. JAN. 1991

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SEDIMENT STUDY

PHOTOS 8

MFORT-002/PHOTOS.DGN/91-03-26