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Prince Edward Island: Coastal Environments and the Cleanup of Oil Spills

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PRINCE EDWARD ISLAND:

COASTAL ENVIRONMENTS AND THE

CLEANUP OF OIL SPILLS

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ABSTRACT

The coasts of Prince Edward Island represent only a small fraction of Canada's total coastline, but they are among the most intensely used during summer months. A major coastal spill, therefore, could have a severe impact on the island's economy. This review of the shoreline and process characteristics of the coasts of Prince Edward Island was prepared as part of a contingency plan for oil spills in the Atlantic Region. The shore zone has been divided into eight coastal environments which are defined and described in terms of the coastal processes and geomorphology. The straight, high-energy shorelines, which are exposed to waves out of the north, are predominantly bedrock cliffs or well-developed barrier beach shorelines backed by lagoons. By contrast, on the south and east coasts the many sheltered sections of shoreline result from the complex coastal configuration and the short fetch distances. These coasts are characterized by a wide range of shoreline types, from marshes to cliffs; there are few areas of extensive beach accumulation. In areas of low coastal relief on the Northumberland Strait shore, the large tidal ranges produce many sections of wide flats that are exposed at low tide. Access to the shore zone is relativly easy in most areas due to the dense network of roads or tracks on the island. Prince Edward Island is not a high-risk area in terms of ship-traffic density; however, a major shipping route traverses the Gulf of St. Lawrence to the north, and numerous small tankers or oil barges service local ports on and adjacent to the island.

This report reviews relevant information on the nature and degradation of oil and on the shoreline processes and shoreline types. The expected impact and persistence of spilled oil is related to the major shoreline types that occur on the island, and recommended protection and cleanup procedures are presented. Each of the available onshore protection and cleanup techniques is reviewed and shoreline sensitivity is discussed in terms of spill-response priorities and operational decisions. A series of checklists is presented that can be used to identify relevant spill and shoreline information requirements for response decisions.

RÉSUMÉ

Les côtes de l'Ile-du-Prince-Édouard ne constituent qu'une fraction de l'ensemble des côtes canadiennes, mais elles comptent parmi celles qui sont le plus utilisées pendant l'été. Un déversement important pourrait donc y avoir des répercussions extrêmement sérieuses sur l'économie de l'île. Le présent examen des rives et des caractéristiques dynamiques des côtes de cette province fait partie d'un plan d'urgence élaboré pour la région de l'Atlantique en prévision des déversements. La zone côtière a été divisée en huit milieux à partir des caractéristiques dynamiques et de la géomorphologie. La côte nord de l'île présente des rivages rectilignes et exposés à de fortes vagues. Elle est surtout constituée de falaises de roche-mère et d'importants cordons littoraux délimitant des lagunes. A l'opposé, sur les côtes sud et est, les nombreux secteurs abrités du rivage proviennent de la configuration complexe de la côte et du peu de longueur des fetchs. Ces côtes présentent de très nombreux types de rivages qui varient des marécages aux falaises, et on y observe, par endroits, de vastes plages. Dans les régions au relief peu accentué du détroit de Northumberland, le marnage imporant a engendré de vastes bancs qui émergent à marée basse. Les rivages sont faciles d'accès dans la plupart des régions à cause de l'important réseau routier et ferroviaire. Pour ce qui est de la densité du trafic maritime, l'Ile-du-Prince-Édouard n'est pas une région où les risques de déversement sont très élevés. Toutefois, une important vois de navigation traverse le golfe Saint-Laurent au nord de cette province, qui est par ailleurs approvisionnée par de nombreux petit pétroliers ainsi que par des péniches.

Le présent rapport passe en revue les informations intéressantes portant sur la nature et la dégradation des hydrocarbures et sur les types de rivages et leur dynamique. Nous établissons un parrallèle entre les principaux types de rivages

rencontrés et les répercussions et la rémanence prévues des hydrocarbures déversés. Ceci nous permet de formuler des recommandations sur les méthodes propices de protection et de nettoyage. Nous passons en revue les méthodes accessibles de protection et de nettoyage et nous discutons de la fragilité du rivage en fonction des priorités et des tactiques du nettoyage. Nous présentons une série de listes permettant de déterminer les caractéristiques pertinentes des déversements et des rivages et de décider ainsi des mesures à prendre.

ACKNOWLEDGEMENTS

The study was initiated and encouraged by Dr. F.C. Duerden, Coordinator, Atlantic Region, Environmental Emergency Branch. The report illustrations were draughted by Mrs. G. Dunn and K. Lyle processed the photography. L.M. Zimlicki-Owens prepared the lay-out, edited and typed the report.

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PART 1 - FOREWORD

1.1 INTRODUCTION

Prince Edward Island is one of the most popular summer resort areas in Canada and the shorelines of the island are a major recreational attraction. In this respect, the coasts are particularly sensitive to pollution and a major oil spill could have a severe impact on the island's economy.

The preparation of practical and effective contingency planning for this region is an important factor for minimizing the impact of a major oil spill. One part of the planning for preparation of an effective spill-response operation is the collection of information and data on the coastal processes and shoreline types of the area. This report was prepared as part of this planning process for the island and focusses on the protection of shorelines from oil on the adjacent waters and on the cleanup of oil stranded on the shorelines.

The description of the coastal processes, shoreline types, expected impact of oil, and protection and cleanup methods is intended to provide an understanding to the level that is necessary for basic spill-response decisions. Protection and cleanup operations require more detailed site-specific information, which cannot be practically covered in this report. To date, no systematic mapping survey of the shoreline character of Prince Edward Island has been carried out that is adequate for effective contingency planning. The checklists described in Part 9 of this report are designed to assist in the collection of more detailed information and data that would be necessary for site-specific decisions during a response operation. The shoreline information checklist (#2) could be used as the framework for the collection of further data as part of a pre-spill planning programme.

The information contained in this report was obtained from aerial surveys and ground studies carried out at various periods between 1972 and 1975 and from a complete aerial reconnaissance survey of the island's coasts in May 1978. Published and unpublished information on the island's coasts and on previous spills has been reviewed. Experience gained from field studies of major oil spills in similar coastal environments has been applied to this region. The checklists were developed as a result of this experience and from discussions with others closely involved in the preparation of spill-response procedures.

1.2 OBJECTIVES

The primary objectives of this report were as follows:

(1) to define and describe the coastal environments of Prince Edward Island,

(2) to explain the significant coastal processes and shoreline characteristics in each environment,

(3) to discuss the broad relationships between coastal processes, shoreline types, and spilled oil,

(4) to discuss the expected impact and persistence of stranded oil on the major shoreline types of Prince Edward Island,

(5) to assess available onshore protection and shoreline cleanup methods in terms of their applicability and effectiveness to the major shoreline types of Prince Edward Island,

(6) to discuss sensitivity factors of the shore zone as they relate to coastal oil spills and to shoreline protection and cleanup decisions,

(7) to present a series of checklists for the collection of information that would be required for spill-response decisions related to: (a) protection/cleanup priorities, and (b) the selection of appropriate protection/cleanup techniques, and

(8) to present a bibliography of relevant coastal and cleanup information sources.

1.3 FORMAT

The first section of this report (Parts 2 and 3) describes in detail the coastal processes and shore-zone character of Prince Edward Island. The second section (Parts 4 to 9) presents a discussion of topics related to the impact and cleanup of stranded oil.

The initial description of the coastal processes and geological characteristics of Prince Edward Island (Part 2) provides a general background for the subdivision of the island's shoreline into eight coastal environments. These environments are defined primarily on the basis of shore-zone sediment transport systems. The shore-zone character, coastal processes, and shoreline types within each of the eight environments are described in detail (Part 3).

In the second part of the report, the relevant properties of oil, and the degradation and persistence of spilled oil (Part 4) are discussed prior to consideration of the characteristics of coastal processes and shoreline types (Part 5). These two chapters form the basis for the discussion of (a) the impact and persistence of stranded oil, and (b) the applicable protection and cleanup techniques for each of the island's major shoreline types (Part 6). The protection and cleanup techniques are described in more detail (Part 7) and the factors that are involved in protection and cleanup decisions are assessed in terms of shoreline sensitivity to coastal oil spills (Part 8). A series of spill information checklists are presented and are accompanied by a brief text discussion (Part 9).

The bibliography references all sources cited in the text and an appendix defines the terminology used in this report.

PART 2 - PRINCE EDWARD ISLAND

SYNOPSIS

Prince Edward Island has a long coastline due to the complex shoreline configuration of the east and south coasts. The west and north coasts are relatively straight due to shoreline simplification caused by erosion of the bedrock outcrops and by deposition of sediments to form barrier systems that enclose lagoons and estuaries. Shoreline energy levels and sediment transport rates are lower on the more sheltered east and south coasts; rates of shoreline change are also generally lower in these sections.

The prevailing winds are out of the west-southwest and there is a seasonal difference in wave-energy levels due to the dominance of high wind velocities during winter months. The north-facing coasts are exposed to long fetch distances (q.v.), whereas elsewhere fetch distances are generally less than 50 km. As a result, wave-energy levels are highest on the north-facing coasts.

Tides are less than 1.0 m in height on the north coast but increase up to maxima of 3.0 m in Northumberland Strait. Ice plays a major role in limiting shoreline processes for up to 4 months each year. Relief in the coastal zone is low, usually less than 20 m, and the bedrock outcrops are unresistant, red sedimentary rocks, predominantly sandstones, that are readily eroded by shoreline processes.

2.1 INTRODUCTION

Prince Edward Island is located in the southern Gulf of St. Lawrence and is separated from the mainland coast of New Brunswick and Nova Scotia by Northumberland Strait. Although the maximum length and average width of the island are only in the order of 200 km and 30 km respectively, the coastline is indented and is relatively complex in many sections (Fig. 1) and has a total length of 1260 km.

The tidal range is generally less than 1.5 m on the west and north coasts with maximum ranges up to 3.0 m occurring on the Northumberland Strait coasts. The north-facing coasts are exposed to waves generated across the Gulf of St. Lawrence and

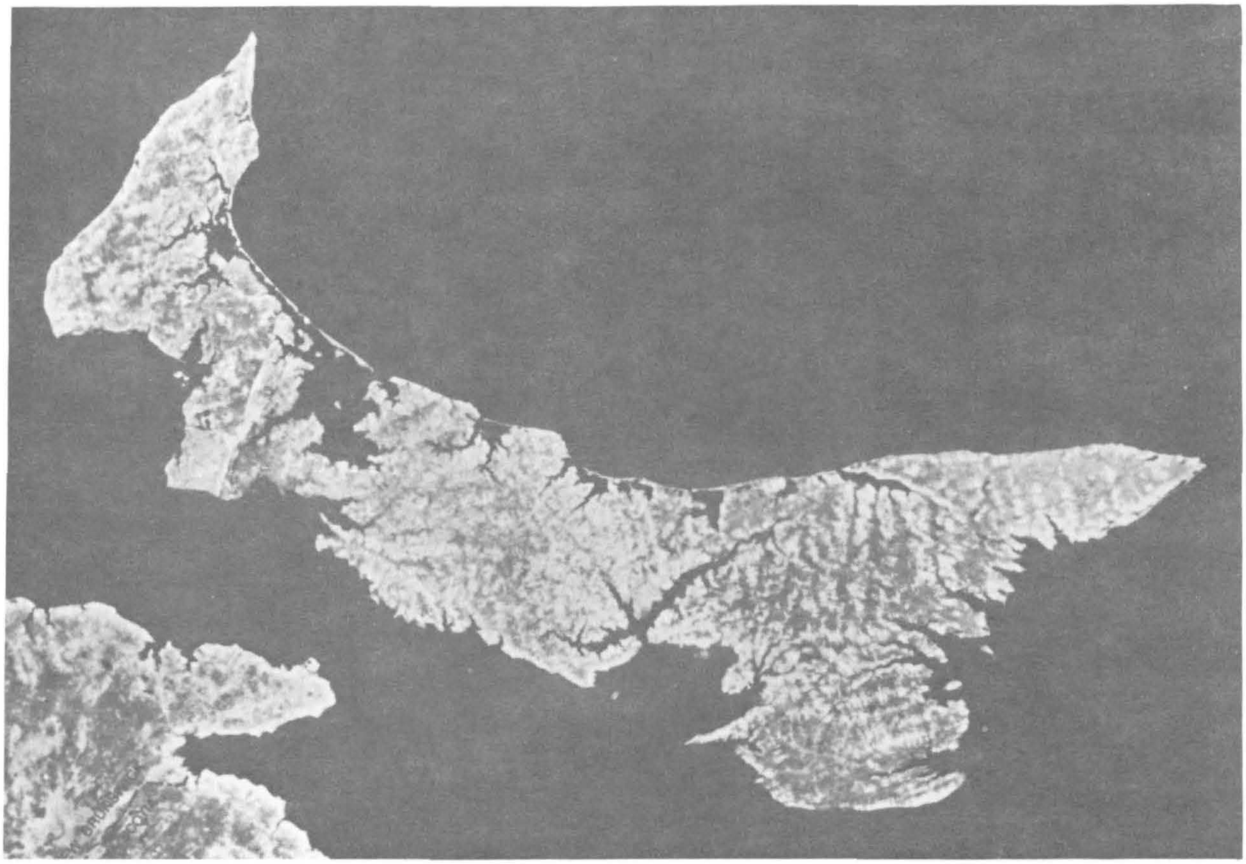

Figure 1. Satellite image mosaic of Prince Edward Island reproduced from Mosaic "E" - Maritime Provinces; National Air Photo Library, Ottawa, 1975, (scale is approximately 1 cm to 12 km).

this relatively high-energy coast is in marked contrast to the sheltered shores of Northumberland Strait where fetch distances rarely exceed 50 km and where tidal processes play a more significant role.

Relief on the island is generally less than 100 m and the coastal zone is characterized by a wide variety of shoreline types which include wide intertidal mud flats, marshes, sand barrier beaches and rock cliffs. As the coastal zone is composed of either sediments or unresistant bedrock outcrops, rates of shoreline change are relatively rapid in sections exposed to high wave-energy levels or in areas of high tidal ranges.

2.2 COASTAL PROCESSES

Shore-zone character and shoreline changes are directly related to inputs of mechanical energy (winds, waves, tides and ice). These factors are described at the regional level and, following a discussion of the geology of the island (Part 2.3), are then related to the transport and distribution of shore-zone sediments (Part 2.4).

Winds

The predominant and prevailing winds recorded at Charlottetown and Summerside are out of the west and southwest (Table 1, Fig. 2a). There is a seasonal variation in direction, with winds out of the southwest predominating from April to September, and those out of the west from October to March (Fig. 2b). Also a marked seasonal variation in average wind velocity occurs with the maxima (>25 km/hr) in winter months between October and April (Fig. 2c).

TABLE 1. Meteorological Data

a. PREVAILING WIND DIRECTION
b. MEAN MONTHLY WIND VELOCITY (km/hr)
c. MEAN DAILY TEMPERATURE (°C)

LOCATION		JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR
Charlottetown	a.	W	W	N/W	N/W	WSW	WSW	WSW	WSW	WSW	W	W	W	W/WSW
	b.	22.5	21.2	22.5	20.1	19.0	17.7	15.6	16.1	17.2	19.0	20.3	21.1	19.3
	c.	-6.7	-7.2	-3.2	2.3	8.6	14.1	18.4	17.9	13.9	8.6	3.3	-3.6	5.6
Summerside	a.	W	W	WNW/N	NNE	SSW	SSW	SSW	SSW	SSW	WSW	W	W	W/SSW
	b.	28.2	26.4	27.4	24.8	24.1	24.3	21.7	22.2	24.0	24.0	26.2	26.7	24.9
	c.	-6.9	-6.9	-2.9	2.7	9.1	14.7	19.0	18.4	14.5	9.0	3.3	-3.7	5.8

Source: Canada, Dept. of Transport, 1968,
and Environment Canada, 1973.

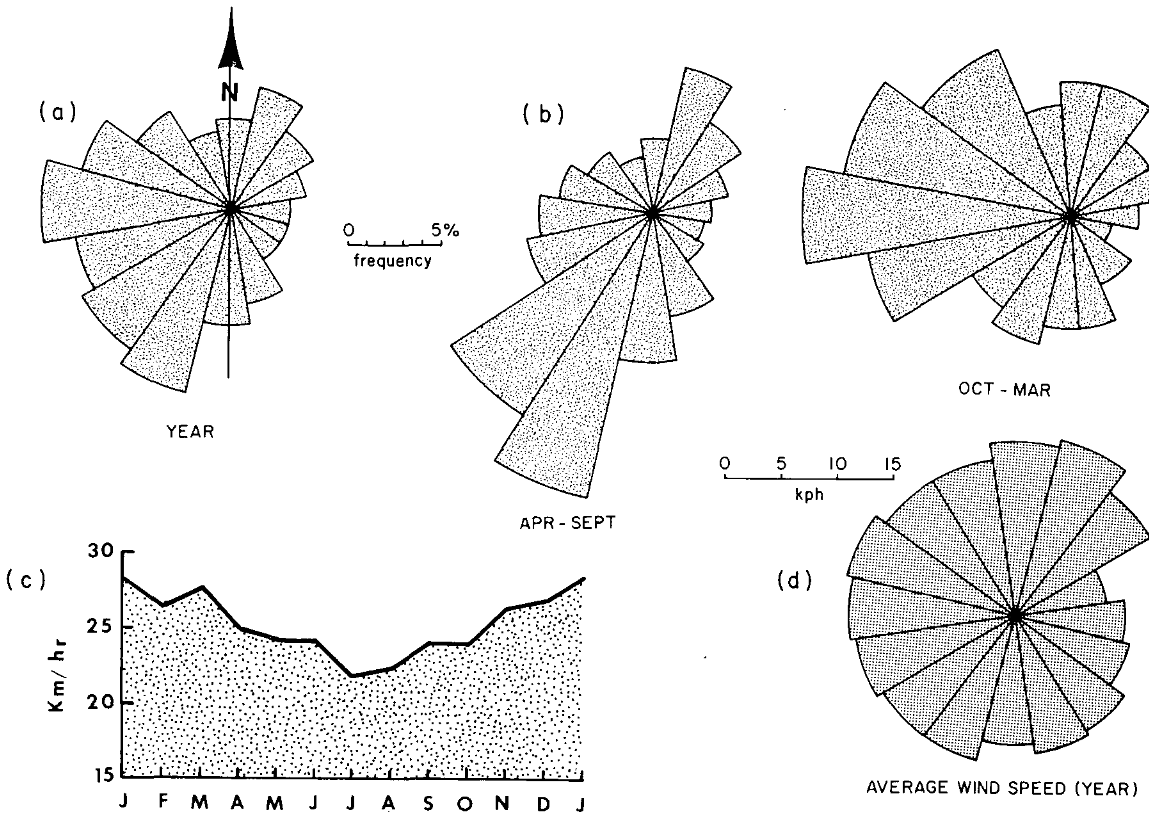

Figure 2. Summerside wind data: (a) annual direction by frequency, (b) seasonal direction by frequency, (c) monthly average velocity, and (d) average annual velocity by direction (source: Canada, Department of Transport, 1968).

Although winds out of the southwest quadrant predominate, there is a secondary wind direction out of the northeast and these winds tend to be of a higher velocity (Fig. 2d). This factor is significant as the longest fetch distances on the island's coasts are those to the north.

Superimposed on the averaged characteristics of the winds is the importance of cyclonic storms that cross the Gulf of St. Lawrence throughout the year. These storms are more intense and more frequent during winter months (October to April), and frequently produce strong winds out of the northern and occasionally eastern quadrants.

Waves

The generation of waves in the Gulf of St. Lawrence is limited by the fetch distances. For Prince Edward Island the maximum fetch on the north shore is to the northeast and is in the order of 700 km. On the other coasts of the island, fetch distances rarely exceed 75 km and frequently are less than 50 km. In these terms, the north shore is an exposed, wave-energy environment, whereas, the remainder of the island's coasts must be regarded as relatively sheltered, wave-energy environments.

The generation of waves is also dependent on the wind. Seasonal variation in wind velocities causes a seasonal change in wave-energy levels. Wave heights are lowest in summer months (Table 2) with maxima occurring in autumn (before ice forms in the Gulf). In the Gulf of St. Lawrence, wave heights increase from west to east in response to the predominant westerly winds (Owens and Bowen, 1977); this variation can be detected in wave height data collected off the north shore of Prince Edward Island (Table 2). Although no long-term wave measurements are available for other sections of the coast, the short fetch distances limit

TABLE 2. Median Significant Wave Height (in m)

	June to Mid September	Mid September to October	November - December	Whole Season	Expected Significant Wave Height Once/Year
NORTH POINT	0.58	1.02	1.10	0.91	5.48
EAST POINT	0.76	0.99	1.28	0.91	5.79

(from Ploeg, 1971)

the generation of waves in other areas. Apart from the north-facing coasts, significant wave heights greater than 1.0 m are not common and occur only during periods of local, high wind velocities.

Tides

Although the tidal range is everywhere less than 3 m, there are significant local variations in the tidal characteristics. The tides are predominantly mixed, semi-diurnal, that is, the tides have two high and two low waters each day with marked inequalities in the height of the tides (Charlottetown, Fig. 3). In western Northumberland Strait and in the vicinity of Rustico, the tidal character changes and is predominantly mixed, diurnal,

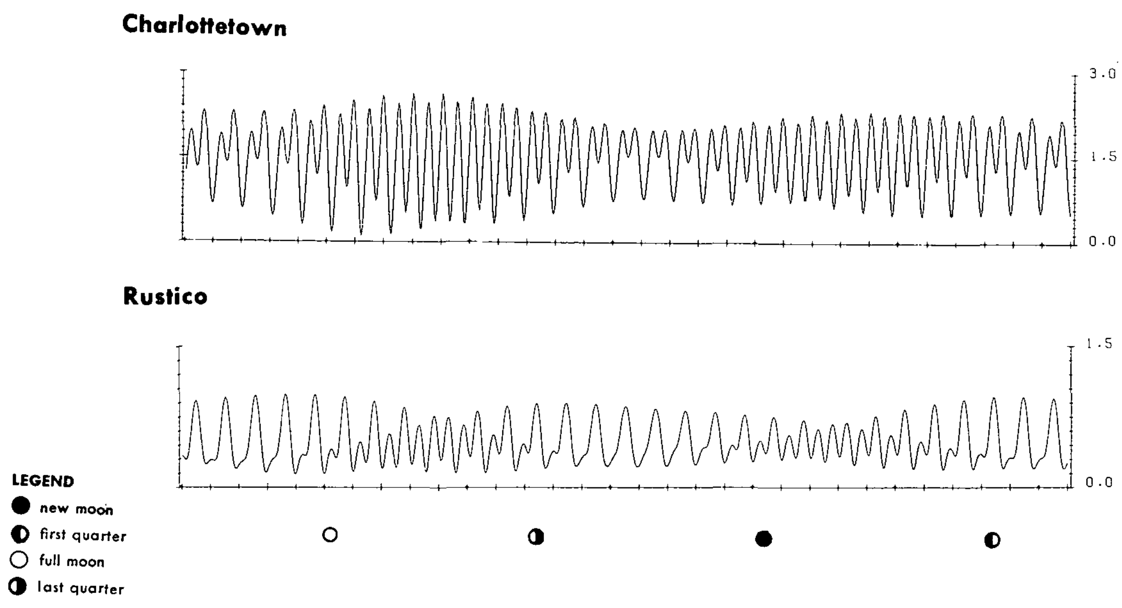

Figure 3. Typical tidal curves for one month: Charlottetown and Rustico. Note the difference in scale (in metres) between the two graphs, (Source: Canadian Hydrographic Service, 1975a).

TABLE 3. Tidal Ranges

LOCATION		MEAN TIDAL RANGE	LARGE TIDAL RANGE
A	North Point	0.8 m	1.2 m
B	Alberton	0.7	1.0
C	Malpeque	0.7	1.1
D	Rustico	0.7	1.1
E	St. Peters Bay	0.6	0.9
F	North Lake Harbour	0.7	1.1
G	Souris	1.1	1.7
H	Georgetown	1.1	1.8
I	Murray Harbour	1.2	1.8
J	Point Prim	1.8	2.8
K	Charlottetown	1.8	2.9
L	Victoria	1.9	2.9
M	Summerside	1.5	2.2
N	Cape Egmont	0.9	1.3
P	West Point	0.8	1.3
R	Miminegash	0.8	1.3

(Source: Canadian Hydrographic Service, 1975a)

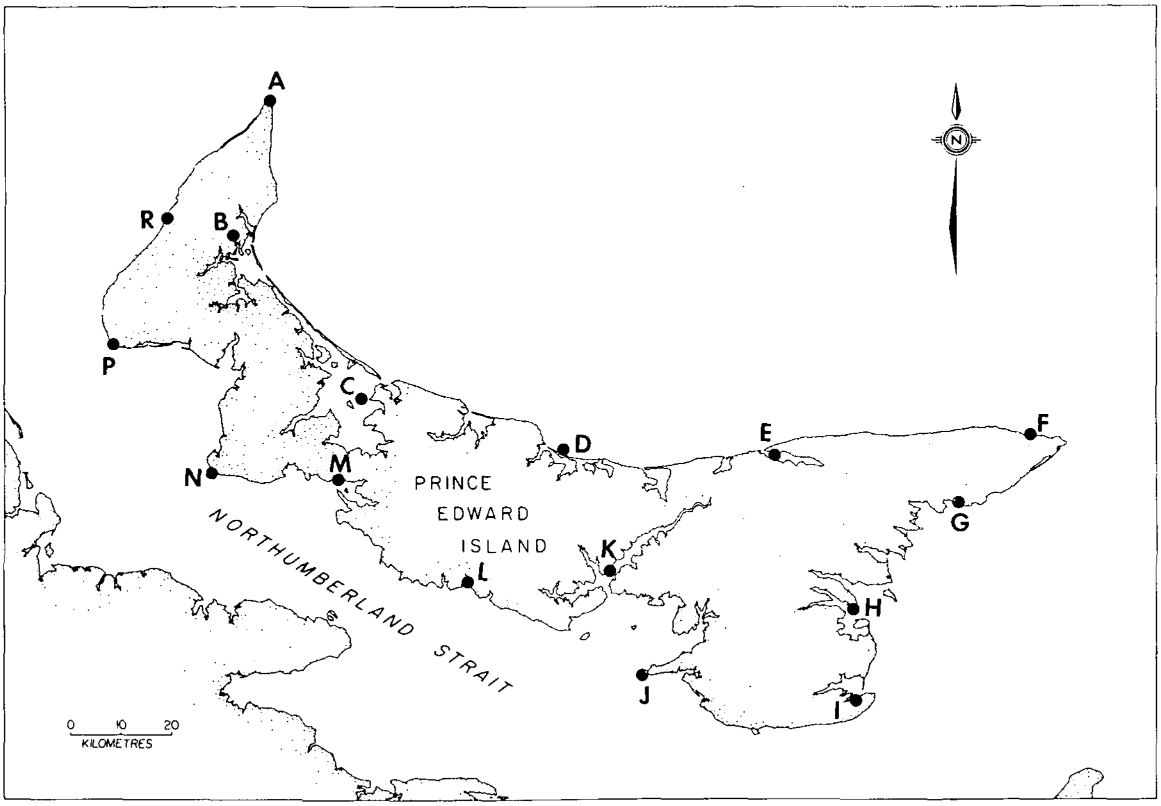

Figure 4. Location of tidal stations referred to in Table 3.

that is, with only one high and low water each day (Rustico, Fig. 3).

The mean tidal range on the west and north coasts is less than 1.0 m (Table 3), but increases in Northumberland Strait to greater than 1.5 m, with maximum ranges up to 3.0 m. An important relationship between waves and tides is that as the tidal range increases available wave energy is dissipated over a wider shore zone. Therefore, on the west and north coasts, which have the highest levels of wave energy, the energy is concentrated in a relatively narrow, vertical section. By contrast, in the more sheltered east and Northumberland Strait coasts, the tidal range is greater and the available wave energy is dissipated over a wider, vertical section of the shore zone.

Ice

The presence of ice in the shore zone or on the sea is an important limiting factor on coastal processes. Ice begins to form in the intertidal zones of sheltered areas (Photo 1a) when air temperatures drop below freezing during December. By early January the intertidal zone is covered by a layer of shore-fast ice, usually referred to as an ice foot (q.v.) (Photo 1b), that will remain until melting occurs in March and April (Fig. 5 and Table 1). On the adjacent sea surface the ice cover varies throughout the winter but is usually greater than 7/10 for at least a two-month period (Fig. 6).

The presence of beach or sea ice for approximately a four-month period each year affects coastal processes by limiting wave

Photo 1a. Initial development of an ice-foot at the upper limit of wave action. Scale is divided into 10-cm sections.

1b. An ice foot prior to development of the sea-ice cover. Photograph was taken at mid-tide, Richibucto, N.B., 3 January 1974.

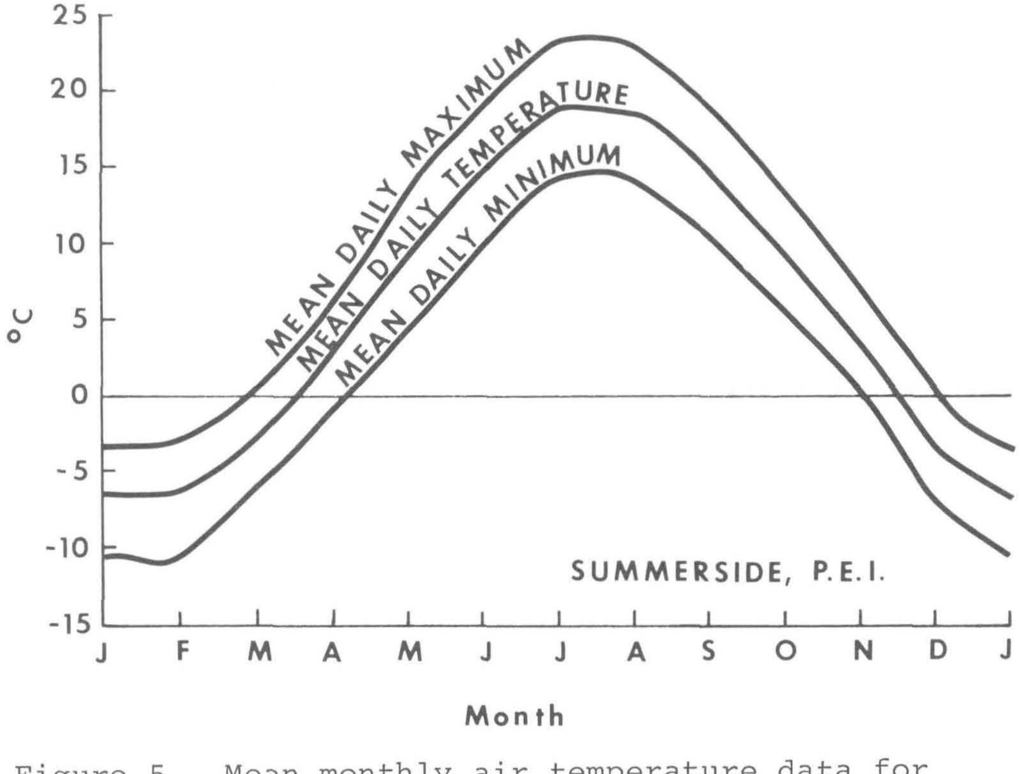

Figure 5. Mean monthly air temperature data for Summerside (from Environment Canada, 1973).

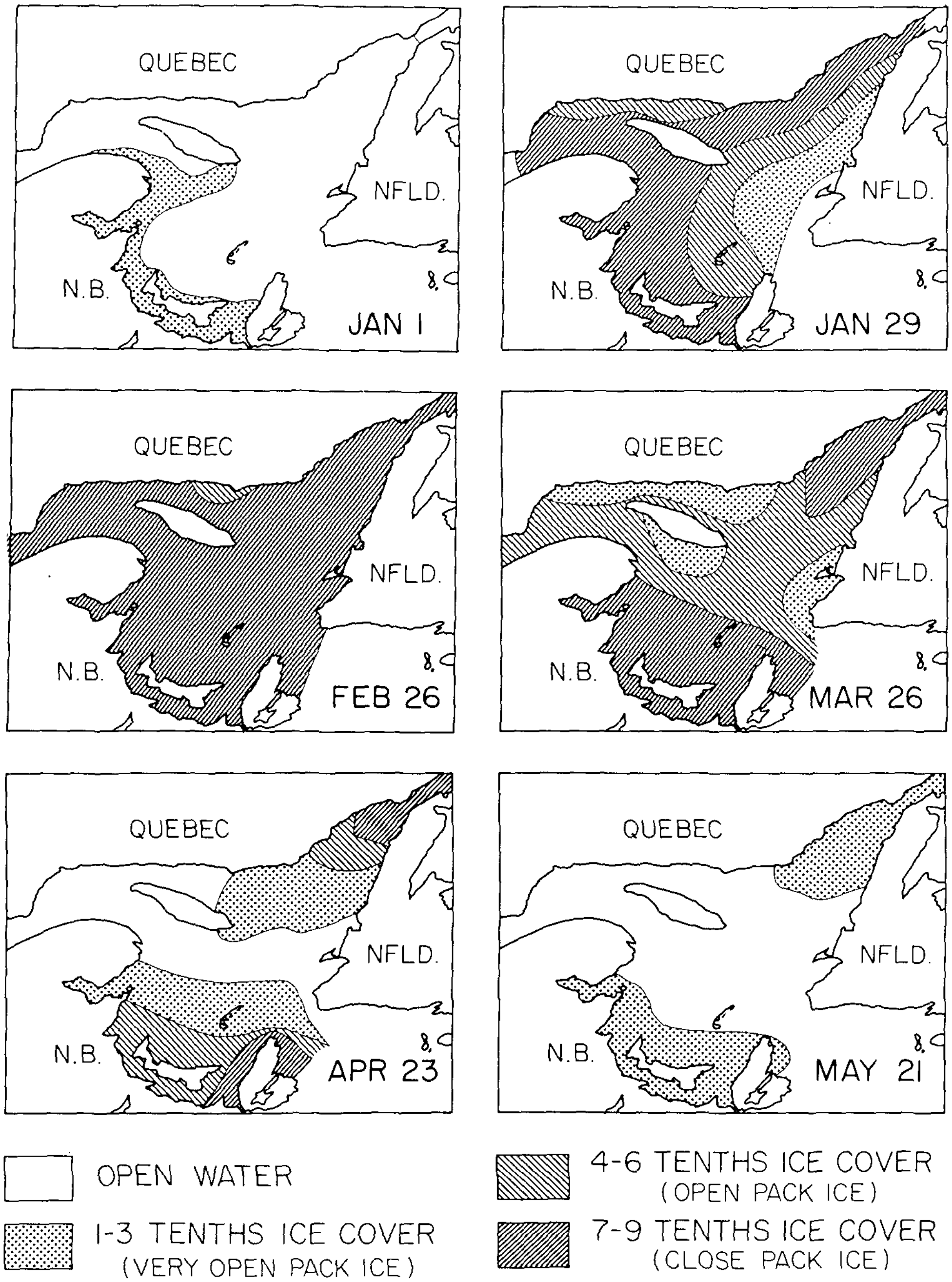

Figure 6a. Five-year mean ice distribution in the Gulf of St. Lawrence on selected dates (after Matheson, 1967).

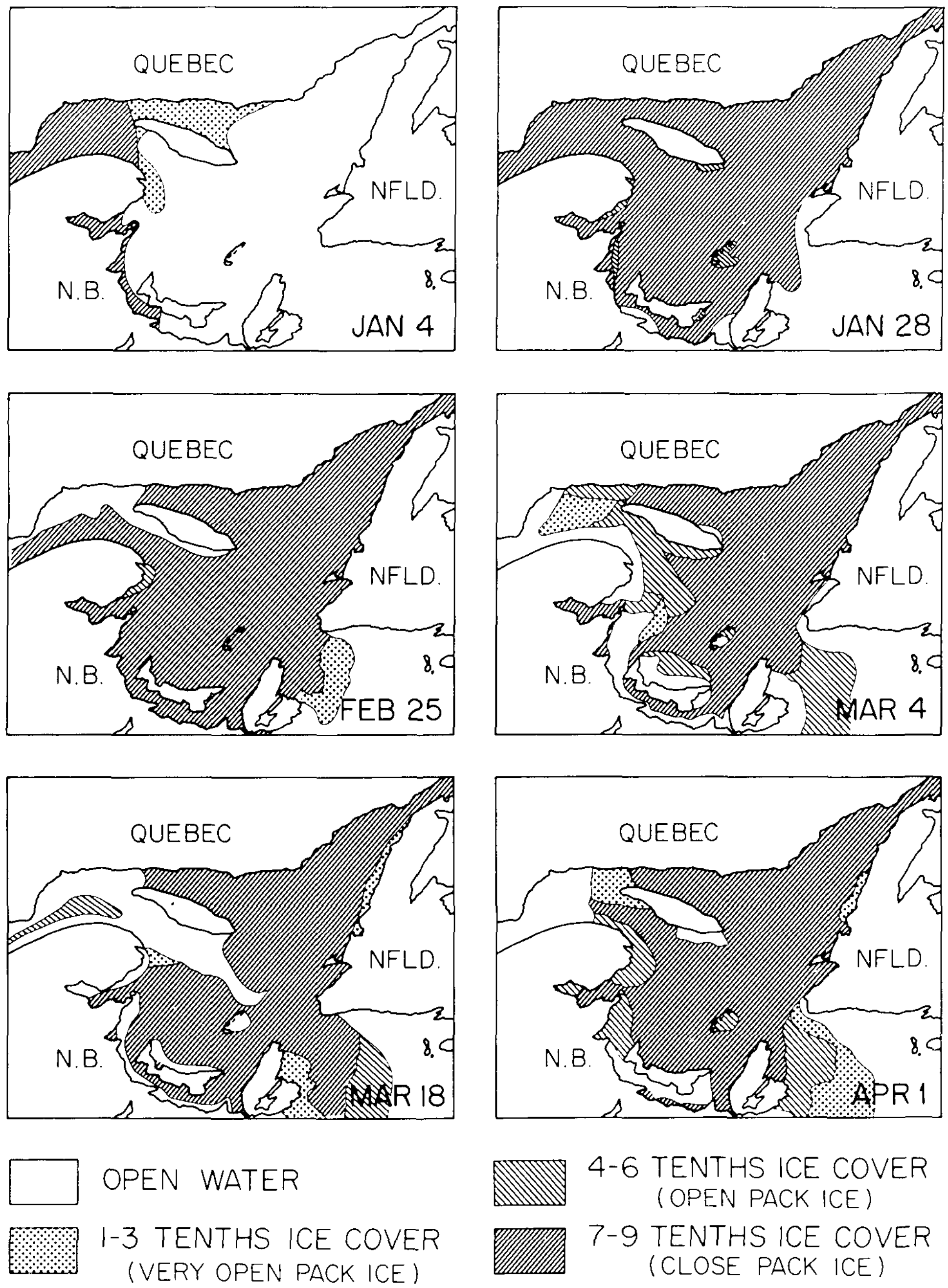

Figure 6b. 1974 Ice distribution on selected dates (from Owens 1976 - compiled from aerial ice-patrol maps, Ice Forecasting Central, Environment Canada).

generation, by dampening existing waves, or by protecting the shore zone from wave action. In the southern Gulf of St. Lawrence, these effects are particularly significant as they occur at the time of year when wind velocities are greatest and when the potential for wave generation would otherwise be at a maximum.

2.3 GEOLOGY

Prince Edward Island is part of an extensive area of undeformed and unresistant, red sedimentary rocks, predominantly sandstones, that forms the southern margin of the Gulf of St. Lawrence. The area is a lowland and coastal relief is rarely greater than 20 m. River erosion along ancient valleys formed the depression now occupied by the waters of Northumberland Strait (Kranck, 1972).

The sedimentary rocks have not undergone major folding or faulting but two important structural trends can be identified. In the western half of the island, broad northeast-southwest structural axes parallel the straight west coast (Prest, 1962). Large headlands (*e.g.*, North Point) and embayments (*e.g.*, Malpeque Bay) have resulted from erosion along these axes. In the east, the structural trends are predominantly east-west (Crowl, 1969; Frankel, 1966) (Fig. 7), and river erosion along fold axes has produced an indented eastern shoreline.

In many areas of the island, the bedrock is overlain by unconsolidated sediments that were laid down as marine sediments at a time of higher sea levels or were deposited by glaciers or

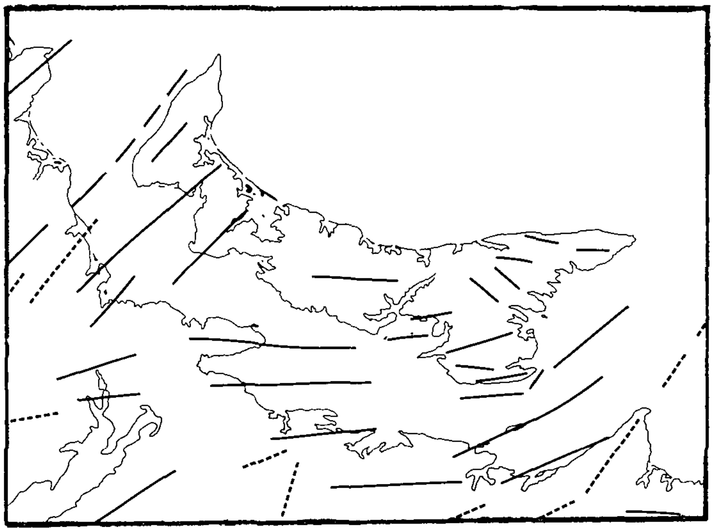

Figure 7. Structural trends: fold axes are indicated by the straight lines and fault zones by the dashed lines (from Owens, 1974).

former rivers. Sediments have been, and are being, supplied to the shore zone from the erosion of these unconsolidated sediments and the unresistant bedrock outcrops. In particular, the large barrier beaches of the north shore are derived from the local erosion, transportation and deposition of sand-sized sediments.

2.4 COASTAL GEOMORPHOLOGY AND SEDIMENT TRANSPORT

The coasts of Prince Edward Island, which include a wide variety of shoreline types, vary considerably in terms of shoreline complexity. The west and north shores have straight coastlines of either bedrock cliffs that parallel local structural trends or extensive barrier beaches. Shoreline simplification by the erosion of bedrock headlands and the growth of barriers to enclose lagoons and estuaries has resulted from high wave-energy levels on this coast. On the south and east coasts, wave energy levels are lower so that erosion and transport rates are also low by comparison to the north shore. On these coasts, the shoreline configuration is more complex as less wave energy is available to erode the headlands and insufficient sediment is available for the development of barrier beaches to enclose the numerous embayments and estuaries.

The general sediment transport directions are indicated in Figure 8 which also shows the general distribution of the major depositional features and of the predominantly bedrock, cliffed sections of coast. A more detailed description of the coastal characteristics is given in the following section (Part 3). The

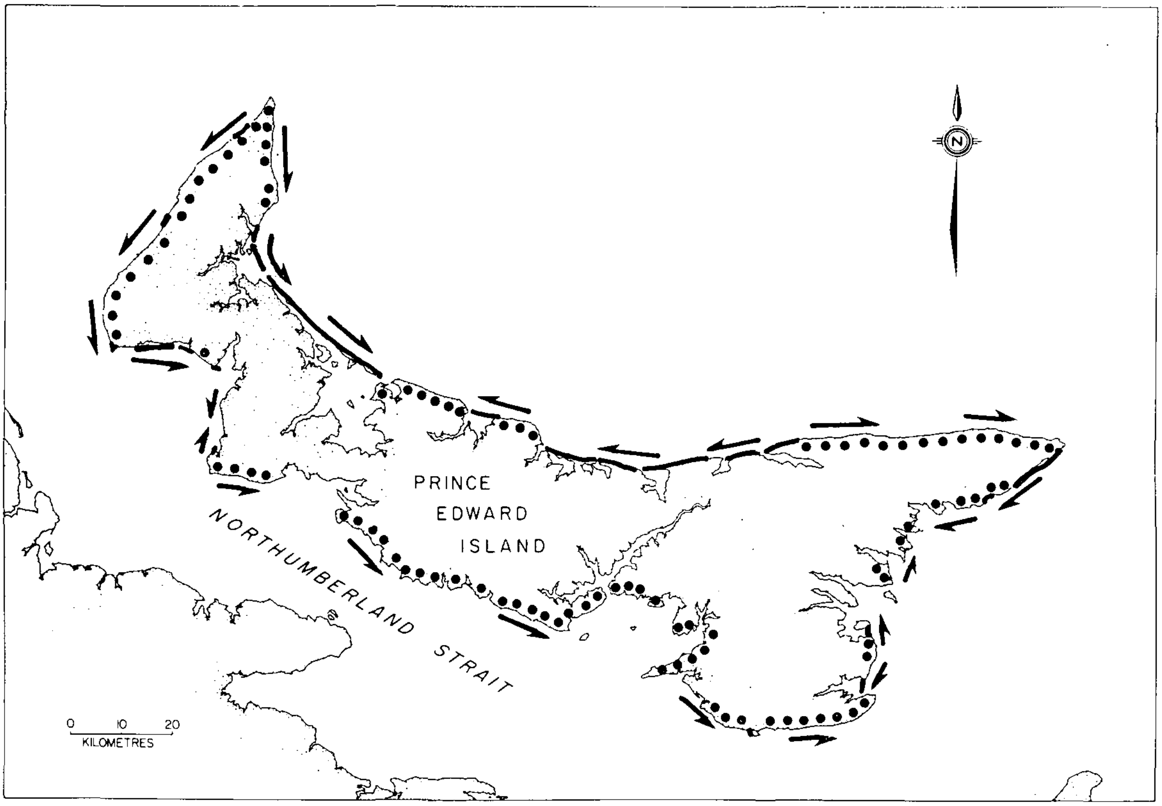

Figure 8. Shoreline character and sediment transport: the arrows indicate net shore-zone sediment transport direction; the solid lines are major depositional features; and the dot pattern indicates predominantly bedrock, cliffed sections of coast.

description of the coast is presented using eight coastal environments that have been defined primarily on the basis of the shore-zone sediment transport systems (Fig. 9).

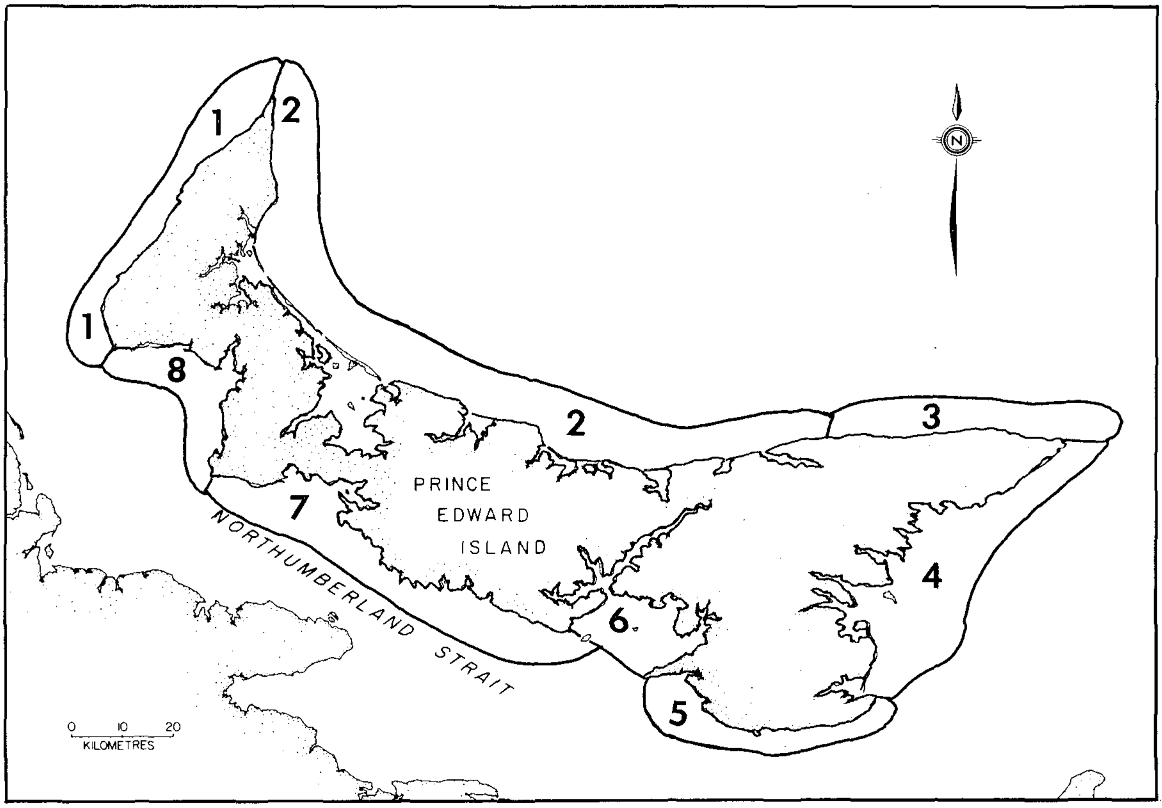

Figure 9. Coastal environments of Prince Edward Island.

PART 3 - COASTAL ENVIRONMENTS OF PRINCE EDWARD ISLAND

SYNOPSIS

The shorelines of Prince Edward Island have been divided into eight coastal environments on the basis of shore-zone sediment transport systems. Each unit is described in detail and particular emphasis is placed on the coastal processes and shore-zone character within each unit. The major process factors and morphological characteristics of each coastal environment are summarized as a table in the final section.

3.1 WEST COAST

This coastal environment is characterized by a straight shoreline of rock cliffs. The uniformity of the coastal geomorphology changes only at three stream exits which have sand barrier beaches and at West Point where a sand foreland has developed.

Relief in the coastal zone is low and cliffs are generally 5 to 10 m in height (Photo 2), but reach a maximum of 20 m locally (Prest, 1962). Rates of erosion are high and Prest (1973) reports an average erosion rate of 0.67 m/year (2 ft.) at North Point between 1935 and 1972.

Most sections of the cliffed coast have narrow beaches of mixed sand, or pebble and cobble sediments (Photo 2). Sand barriers have developed across small estuaries at Nail Pond, Skinners Pond, and Miminegash due to an accumulation of sediments eroded from the adjacent cliffs. The sediments are transported southward along the coast and a large foreland system has developed at West Point (Photo 3).

The mean tidal range in this unit is less than 1.0 m (stations P and R, Table 3, p. 11). The coast has a very short fetch (maximum 60 km) to the west, and waves generated across this

Photo 2. Cliffed coast near Cape Wolfe. Note the narrow beach at the base of the cliff (6 May 1978).

Photo 3. Aerial view to the north of West Point, which is gradually growing southwards due to the transport of eroded cliff sediments from coastal sections to the north (6 May 1978).

fetch are generally small in height. The most significant waves are those from the northern quadrant (see data for North Point, Table 2, p. 9), which generate southerly longshore currents in the shore zone (Fig. 8, p. 18). These currents transport the products of cliff erosion to the south.

3.2 NORTH COAST

The shoreline between North Point and Cable Head (Fig. 9, p. 19) is characterized by large embayments that are separated by rock cliffs. A system of spits and large barrier beaches has developed across the wide, shallow embayments to produce a straight shoreline.

The coastal zone has predominantly low relief and, where present, the cliffs are generally less than 10 m in height, but rise locally to 30 m at Orby Head (Photo 4) and Cape Tryon (see Frontispiece). As noted above, Prest (1973) reports a cliff erosion rate at North Point of 0.67 m/year (2 ft.). In the vicinity of

Photo 4. Orby Head. Cliff heights reach a maximum of 36 m at this location (6 May 1978).

Cape Tryon, Owens (1974) estimates an erosion rate of 1.5 m/year from a comparison of ground photographs from 1954 to 1972.

The barrier beaches and spits are retreating slowly landward at an overall average rate in the order of 0.25 m/year between 1935 and 1968, but local rates are reported as high as 0.49 m/year (Armon and McCann, 1977). In most areas, dunes up to 20 m in height have developed in the backshore (see Frontispiece), and retreat occurs by erosion at the base of the dunes during storms. In some sections, dune erosion has been accelerated due to the destruction of dune vegetation by human traffic (Photo 5). The loss of the vegetation cover results in wind erosion of the dunes and the creation of an unstable dune system. At some sites local breaching of the dunes by waves during storms has produced wash-

Photo 5. Wide sand beach (high water indicated by the arrow) at Brackley. Note the erosion of the foredunes in the left of the photograph and the construction of a boardwalk at right to alleviate the destruction of dune vegetation by pedestrians, (6 May 1978).

Photo 6. Washover channels through the dune-barrier system that encloses New London Bay (at right). The fence system across the channels was constructed to trap wind-blown sand in an attempt to rebuild the dune system (6 May 1978).

over channels (Photo 6) which have led to the deposition of eroded beach sediments on the lagoonal side of the barrier or spit.

The sand barrier system that encloses Cascumpec and Malpeque Bays is the most extensive on the island and is approximately 45 km in length. Historical records indicate that the system has had up to 7 natural inlets whereas at present only 4 exist (McCann, *et al.*, 1977). Similary, the embayments have been closed off by spit growth across New London Bay, Rustico Bay, Covehead Bay, Tracadie Bay, Savage Harbour and St. Peters Bay. Each of these bays is connected to the sea by inlets. Many smaller bays or river estuaries have also been enclosed, for example, the Tignish River and Point Deroche Pond.

In all cases, the beaches of the barrier and spit systems are composed of predominantly sand-size sediments, although pebbles and cobbles are common. At some beaches adjacent to cliffed sections, bedrock is exposed at times in the intertidal zone. Beaches at the bases of cliffs are narrow or absent and are characterized by mixed sand, pebble and cobble sediments. Within the sheltered lagoons, the shorelines are either narrow, low-energy beaches with sand and pebble sediments or marshes.

The mean tidal range in this unit is less than 1.0 m (stations A through E, Table 3, p. 11) and the tides are mixed semi-diurnal and diurnal (Rustico, Fig. 3, p. 10). The north shore of the island has the highest wave-energy levels due to the relatively long fetch to the north. Average wave heights are generally low in summer months (<0.5 m), but increase to over 1.0 m in autumn and winter (Table 2, p. 9). McCann and Bryant (1972) note that this seasonal change in wave energy levels results in erosion of the beach by storm waves during autumn and winter, and in rebuilding during spring and summer months as eroded sediments are returned to the beach from the nearshore zone.

In the western half of the unit, nearshore and beach sediments are transported from the north and northwest towards the east (Fig. 8, p. 18). Transport rates vary from 70,000 m^3/year in the northwest to a maximum of 200,000 m^3/year in the southeast section of this western half (Armon and McCann, 1977). East of Cape Tryon the sediment transport is from east to west as evidenced by the spit systems which, in all cases, have grown towards the west.

Within the inlets, tidal current velocities are generally greater than 0.5 m/sec and in some cases (*e.g.*, Alberton Inlet and Malpeque Channel) frequently exceed 1.0 m/sec (Armon and McCann, 1977; Canadian Hydrographic Service, 1975b).

The beaches of the National Park area within this unit are heavily used in summer months and are a primary economic resource for the island. At several locations, efforts have been made to reduce dune vegetation destruction by the construction of boardwalks to control pedestrian access and to reduce erosion rates on cliffed sections where property is endangered (Photo 7). In the latter case, stone nets of local rocks have been used to artificially stabilize the cliffs (Baird, 1973).

3.3 NORTHEAST COAST

This short, straight coastline section between Cable Head and East Point is considered a separate unit as the sediment transport system is characterized by a west to east movement of material in the shore zone (Fig. 8, p. 18). The shoreline is

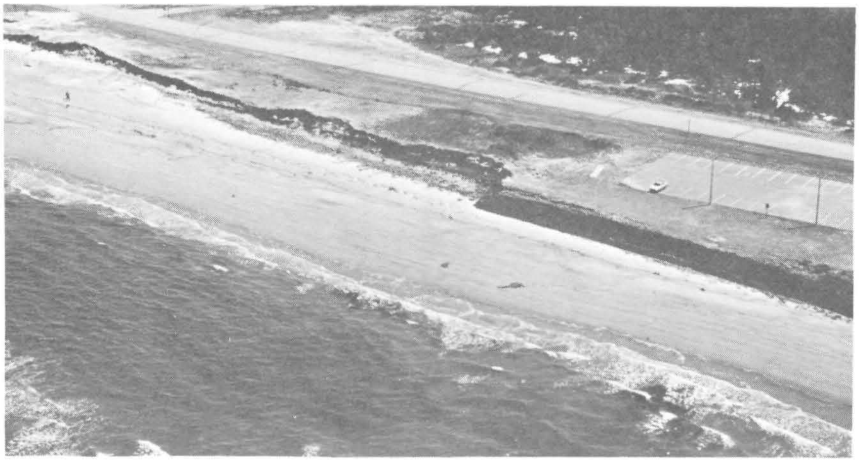

Photo 7. Shoreline erosion of unconsolidated cliffs (at left) at Dalvay Beach. The section at right has been protected by a network of stone baskets (6 May 1978).

predominantly cliffs of rock or unconsolidated sediments. Pocket beaches have developed in small embayments to the east of Shipwreck, Sylvester, Surveyor and Beaton Points and a barrier encloses North Lake (Photo 8).

This is an area of low shore-zone relief and cliff heights range between 2 and 6 m (Photo 9). In many sections the bedrock is mantled by unconsolidated sediments that are up to 3 m thick (Prest, 1973). At several locations these sediments form the entire cliff sequence in the backshore (Photo 10). No data are available on erosion rates but it is expected that these rates are in the same order (1 to 2 m/year) as elsewhere on the north coast.

Photo 8. Oblique aerial view to the west of North Lake. East Point is indicated by the arrow (August 1972).

Photo 9. Shore zone near Short Point, west of Naufrage. The bedrock is exposed in the shore zone as an intertidal rock platform and the bedrock in the cliffs is mantled by a 1 to 2 m-thick layer of unconsolidated sediments (6 May 1978).

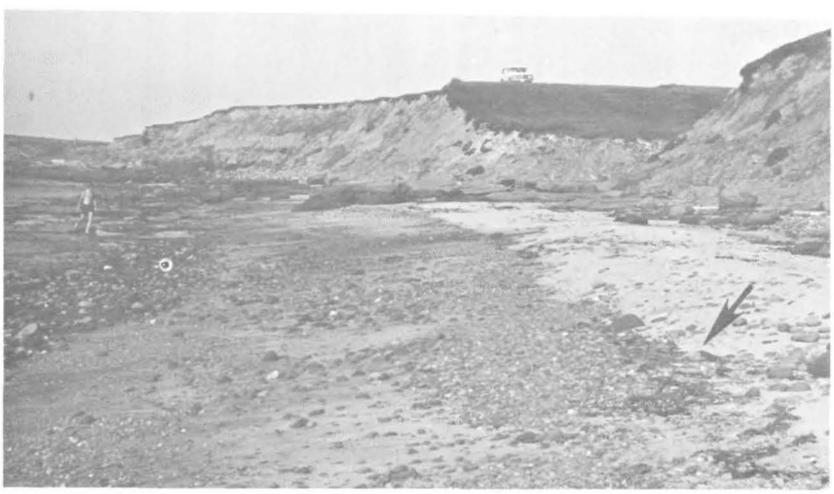

Photo 10. Cliff of unconsolidated sediments to the west of Long Point, near Bayfield. At this location, the beach is a mixture of sand, pebbles, cobbles and bedrock outcrops. The high-water mark is indicated by the arrow (photograph by J.R. Harper; August 1972).

The shore zone is characterized by either rock platforms (Photo 9), short sections of sand beaches, or narrow beaches of mixed sediments that range in size from sand to boulders (Photo 10).

The mean tidal range is less than 1.0 m (station F, Table 3, p. 11) and the tidal character is similar to that of the Rustico area (Fig. 3, p. 10). The wave climate is the same as that described for Unit 2 with a distinct seasonal variation in wave heights (Table 2, p. 9). The prevailing direction of wave approach is out of the west to northwest and these waves generate a strong west to east sediment transport in the beach and nearshore zones (Fig. 8, p. 18).

3.4 EAST COAST

This unit has a complex coastline configuration that is characterized by large estuaries, few of which have been enclosed by barriers or spits. Beaches are best developed and most extensive in the northern section between East Point and Deane Point where material transported from the west around East Point has provided sediment for beach accretion.

The estuaries of this coast were formed by river erosion along east-west structural trends. With the post-glacial rise in sea level, the broad valleys were flooded to give the present configuration of headlands and large re-entrants. Relief is generally low throughout the unit and cliffs rarely exceed 10 m in height. In many areas, the bedrock exposures are mantled by 2 to 3 m-thick deposits of unconsolidated sands and gravels (Photo 11).

Photo 11. Cape Abell, a low headland of bedrock in the intertidal zone and a cliff with bedrock at the base that is covered by a thick deposit of unconsolidated sediments (6 May 1978).

Cliff erosion rates vary considerably depending on local exposure to wave attack. For example, on the northeast shore of Bruce Point, Prest (1973) notes an average erosion rate of 0.67 m/year (2 ft.) from 1935 to 1958, whereas the southwest shore of the headland showed negligible recession. Over the same time period, Bruce Point itself retreated at a rate in the order of 2.75 m/year (9 ft.) (Prest, 1973).

The numerous small spits are characterized by predominantly wide, sand beaches (Photo 12), dunes, and marshes on the lagoonal shores. These spits are generally low in height and are limited in size due to low sediment supply rates to the shore zone. The largest accumulation of sediment is at Basin Head where the deposit developed by sequential seaward growth of beach ridges (Photo 13). At least 30 individual ridges can be identified (Palmer, 1974). The northeast half of the deposit is eroding and the beach ridges are truncated where they intersect the shore

Photo 12. The spit that has developed across Eglinton Cove is characterized by a wide, flat, intertidal terrace, low dunes, and marshes on the lagoonal shore (photo taken at low tide, 6 May 1978).

Photo 13. The beach-ridge complex at Basin Head. The barrier across South Lake is indicated by the large arrow and beyond South Lake the coast turns abruptly to the west at East Point (indicated by the small arrow) (August 1972).

zone. The other major deposits are also in this northeast section across South Lake and at Little Harbour. All three of these deposits have developed due to their proximity to the source of sediment supply around East Point.

Although the rivers carry sediment to the coastal zone, only small amounts of the material reach the outer shores as the riverborne sediments are trapped in the drowned valleys. For most of the region, with the exception of the northern section, the primary sediment source is local headland and cliff erosion. The predominant shore-zone sediment transport direction on the outer coasts is from north to south, with a reversal of direction between Graham Point and Howe Point (Fig. 8, p. 18). These drift directions are inferred from the growth patterns of spits that partially enclose some of the estuaries. Apart from the northeast section, sediment transport is compartmentalized due to the alternating systems of headlands and broad bays.

The tidal range on this coast is in the order of 1.0 m at mean tides and up to 1.8 m at large tides (Table 3, p. 11). Because of the higher tidal range on this coast and the generally low gradients across the shore zone, wide tidal flats occur in many of the estuaries, for example, Colville Bay near Souris, and intertidal bars are exposed on many beaches at low tide (Photo 12). The prevailing and dominant winds on this coast are offshore (Fig. 2a, p. 8) so that this unit is sheltered from all waves except those out of the eastern quadrant, which have a maximum fetch of 100 km. The wave climate is characterized by infrequent periods of high-energy wave action during autumn storms and relatively calm conditions during most of the remaining year.

3.5 SOUTHEAST COAST

Between Murray Head and Point Prim the coast is relatively straight, with the exceptions of Gascoigne Cove and Pinette Harbour. The predominantly rock cliffs that characterize the straight eastern section give way to low cliffs with wide, intertidal rock platforms and intertidal sand-mud flats west of Bell Point.

The straight eastern section of cliffs has predominantly narrow, coarse-sediment beaches except at Wood Islands, where one of two sandstone bedrock islands is connected on the west side by a sand barrier to the mainland. The cliffs in this eastern section range in height from 5 to 25 m, although they are generally less than 15 m. The shore zone is predominantly bedrock or narrow, pebble-cobble-boulder beaches (Photo 14).

Photo 14. Straight section of cliffed coast near High Bank. The cliffs are bedrock and in this section the beaches are narrow or absent (August 1972).

West of Bell Point the nearshore zone is shallower and in many places a wide (up to 100 m) intertidal zone is exposed at low tide (c.f. Photo 16). In this section some of the intertidal rock platforms are mantled by a veneer of fine-grained, red sediments that are organized by waves into a series of low parallel or sub-parallel bars. Sand spits have developed to partially enclose Gascoigne Cove. These are the only major beach accumulations in the western section of this unit. Within Pinette Harbour, the estuarine environment has extensive intertidal mud deposits exposed at low tide.

No data on shoreline changes are available for this unit. Wave action is limited by the sheltered location of this coast, nevertheless, erosion rates are high (up to 1.0 m/year) due to the unresistant nature of the cliff materials. Maximum fetch distances are in the order of 50 km to the west-southwest and 25 to 40 km to the south. The prevailing wave direction is out of the southwest quadrant, resulting in a west to east transport of sediment in the shore zone (Fig. 8, p. 18). The tides increase to the west from a mean and large range at Wood Islands of 1.5 and 2.2 m respectively (Canadian Hydrographic Service, 1975a) to 1.8 and 2.8 at Point Prim (Table 3, p. 11).

The coast is a sheltered wave-energy environment so that tides assume greater importance in terms of shoreline processes than on the west, east and north coasts of the island.

3.6 HILLSBOROUGH BAY

This large embayment is a very sheltered wave-energy environment that is characterized by a complex coastline configuration of bays and estuaries. Due to low coastal relief and a high tidal range (up to 3.0 m), many sections of the shore zone have a wide (up to 1 km), intertidal zone exposed at low tides.

Relief throughout this unit is low, and cliff heights rarely exceed 5 m. Three broad, drowned valleys coalesce at Charlottetown Harbour and to the east the broad estuary of the Vernon River exits into Orwell Bay. These valley systems form the majority of the coastline in this unit and are very low-energy environments characterized by wide, intertidal mud flats and marshes (Photo 15). In the open sections of the bay, energy levels are higher and the intertidal sediments are frequently organized by wave action into a series of parallel bars (Photo 16 and Frontispiece). Even in the open bay, marshes are common in sheltered

Photo 15. Marsh in the Hillsborough River, north of Charlottetown (6 May 1978).

Photo 16. Wide (1 km), intertidal zone of bedrock mantled by fine-grained sediments at Bellevue Cove (photo taken at low tide, 7 May 1978) (c.f. Frontispiece).

locations. In a few areas, rock cliffs and intertidal rock platforms characterize the shore zone (Photo 17).

The shore zones are dominated locally either by wave- or tide-induced processes, depending on the degree of exposure. In restricted channels, strong currents are generated due to the high

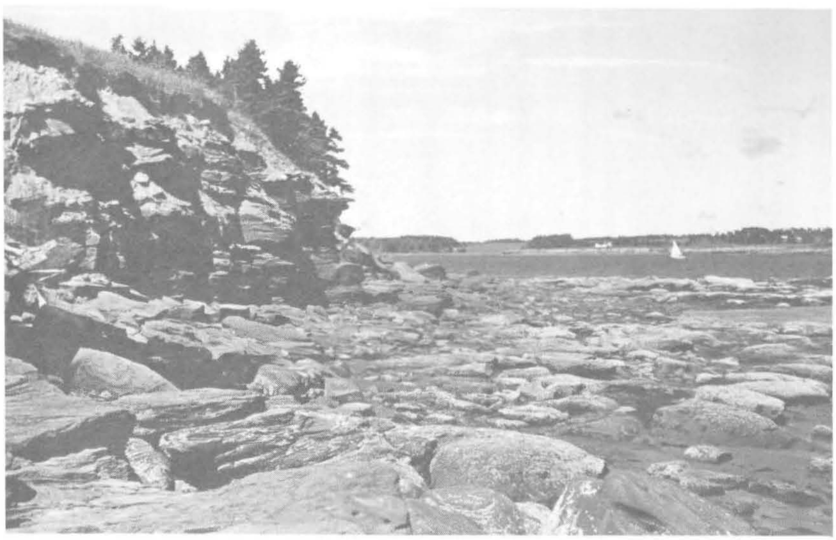

Photo 17. Rock cliffs and intertidal rock platform at Blockhouse Point (August 1972).

tidal ranges (up to 3.0 m; Charlottetown, Table 3, p. 11); Bartlett (1977) notes that currents up to 150 cm/sec have been recorded in Charlottetown Harbour.

3.7 SOUTH COAST

The Northumberland Strait coast between Rice Point and Cape Egmont has an extremely varied shoreline of rock cliffs, bays and intertidal flats. Bedeque Bay is an extensive, sheltered embayment in the western section of the unit where the structural trends are predominantly northeast-southwest. Elsewhere the generally straight shoreline trend is interrupted by numerous small coves, pocket beaches and estuaries.

The coasts of this unit have a considerable variety of shoreline types. The outer sections of coast are predominantly cliffs of bedrock (Photo 18) or unconsolidated sediments (Photo 19). Relief is low throughout most of this unit and cliff heights rarely

Photo 18. Straight coastline of bedrock cliffs west of Rice Point (6 May 1978).

Photo 19. Cliff of unconsolidated sediments to the east of Cape Egmont. Note the mixed (sand to cobble) sizes of beach sediments (Photo by J.R. Harper; August 1972).

exceed 10 m. The beaches adjacent to the cliffs are generally narrow and composed of mixed sand to boulder-size sediments. In the bays and coves, sand beaches fronted by wide, intertidal flats (c.f. Photo 16, p. 37) are common. Mud flats and/or marshes characterize the shore zone in the sheltered estuaries. Wave energy levels at the shoreline vary locally due to the crenulate nature of the coast. No data are available on rates of erosion but they are expected to be up to 1.0 m/yr due to the unresistant nature of the cliff materials.

Tidal range decreases to the west in this unit (stations L, M and N, Table 3, p. 11). Fetch distances are less than 50 km on most exposed shoreline sections and this is a relatively low wave-energy environment. The predominant wave direction is out of the southwest and this results in a west to east transport of shore-zone sediments (Fig. 8, p. 18). The littoral transport system is interrupted by the presence of headlands, and sediments tend to collect in the bays and coves.

3.8 EGMONT BAY

The shorelines of Egmont Bay are significantly different from the adjacent coasts. This is an area of low relief with low, sandy barriers or narrow beaches, wide tidal flats, and extensive marshes. Shoreline changes are rapid due to the unresistant nature of the shore-zone materials.

North of Cape Egmont a high (15 m) cliffed section of coast (Photo 20) gives way to a large, low sand spit across the Haldimand River estuary. To the north, the east coast of Egmont Bay is a low shore of narrow sand beaches and marshes (Photos 21 and 22).

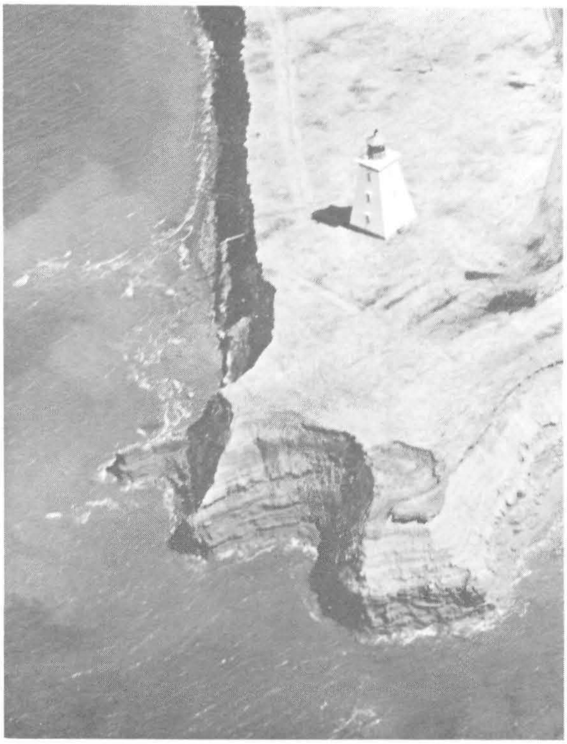

Photo 20. Cliffed coast at Cape Egmont. Cliff height is in the order of 15 m (6 May 1978).

Photo 21. Sediment accumulation behind a jetty at St. Chrysostome on the east coast of Egmont Bay. The transport direction is from north to south and the trapping of the sediment has led to downdrift starvation and shore-zone erosion (6 May 1978).

Photo 22. Small marsh behind a barrier beach in an estuary just north of Rocky Point. The ditches in the marsh were constructed for wildfowl management (6 May 1978).

Percival and Enmore Bays are partially enclosed by a shallow shoal across the entrance to the bays and the shore zone has extensive tidal flats up to 2 km wide at low tide.

On the north shore of Egmont Bay, a line of low, narrow, sand barriers encloses a narrow lagoon (Photo 23). Relief is low except between McIsaac Cape and Grand Digue, which has a 2 km section of low cliffs. The sediment source for the development of the low north-shore barriers is material that has been transported past West Point. The predominant transport direction on this shore is west to east (Fig. 8, p. 18).

Photo 23. Very low barrier beach, part of Indian Point Sand Hills, on the north shore of Egmont Bay. Sediment transport is from west to east (bottom to top) and the low barrier is frequently overwashed during storms (6 May 1978).

Although there are many beaches and sediment deposits within Egmont Bay, there is not a large supply of sediment to the shore zone. This is evidenced by shoreline erosion downdrift of jetties due to sediment starvation, for example, to the east of West Point and at Chrysostome (Photo 21), and by the frequent shoreline changes that characterize the barriers and spits (Forward, 1960). In addition, most sections of the coast are erosional, with rates in the order of 1 to 2 m/year, reaching a maximum of 3 m/year in restricted areas (Forward, 1960).

The high erosion rates result from the exposure of the coasts to waves out of the west and southwest which are generated over fetch distances up to 50 km. The mean tidal range is less than 1.0 m (Table 3, p. 11) so that wave action is restricted to a narrow vertical range. This unit has more exposed coasts than other sections of Northumberland Strait due to its orientation to face the prevailing and dominant winds out of the west and southwest.

SUMMARY

The primary characteristics of the coastal environments described in this section are summarized in Table 4. Ice is not included in the table as this factor is relatively constant throughout the island. Ice forms initially and persists longest in sheltered areas and is present in all environments for up to four months each year.

TABLE 4. COASTAL ENVIRONMENTS OF PRINCE EDWARD ISLAND

SUBDIVISION	RELIEF AND GEOLOGY	COASTAL ZONE		FETCH, WAVE EXPOSURE AND TIDES	SEDIMENT AVAILABILITY AND TRANSPORT
		SHORE-ZONE CHARACTER	BEACH CHARACTER		
1. West Coast	Low relief, cliffs less than 10 m; bedrock exposed along coast; structural trends northeast-southwest	Straight shoreline of predominantly cliffed coast, with small barriers across estuaries and a foreland at West Point	Beaches of coarse sediments on cliffed sections; sand beaches with dunes at four restricted locations	Fetch to west is 60 km; waves out of the north are more important; moderate wave-energy environment; tidal range up to 1.3 m	Sediment eroded from cliffs transported to the south; sediments generally scarce except at West Point
2. North Coast	Low relief, cliffs less than 10 m but rise at two locations to 30 m; bedrock exposed along the coast; structural trends northeast-southwest	Straight shoreline of cliffed rock headlands and extensive barriers or spits across embayments; large bays or lagoons behind barriers; cliff erosion rates 1 to 2 m/yr; bedrock exposed in intertidal zone at headlands	Barrier and spit sections have wide sand beaches and high dunes (up to 20 m); overwash common in some sections during storms; adjacent to cliffs beaches are absent or composed of coarse sediments; beaches subject to seasonal erosion-accretion cycles	Maximum fetch to the northeast is 700 km; exposed high wave-energy environment; seasonal variation in energy levels related to prevalence of storms in autumn and winter months; large tides range from 0.9 to 1.1 m	Sediment supply relatively abundant except in northwest and east, transport directions converge from the east and west
3. Northeast Coast	Low relief, usually less than 5 m; bedrock exposed along coast, often mantled by unconsolidated sediments; structural trends east-west	Straight, predominantly cliffed coast with bedrock exposed in intertidal zone in most sections; several small pocket sand beaches and a barrier across North Lake	Beaches adjacent to cliffs have sand to boulder size sediments; sand beaches with low dunes where cliffs are absent	Maximum fetch to the northeast is 700 km; exposed high wave-energy environment; seasonal variation in energy levels related to prevalence of storms in autumn and winter months; tidal range up to 1.1 m	Sediments generally scarce, transported through shore zone to the east past East Point
4. East Coast	Low relief, usually less than 10 m; bedrock exposed at headlands, usually mantled by unconsolidated sediments; structural trends east-west	Broad estuaries separated by headlands gives a complex shoreline configuration; some bays partially enclosed by spits; large sediment accumulations in the northeast section; bedrock exposed in intertidal zone adjacent to cliffs; erosion rates variable but over 2 m/yr on exposed sections	Adjacent to cliffs beaches are of sand to boulder size sediments; in lagoons and bays sheltered beaches are narrow and are of poorly-sorted sediments; exposed sand spits have dunes with wide intertidal zone and parallel bars exposed at low tides; marshes in bays	Maximum fetch to the east is 100 km, but predominant winds are from the west; sheltered wave-energy environment, with occasional exposure to high-energy wave conditions during storms; large tides range from 1.7 to 1.8 m	Sediments generally scarce except in northeast section; transport is compartmentalized due to headlands and valleys and sediments may be locally abundant; transport direction predominantly to the southwest and south, with a reversal to the north between Graham Point and Howe Point

5. Southeast Coast	Relief varies up to 25 m, but generally less than 15 m; bedrock exposed along coast, usually mantled by unconsolidated sediments; structural trends east-west	Straight coast in east with embayments in west; east has cliffs, few beaches and bedrock in shore zone; in west spits partially enclose some bays and bedrock outcrops across the shore zone	Beaches narrow and of coarse sediments or absent in east, except at Wood Islands; in west, wide intertidal zone, often bedrock mantled by parallel bars or mud deposits	Maximum fetch 50 km to southwest and 25/40 km to south; sheltered wave-energy environment with increasing importance of tides to the west; large tides range from 2.2 to 2.8 m	Sediments generally very scarce; prevailing transport direction is to the east
6. Hillsborough Bay	Low relief, rarely exceeds 5 m; bedrock exposed in shore zone, usually mantled by unconsolidated sediments	Complex shoreline configuration of estuaries that enter a large embayment; few sections of cliffs or large beach systems; mixed shore-zone types	Beaches narrow and of mixed sediments; marshes in sheltered sections and wide mud flats or intertidal bars in many areas	Very sheltered wave-energy environment, particularly in estuaries; tidal processes important; tidal range up to 2.9 m	Sediments generally scarce; intertidal deposits usually a thin veneer over bedrock platforms; transport directions very localized
7. South Coast	Relief generally low, less than 10 m; bedrock exposed in shore zone usually mantled by unconsolidated sediments; structural trends east-west in east, northeast-southwest in west	Shoreline complexity increases in the west, elsewhere a crenulate coast of small bays and headlands; cliffed coasts in east give way to mixed shorelines in Bedeque Bay; few areas of large beach systems	Beaches narrow and of coarse sediments or absent on cliffed sections; marshes and mud flats with intertidal bars in sheltered sections	Maximum fetch distances less than 50 km; sheltered wave-energy environment; tidal processes important, particularly in eastern areas; large tides range from 1.3 to 2.9 m	Sediments generally scarce; intertidal deposits usually a thin veneer over bedrock platforms; prevailing transport direction is to the east
8. Egmont Bay	Low relief, rarely exceeds 5 m; bedrock exposed at coast in a few sections only; structural trends northeast-southwest	Straight coasts of barrier beaches, beaches, marshes, and a few sections of exposed bedrock cliffs; estuarine coast in northeast with extensive mud flats and marshes; high rates of shoreline change and rapid erosion	Beaches are sandy and low with dunes rarely over 3 m; marshes and mud flats in sheltered areas, particularly in the northeast	Maximum fetch 50 km but exposed to waves out of the west; moderate wave-energy environment; autumn storm waves an important feature of the wave climate; tidal range up to 1.3 m	Sediments generally scarce although low beaches have developed in many areas; basically an eroding coast with limited sediment input; transport predominantly to the east and south, with a reversal to the north in the southeast

PART 4 - OIL

SYNOPSIS

The physical and chemical characteristics of crude and refined oil vary considerably and these properties change constantly following a spill. "Light" oils spread rapidly and have volatile components as well as high rates of evaporation. "Heavy" oils are very viscous and often degrade slowly. The impact of a spill depends on both the properties of the oil and the volume spilled. Oil rarely covers the entire shore zone except in cases where large volumes of oil are spilled.

The persistence of stranded oil is a function of the properties and volume of the spilled oil and of the available mechanical and thermal energy. Waves, tides and temperature are the principal energy inputs to oil stranded in the shore zone. Immediately following a spill, degradation rates are usually high, largely as a result of evaporation of the light fractions. Oil that is buried or is stranded in sheltered environments or above the normal limit of wave action degrades slowly as levels of mechanical energy are low.

4.1 INTRODUCTION

The impact of oil stranded in the shore zone depends primarily on: (a) the chemical and physical properties of the oil, (b) the volume of spilled oil, (c) the shoreline type and shore-zone sediments, and (d) the coastal processes in the spill area. In this section the discussion focusses on those aspects of oil which relate to the impact and the degradation of stranded oil. Shoreline types and coastal processes are described in Part 5 (p. 59), which is followed by an assessment of the expected impact of a spill on the shoreline types that occur in Prince Edward Island (Part 6, p. 85).

4.2 PROPERTIES OF OIL

The physical and chemical properties of crude and refined oils vary considerably depending on the combination of the compounds in the oil which range from light gases to heavy solids (see Appendix, p. 163). In terms of the impact of a spill, the most important properties are: (1) the boiling point, (2) the flash point, (3) the pour point, (4) the surface tension, and (5) the viscosity.

(1) The boiling point of the fractions within an oil determines the temperature at which those fractions will evaporate. Evaporation is a major degradation process in light, volatile oils.

(2) The flash point is the lowest temperature at which fractions of the oil will ignite. Knowledge of the flash point of the oil is an important safety factor for personnel in the area of a spill.

(3) The pour point is the temperature below which the oil will not flow. For the many different oil types these temperatures range between -57°C and +32°C, but the majority of oils have a pour point below 0°C. An oil with a pour point that is higher than the ambient air or water temperatures acts as a semi-solid material. Air temperatures at one site can vary considerably from day to night and as weather conditions and seasons change, so that the ability of stranded oil to flow can vary accordingly.

(4) The surface tension of oil controls the spreading of thin layers of oils which have a low viscosity. The surface tension of these oils can be lowered by the application of dispersants to increase solubility and mixing. Conversely, surface tension can be increased by the application of collectants to

prevent or reduce spreading of low viscosity oils.

(5) The viscosity is a measure of the resistance of the oil to flow, in terms of the internal cohesiveness of the material. This property, therefore, controls the rate of spreading of the oil and the degree to which oil can penetrate into beach sediments. Temperature is a major factor in determining viscosity and as temperatures increase then viscosity decreases and the oil spreads more readily. As oil spreads, more surface area is exposed and, therefore, weathering rates increase. Viscosity plays an important role in determining weathering rates by controlling the total exposed surface area of the oil.

To simplify the discussion throughout this report, oils have been grouped into three broad categories:

(1) *Liquid or free-flowing oils* (such as unweathered light crudes, aviation gasoline, diesel fuels, kerosenes, and most other refined oils). These have high rates of evaporation and are generally very volatile and potentially flammable, so that they should be approached with care. The oils of this group have a low viscosity and float on water, but rarely form stable emulsions.

(2) *Very viscous oils* (such as heavy crudes, weathered light crudes, and Bunker fuels). These are less volatile due to the lower amounts of light fractions, a result of either refining processes or of natural evaporation. The oils of this group float on water and readily form emulsions (for example, "chocolate mousse" - a water-in-oil emulsion).

(3) *Semi-solid or tarry oils* (such as asphalt, weathered crudes or weathered Bunker fuels). These are non-volatile and are very viscous at normal (<38°C) temperatures. They may float on water or sink, and generally they do not emulsify.

The light, free-flowing oils spread rapidly and usually form only a thin layer and/or penetrate deeply into most shoreline sediments. In general, the more viscous oils contaminate smaller sections of shoreline but result in thicker deposits of oil. These viscous oils penetrate shoreline sediments on pebble or cobble beaches, which have large spaces between particles. Some penetration by viscous oils into the upper few centimetres of sand-size sediments can occur when air temperatures are high enough to decrease the viscosity.

An assessment of the potential impact of a spill requires the identification of the character and properties of the oil on the water. This knowledge can then be applied to estimate the expected penetration of oil into sediments and the potential effect of oil on shore-zone plants and animals.

Spilled oil is dynamic in the sense that the physical and chemical properties change through time. In particular, the volatile oils undergo rapid change due to evaporation when exposed to air (Mackay and Matsugu, 1973). Rates of change are relatively slow in winter months when ambient temperatures are low, but increase rapidly as temperatures increase in spring and summer. Also, wave action can alter an oil into an emulsion, which results in changes in the viscosity. It is important, therefore, to anticipate these changes when assessing the expected impact of spilled oil on the shoreline.

4.3 VOLUME OF OIL

The impact of a spill is partly determined by the volume of oil. If the oil is on the water following a spill, an estimate of the expected volume that will be stranded is of great value in assessing the probable impact and in preparing a suitable response. On the other hand, if the oil has already become stranded an estimate of the volume on the shore will provide information for the selection of the most suitable cleanup method. If shoreline contamination involves small amounts of oil, the oil is usually washed ashore in patches and is deposited in the upper intertidal zone. Only in the case of very large spills does oil completely cover the intertidal zone.

When gathering the baseline spill information, note should be made of: (a) the source of the spill, (b) the volume spilled (if known), and (c) the duration of the spill. In the latter case (c), this involves a knowledge of whether or not the spill has terminated. A continuous leakage of oil from the source will pose different protection and cleanup problems than a single spill in which no further oil would be released.

The amount of stranded oil on a shoreline must be considered both in terms of surface distribution and the depth of penetration into the sediments. An estimate of the surface area covered with oil can be expressed as a percentage, and this estimate should indicate not only the total coverage but also the actual distribution on the beach (*e.g.*, the lower half of the intertidal zone may have a 10-20% cover, whereas, adjacent to the high water level the cover may be 60-100%). The depth of oil penetration beneath the surface can be determined by digging pits in the beach with a shovel or by obtaining cores using a wide plastic tube.

4.4 DEGRADATION OF SPILLED OIL

The natural degradation of oil involves changes in the physical properties and/or chemical composition. The processes by which these changes take place are bio-degradation (particularly microbial oxydation), emulsification, evaporation, dissolution and photo-oxydation. The composition and physical nature of the oil are the primary factors that control the process of degradation. Refined oils, such as gasoline or kerosene, degrade very rapidly (*i.e.*, they have a low persistence) because the light (volatile) fractions evaporate rapidly when exposed to the atmosphere. Residual fuel oils or Bunker oils are less readily degraded as the light fractions are removed during the refining process, thus when spilled these oils are more persistent than the lighter grades.

As oil weathers and changes chemically the physical properties also change. For example, the process of emulsification leads to a lower viscosity so that oil flows more readily, whereas, the loss of the lighter fractions in stranded oil produces a more asphaltene residue to give a higher viscosity.

4.5 PERSISTENCE OF STRANDED OIL

Persistence is a function of the rate of natural degradation and physical dispersion of stranded oil and is an important factor in protection and cleanup decisions. If natural degradation and physical dispersion rates are rapid at a particular site, no cleanup response may be necessary.

The relationship between the weathering and persistence of stranded oil to the inputs of energy and to the properties of oil is illustrated in Figure 10. The amount of mechanical energy available for the degradation processes is the primary factor in the persistence of oil. Mechanical energy at the shoreline is

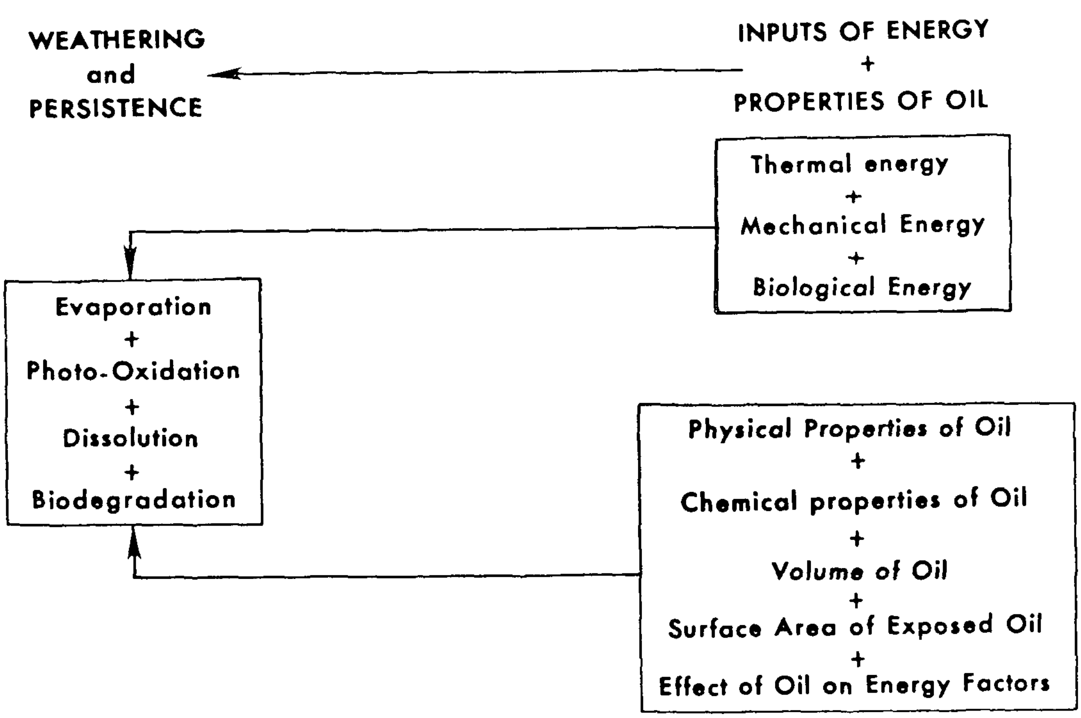

Figure 10. Factors that affect the degradation (weathering and persistence) of stranded oil (from Owens, 1977).

derived from waves and winds and results in the dispersion and physical breakdown of the stranded oil. The relationship between the inputs of mechanical energy and the shore zone is illustrated in Figure 11.

Two important factors which also affect degradation processes and persistence are: (a) the depth of oil penetration in the shore sediments or burial of the oil, and (b) thermal energy. In the first case, oil that is buried by sediments, or that has penetrated into a beach, is protected from wave action unless the oil is exposed by beach erosion. The second factor, thermal energy, is related to air and water temperatures and as these increase so do

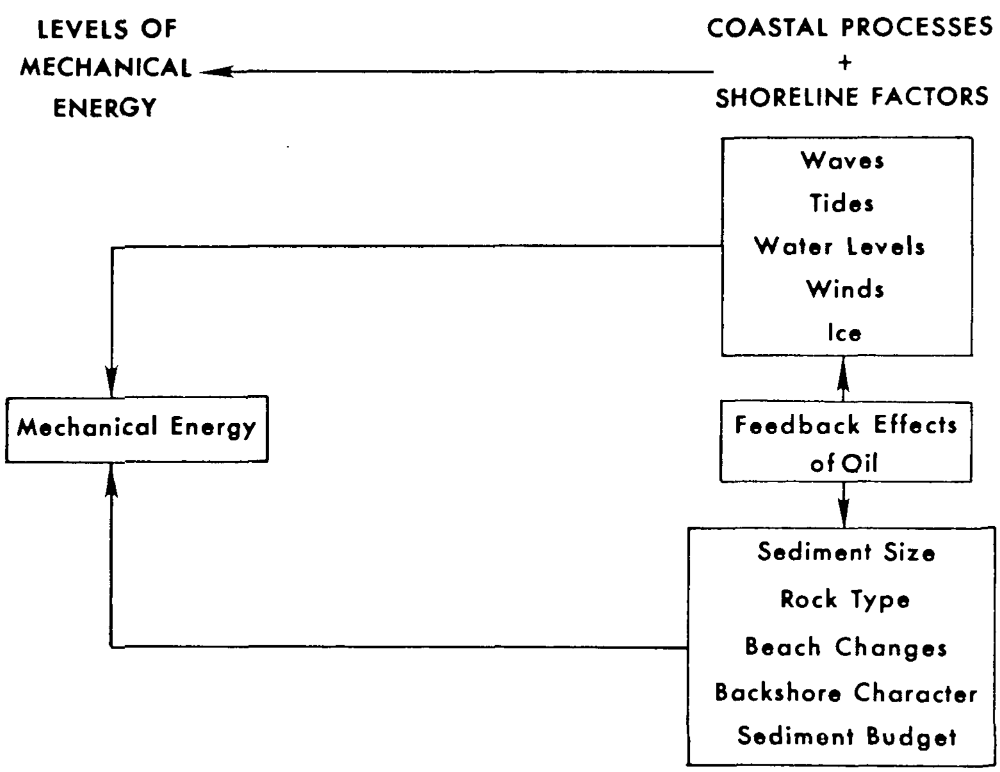

Figure 11. Factors that affect levels of mechanical energy at the shoreline (from Owens, 1977).

rates of most degradation processes. Temperature changes also affect the viscosity and pour point of the oil. As temperatures rise above the pour point, the oil then becomes fluid and can penetrate into sediments, but this may be offset by the fact that higher temperatures may also cause an increase in physical and biochemical degradation.

The rate of dispersion of stranded oil is initially a function of removal by wave action. In the period immediately following a spill, inputs of thermal or biochemical energy are considered less important than the contribution from inputs of mechanical energy (Owens, 1978). In general, as levels of mechanical (wave) energy increase, rates of natural dispersion and degradation increase. The wave-energy level at any location is a function of a combination of process and shoreline factors that are outlined in Figure 11 and discussed further in Part 5.

As an example of the local variability in persistence, Thomas (1977) measured rates of oil removal following the "*Arrow*" spill in Chedabucto Bay. In Figure 12, Station 3 is a moderately exposed site, Station 5 is a sheltered location, and Stations 6 and 7 are very sheltered shorelines. The results indicate that natural oil removal varies in proportion to exposure to wave action and to changes in local wave-energy levels. On very exposed beaches in Chedabucto Bay virtually all stranded oil was removed within the first year.

Where oil is stranded in sheltered sites or above the limit of wave activity, mechanical energy levels are low and natural

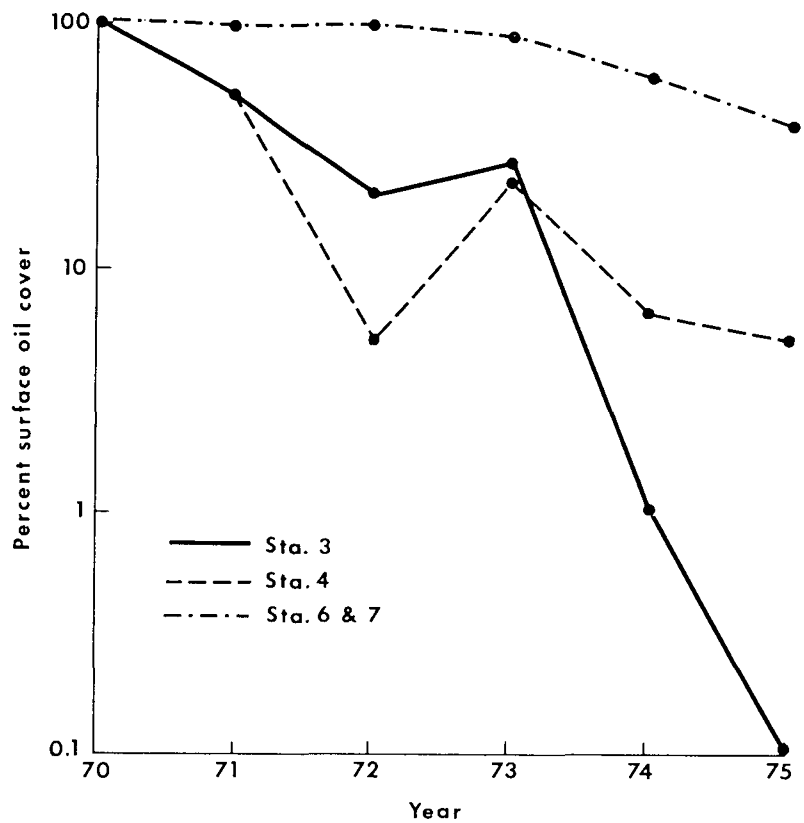

Figure 12. Surface oil cover at the high-water mark from stations in northern Chedabucto Bay, 1970-1975 (from Thomas, 1977).

removal is a function of thermal energy levels and biochemical processes, and usually proceeds at relatively slow rates. A study by McLean and Betancourt (1973) in Chedabucto Bay demonstrates that oil stranded on a sheltered location, which was not exposed to wave action, lost 20% by weight within the first year, but thereafter degradation virtually ceased (Fig. 13).

Once stranded oil reaches a quasi-equilibrium with local environmental conditions, the rates of weathering decrease rapidly, until such time as these environmental conditions change. The latter can occur as temperatures increase during spring and summer months or as inputs of mechanical energy expose new surface

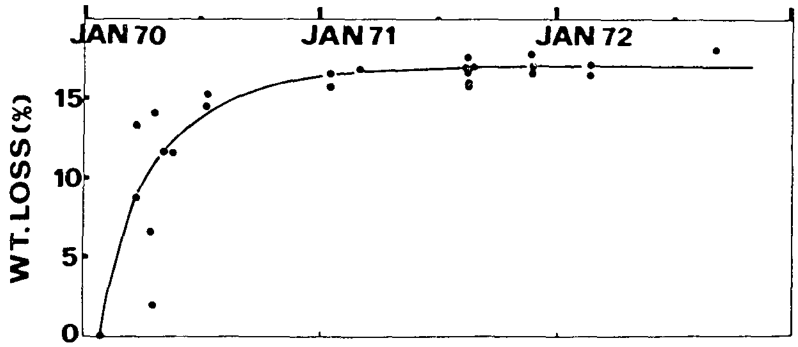

Figure 13. Variation in weight loss of weathered Bunker C oil with time (from McLean and Betancourt, 1973).

areas of oil. In those cases in Chedabucto Bay where stranded oil is not exposed to wave activity Vandermeulen (1977) estimates a residence (or persistence) time of longer than 150 years.

From studies following the *"Arrow"* spill, Vandermeulen (1977) describes the general pattern of natural oil removal as follows:

(a) short-term removal by wave action: about 50% of the oil that was stranded within the zone of wave action was removed within 1 year; 75% within 3 years; and 95% within 7 years. The rate of oil removal at each site was a direct function of the level of wave energy (see Part 6.2, p. 85).

(b) long-term removal by biochemical processes: oil deposited above the limits of wave action or in sites sheltered from wave action showed very slow rates of degradation, particularly if the oil was buried in the sediment.

An assessment of the persistence time for oil stranded on beaches subject to wave action can be estimated from: (a) the volume and type of the oil, (b) the depth of oil penetration, and

(c) the levels of wave energy at the shoreline. Such an assessment may be of great importance in deciding whether or not natural cleaning of the shore would occur within an acceptable period of time. As energy levels at the shoreline increase, then rates of natural dispersion and degradation of stranded oil increase and requirements for a cleanup response may decrease. Figure 14 combines the major factors and provides the framework for assessing the potential persistence of stranded oil.

TYPES OF OIL	THICKNESS OF OIL ON SHORE SURFACE	DEPTH OF OIL PENETRATION	WAVE ENERGY LEVEL AT SHORELINE (a)	AIR TEMPERATURE		EXPECTED PERSISTENCE
Light Volatile ↓ Tarry	Very thin (<1.0cm) ↓ Thick (>10.0cm)	All oil exposed on shore surface ↓ All oil buried below beach surface	High energy levels: Exposed coast ↓ Low energy levels: Totally sheltered coast	High (>25°C) ↓ Low (<0°C)	↓ INCREASING PERSISTENCE	Days/weeks ↓ Decades

Figure 14. Persistence factors for stranded oil, for (a) refer to Table 5, p. 72.

PART 5 - SHORELINES

SYNOPSIS

The character of the coastal zone results from a combination of factors related to the physical processes and to the substrate (bedrock or sediments). The single most important process is the action of waves as this action controls the erosion and transport of shore-zone materials (sediments or oil). Ice plays an important role on Prince Edward Island for up to 4 months each year by preventing wave generation, dampening existing waves, and protecting the shore zone from the effects of waves.

The level of wave energy at the shoreline is a function of fetch, exposure and winds. The highest wave-energy levels occur on straight, exposed coasts with a long fetch during periods of high-velocity, onshore winds. Wave-energy levels are lowest in sheltered bays or estuaries or where the coast is protected by headlands. The strongest winds, which occur in winter months, cause a marked seasonal variation in wave-energy levels. The presence of ice during the period December to April is a critical factor as the potential for wave generation is at a maximum between October and April.

Beach changes result from the redistribution of sediments in response to changes in wave-energy levels. Erosion caused by strong wave activity during storms is usually balanced by accretion and beach recovery during periods of lower wave-energy levels.

The dispersion rate of stranded oil decreases as levels of wave energy at the shoreline decrease. Stranded oil that penetrates the beach or that is buried by beach sediments is dispersed and degraded very slowly unless exposed to wave action during a period of erosion.

The character of the coastal zone can be categorized into: (a) coasts with sediment, and (b) coasts without sediment. Further division of those coasts with sediments is based on (i) the size of the sediments, and (ii) the presence of vegetation in the shore zone. The major shoreline types on Prince Edward Island are: rock cliffs, unconsolidated cliffs, dunes, rock platforms, intertidal mud/sand flats, sand beaches, mixed (sand to cobble) beaches, pebble/cobble beaches and marshes. An important aspect of the shore-zone character in spill response operations is the accessibility to the shore by equipment and personnel.

5.1 INTRODUCTION

The objective of this section is to review the processes that control coastline development and changes on Prince Edward Island. From this basis the form and sediments of the coastal zone are considered and the major shoreline types are then identified and described.

5.2 COASTAL PROCESSES

Coastal processes include waves, tides, water-level changes, winds and the effects of ice. These processes act to form or change the coastal zone and play an important role in affecting stranded oil. The action of wind-generated waves is the most important form of energy at the shoreline.

Waves

Waves are generated by the interaction of the water surface with winds and gravity. Waves transmit energy through the water and this energy is largely dissipated in shallow water or on the beach. The level of wave energy is controlled by the velocity and duration of winds over the water surface and by the fetch. The mechanical energy that waves transmit to the beach causes the erosion of rocks, the transport of beach sediment, and the physical dispersion and breakdown of oil.

Oil on the sea surface can be mixed with water by the action of waves breaking near the shore to form emulsions, such as "chocolate mousse". On the shoreline stranded oil can be broken down into smaller particles by wave action or may be abraded by sediments that are moved by wave action.

Where the water depths at the shore are deep, as in the case of breakwaters or steep rocky coasts, waves are frequently reflected back to sea. This reflection can prevent oil from being stranded on that section of the shore zone and the turbulence created by the meeting of incoming and reflected waves can lead to mixing and dispersion of the oil into the water (Owens, 1977).

Variations in levels of wave energy through time or between different sections of coast result in differential rates of sediment transport and of oil dispersion. Stranded oil is abraded or buried as beach sediments are eroded or transported in the shore zone by wave action. The processes by which this can occur are discussed in Part 5.3 (p. 65). Variations in wave-energy levels due to exposure or fetch are considered in Part 5.4 (p. 71).

Tides

The water-level changes associated with the tides are a major factor in controlling the concentration of wave energy at the shoreline and, therefore, the rate at which wave action can disperse stranded oil. The effectiveness of wave action decreases as tidal range increases because wave energy is dissipated over an increasingly larger vertical range. Wave energy is most effective at the turn of the tide (the slack water period) as the water level remains almost constant for periods up to 3 hours. Between these slack water periods the water level is continuously changing and waves are therefore active at one level for only a short period of time. As the elevation difference between high- and low-water levels increases, the available wave energy is spread over a wider vertical section of the shoreline. When comparing two sections of coast with the same wave-energy levels, but with different tidal ranges, oil stranded in the intertidal zone would be dispersed more rapidly on the coast with the smaller tidal range.

During periods of diurnal tides (*e.g.*, Rustico, Fig. 3, p. 10) only one high- and one low-water period occur each day; this affects wave energy concentrations. Waves can act at the high and low levels for only half of the time that they would otherwise do on coasts with semi-diurnal (twice daily) tides. On the other hand, the changes in tidal elevation are slower so that wave energy between high- and low-water periods is concentrated at a particular elevation for twice the length of time when compared to areas with semi-diurnal tides.

In addition to the geographical variation in tidal range (Table 3, p. 11), there is a variation in monthly and six-monthly cycles. The monthly cycle of spring(high) and neap(low) tidal ranges is shown in the tidal curves in Figure 3 (p. 10). If oil is stranded on the higher parts of the shoreline during periods of spring tides it will not be affected by wave action until the next spring tide period, unless there is an increase in wave height that allows waves to act on that part of the shoreline. This factor is particularly important if oil is stranded when the maximum tidal ranges occur during the periods of spring and autumn spring tides.

Usually salt marshes are covered by water only during spring tides. In these environments the timing of a spill is, therefore, important as oil would not be stranded on the marsh surface except during spring tides or storm surges.

Tidal range has a significant effect on the non-mechanical degradation of oil stranded in the intertidal zone. As the water level rises and falls, sections of the shore-zone are alternately exposed and submerged. Therefore, degradation processes related to wetting and drying, and to temperature and sunlight occur at different rates in different parts of the intertidal zone. Oil in the lower intertidal zone is submerged for approximately 75% of the tidal cycle whereas oil stranded at the high-water level would be exposed for 75% of the cycle. In general, oil in the upper sections of the intertidal zone weathers more rapidly due to this differential exposure.

Tidal range also affects the distribution of oil on the shore zone. Where the range is low, oil is concentrated in a narrow vertical band and tends to form a thick deposit. As the range increases the oil is distributed over a wider intertidal zone.

Tides generate currents as water moves from one area to another during the tidal cycle. This movement of water is particularly important in bays or lagoons connected to the sea by inlets as oil may be transported through an inlet during flood tides. The oil would then probably become stranded in sheltered lagoons or bays where wave-energy levels and rates of mechanical degradation are low. In these environments the impact of the oil on wildlife and vegetation may be high as these are often sensitive ecological areas.

<u>Winds</u>

The primary effect of winds is associated with wave generation, however, wind action can also cause water-level changes at the shoreline and can bury stranded oil by the transport of fine-grained sediments.

During periods of strong onshore winds water can be piled against the shoreline, resulting in storm surges. These surges cause waves to break on the shore zone above the high-water level, often resulting in dune erosion or overwash. Oil stranded during such storm surges would then be deposited above the normal level of wave activity or could be carried into the backshore lagoon on barrier beaches.

Fine-grained sediments transported by wind action could bury oil stranded on the upper beach (O'Sullivan, 1978). The effect of this burial would be to reduce rates of weathering as well as to disguise the presence of the oil.

Wind velocity is an important factor in the evaporation of the light fractions of oils (McMinn and Golden, 1973). Evaporation can result in complete dispersion of light-grade oils, however, the effect on heavier oils would be to reduce the volume and to produce an asphaltene residue with a higher viscosity.

Ice

The formation of ice on the water surface reduces wave generation during winter months. In the southern Gulf of St. Lawrence the presence of sea ice coincides with the period of maximum wind velocities, and thereby prevents wave generation at a time when mechanical energy levels at the shoreline would otherwise be high.

Ice that forms on the shoreline, usually referred to as an ice foot (q.v.), protects the shore zone from wave action (Photo 1, p. 13). The ice foot forms before and persists longer than sea ice. Waves can be reflected from an ice foot to cause mixing and the physical breakdown of oil on the water surface as well as preventing the oil from reaching the ice foot.

Although an ice foot prevents oil from becoming stranded on the shore (Ruby, *et al.*, 1977), the development of an ice foot after oil is stranded can result in the burial of oil if cleanup has not been implemented. In such cases the oil would remain buried beneath or enclosed within the ice until the ice foot thaws.

5.3 BEACH CHANGES

On coasts with sediments the most important effect of wave energy is the transportation and redistribution of the beach sediments. On rocky coasts devoid of sediments the wave energy is reflected back from the rocks or is absorbed in eroding the rock surface.

The beach changes that are associated with wave action result from either the onshore-offshore movement or the alongshore movement of sediments. The actual amount of sediment transported and the magnitude of beach change are related to the size of the material and to the available wave energy. As sediment size increases, so the level of energy necessary to initiate and maintain transportation increases. Sands are readily moved by all but the smallest waves, but cobbles require a much higher force for transportation. An increase in wave energy on a beach results in higher rates of sediment transport and, therefore, an increase in the amount of beach change that can occur.

During periods of high-energy wave activity (*i.e.*, storms) beaches are usually eroded. On sand beaches this results in movement of sediment into the nearshore zone adjacent to the beach. As energy levels decrease after the storm, the sediment is returned to the beach by constructive wave action. The mechanism of sediment return is often associated with the onshore migration of a ridge which welds onto the beach, provided that the sequence is not interrupted by further storm-wave activity (Fig. 15).

Oil stranded on a beach prior to a storm could be eroded by wave action and dispersed. However, if the oil is deposited

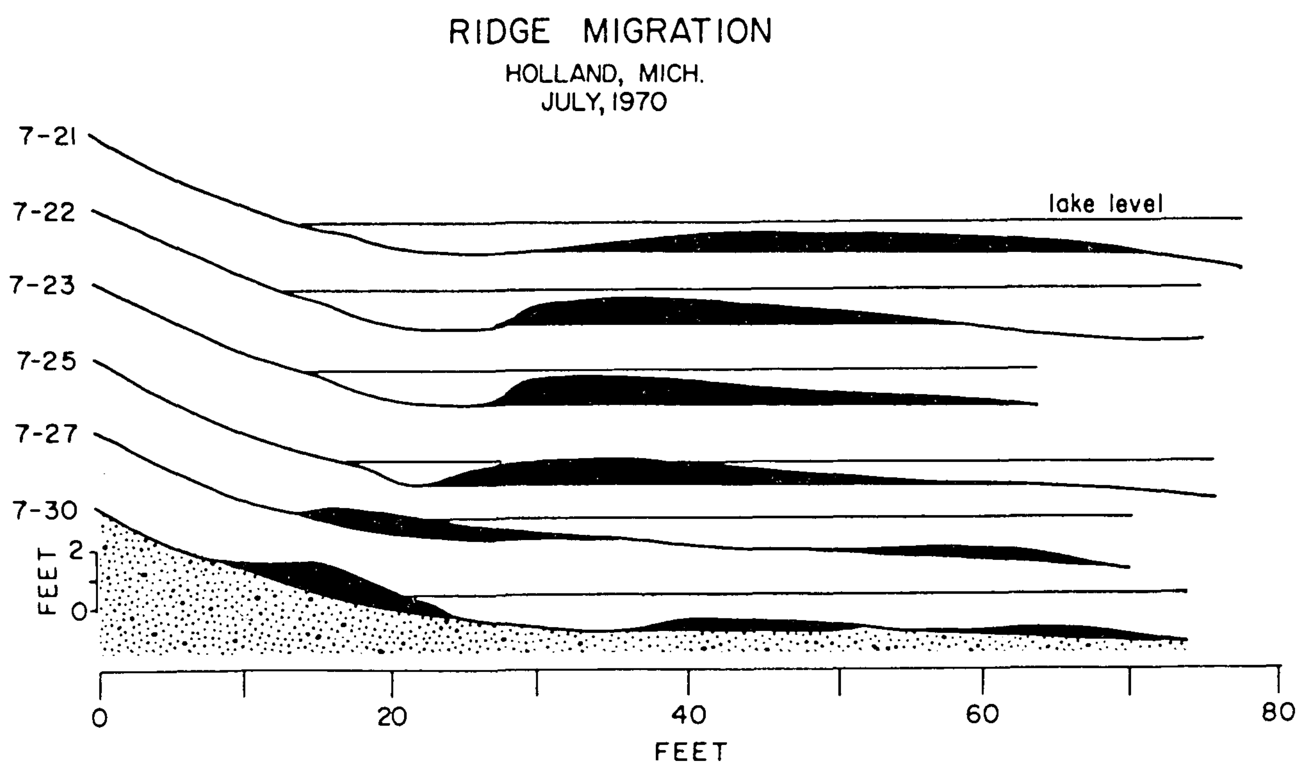

Figure 15. Sequence of onshore ridge migration over a 10-day period (July 21 to July 30, 1970), Lake Michigan (from Davis and Fox, 1971).

immediately following erosion, but before recovery has commenced, the oil would become buried as the ridge migrates onshore (Fig. 16). The buried oil would be degraded very slowly and would then be exposed and dispersed only by further beach erosion.

Superimposed on this storm/post-storm cycle is a seasonal cycle of autumn erosion and spring/summer recovery (Fig. 17) due to the seasonal variation in wave-energy levels (Table 2, p. 9). The effects of this "summer/winter" cycle are similar except that the period of burial is much longer. This would be particularly

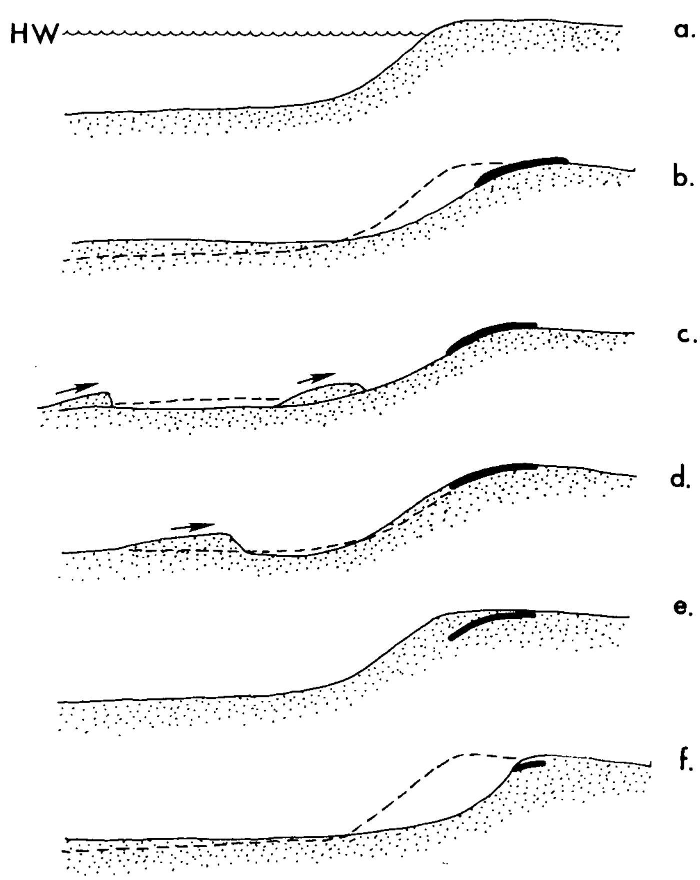

Figure 16. Sequence of storm erosion and oil deposition (b); burial (d)(e); and exposure following a second storm (f) on a sand beach (from Owens, 1977).

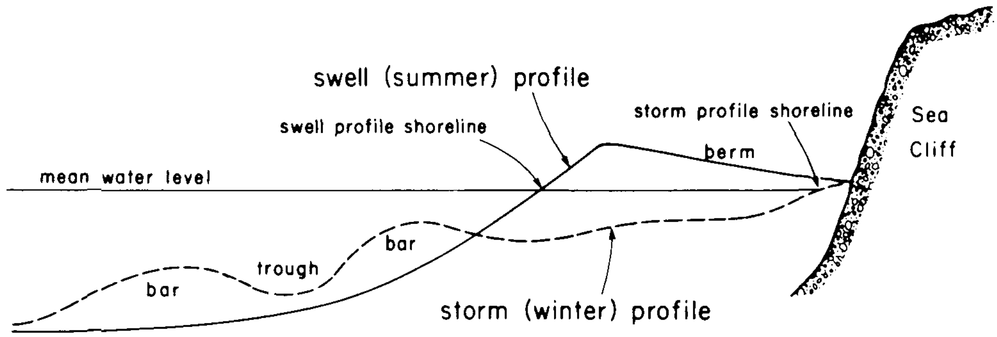

Figure 17. Idealized summer-winter beach profiles (after Komar, 1976).

important if oil were stranded in late spring or summer as the oil could remain buried until the erosion phase of the following autumn.

The effects of storm waves on pebble or cobble beaches are somewhat different. In this case the sediments tend to be moved up the beach by storm-wave action to form a storm ridge. Oil stranded during higher water levels on the storm ridge of a pebble or cobble beach would then be buried by this upward migration of sediment during a period of storm-wave activity (Fig. 18).

Beach changes can have a strong alongshore component as sediments are transported by waves that approach the shore at an angle. A common feature on sand beaches is a type of rhythmic topography called beach cusps. These features can be of various sizes and can migrate along the beach, causing alternating periods of erosion and deposition on a given section of the shore. The movement of such features on a beach with stranded oil would result in a continuous sequence of burial and erosion of the oil (Fig. 19).

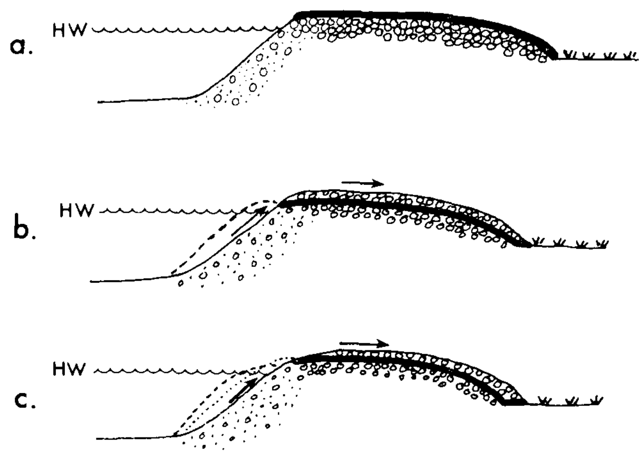

Figure 18. Effects of storm-wave activity on oil stranded on a cobble beach: (a) oil is deposited above the normal limit of wave action during storm conditions; (b) a second storm erodes the beach and waves push material onto the upper beach to cover the oil; (c) a subsequent storm continues the process, gradually exposing more of the buried oil layer (from Owens, 1977).

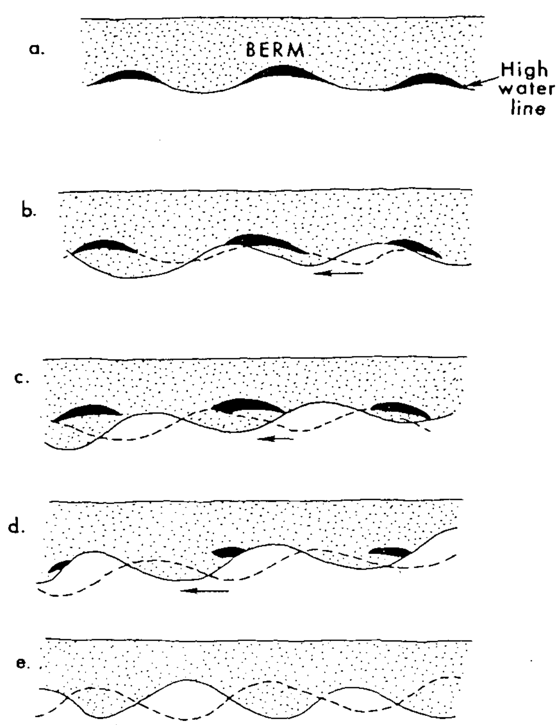

Figure 19. Plan view of the effects of oil deposited at the high-water level by migrating rhythmic topography (from Owens, 1977).

The shore zone is a dynamic environment. The beach changes discussed above are an integral part of the dynamic framework in which sediments are continuously transported and redistributed. Oil can play an important role in reducing rates of change if the oil cover is sufficiently thick to prevent sediment movement or if the oil binds the sediments together and prevents the movement of individual particles. The latter is particularly common with heavy or weathered oils that frequently form an "asphalt pavement" (Photo 24). Once the sediments are immobilized and the voids filled with oil, dispersion occurs only slowly. This is a common feature of oil stranded in sheltered wave environments. In addition to the reduced role of mechanical degradation due to burial or to the formation of asphalt pavements, Colwell, *et al.*, (1978) note that in these instances weathering and microbial degradation are also ineffective.

Photo 24. Edge of an asphalt pavement, Straits of Magellan, January 1977 - 2 1/2 years after the spill. Scale is 30 cm in length.

5.4 SHORELINE EXPOSURE AND WAVE-ENERGY LEVELS

The levels of wave energy on a shoreline depend on the degree of exposure or sheltering as well as on the generation of waves over the adjacent fetch. Exposed shorelines are defined as having no protection and these receive the full force of incoming waves. Sheltered shorelines are common in embayments and lagoons or on irregular coasts where headlands or islands act to protect the shore zone from wave action. For example, the effect of sheltering is clearly evident when comparing the high wave-energy levels on the exposed shores of the north coast of the island with the low-energy environments on the adjacent east coast.

The actual levels of incoming wave energy are primarily a function of winds and fetch. The fetch lengths control maximum wave-energy levels by limiting the surface area over which wave generation is possible.

There is considerable geographical variation of energy levels around the island due to the available fetch distances and to the degree of local exposure or sheltering. Superimposed on these factors are temporal variations in wave-energy levels that result from changes in wind velocities due to weather patterns. The highest levels of wave energy occur during periods of storm winds which are most common in ice-free winter months. But even an exposed coast with large available fetch distances may have very low levels of wave energy at the shore during summer months.

Although it is not possible to accurately determine shoreline wave-energy levels without long-term measurements, an approximate and relative approach can be used for estimation purposes. The index of relative shoreline wave-energy levels for Prince Edward Island (Table 5) is developed using only the primary process factors (fetch and degree of exposure). Wind velocity is not considered as this is assumed to be a constant factor in this region although coasts exposed to either southwest-west or northeast winds would have higher wave-energy levels than east-facing coasts. The impact of ice on the shore is effectively to reduce energy levels to zero as the mobility of the system, in terms of sediment transport, shore-zone dynamics, and oil dispersal, is temporarily suspended.

The basic relationships between the primary shoreline energy factors are illustrated in Figure 20. Tidal range is included in this diagram as the incoming wave energy is dissipated over a wider intertidal zone as the heights of tides increase. The height of the beach, that is the height of the berm or ridge above high-water level, and sediment sorting are response features related directly to energy levels, and can be useful field evidence for establishing an estimate of relative energy levels. The height to which sediment is pushed up a beach to build a berm

TABLE 5. Relative Shoreline Wave Energy Levels for Prince Edward Island

Open straight coast: fetch >100 km	5
Open straight coast: fetch 50-100 km	4
Indented coast: fetch 50-100 km	3
Sheltered coast: fetch <50 km	2
Enclosed bay or lagoon	1
Ice on the shoreline	0

FETCH	COASTAL EXPOSURE	TIDAL RANGE	OFFSHORE ICE	BERM/RIDGE HEIGHT	SEDIMENT SORTING	ENERGY LEVEL
Long (>200km)	Straight (Open)	Low (<1m)	Absent	High	Good	High
↑	↑	↑	↑	↑	↑	↑
Short (<50km)	Indented (Sheltered)	High (>3m)	Present	Low	Poor	Low

Figure 20. Shoreline energy levels.

(on sand beaches) or a ridge (on pebble/cobble beaches) is a direct function of wave height; as wave height and wave energy increase then the higher the berm or ridge.

The degree of sorting of beach sediments can be a useful indicator of shoreline energy levels. Beaches on coasts with high wave-energy levels are usually characterized by well-sorted sediments (*i.e.*, only one size of sediments). In sheltered, low-energy locations the beach is usually composed of a mixture of sediment sizes.

5.5 SHORELINE TYPES OF PRINCE EDWARD ISLAND

The character of the shoreline is a function of the interaction between the coastal processes, energy levels, and the availability and size of the sediments in the shore zone. A primary distinction can be made between those coasts which have sediments in the shore zone and those which do not. In the latter case, this distinction refers to rock coasts or man-made structures that are without sediments exposed in the intertidal zone. On coasts which have sediments in the shore zone, the predominant

TABLE 6. Shoreline Types Based on Substrate

COASTS WITHOUT SEDIMENT	COASTS WITH SEDIMENT
Rock	Mud
Man-made structures	Sand
- concrete	Pebble
- metal	Cobble
- wood	Boulder
	Mixed sediments
	Vegetated
	- marshes
	- backshore dunes

distinguishing feature between shore types is the sediment size (Table 6). A subdivision of shorelines with sediments is vegetated coasts in which plant colonization is the primary feature of the shore zone. This preliminary definition of shore zone types is very simplified as many shores zones are composed of one or more basic types, for example, coasts which have a rock cliff or intertidal rock platform with a sand or pebble beach in the upper intertidal zone.

Wave action on exposed beaches tends to segregate the size fractions of sediments. As wave-energy levels increase, the sorting of beach materials also increases. In high-energy environments the beaches are usually composed of only one size of sediment or the sediments have a distinct zonation across the beach. In low-energy environments, sediments in the shore zone are usually a poorly-sorted mixture of several sediment types (*e.g.*, sands, pebbles and cobbles) (Table 7).

The beach width and height are a direct function of local wave heights and tidal range. On exposed beaches with large fetches, wave heights greater than 1 m are relatively common, and in these locations waves can build berms up to 1.5 to 2 m above

TABLE 7. Sediment Size Grades

TYPE OF SEDIMENT	PARTICLE DIAMETER
Mud	< 0.06 mm
Sand	0.06 - 4 mm
Pebble	4 - 64 mm
Cobble	64 - 256 mm
Boulder	> 256 mm

high-water mark. As exposure and energy levels decrease, the beaches become lower so that in very sheltered environments a beach of poorly-sorted sediments may extend less than 0.5 m above the high-water mark. The width of the intertidal zone is a function of both the tidal range and the nearshore slope. Where depths in the nearshore zone are shallow, wide tidal flats or rock platforms are exposed at low tide.

The nature of the backshore is not of great importance in terms of the impact of the oil except when contamination occurs during periods of above-average water levels. However, backshore geomorphology is a significant factor in terms of sediment supply and accessibility. Many sections of the coastal zone of Prince Edward Island are backed by rock cliffs or easily erodible cliffs of unconsolidated sediments. In these areas beaches are generally very narrow or absent and waves act directly at the base of the cliffs during high tides.

On coasts backed by unconsolidated cliffs, the beach acts as a buffer to wave energy and protects the base of the cliffs from erosion. The reduction of beach width by high water levels or by sediment removal by man reduces the amount of protection and can result in cliff undercutting. The result of this undercutting is usually that the cliff face becomes unstable and slope failure or collapse follows.

The character of the shoreline and backshore morphology determines the accessibility of a given section of coast or beach by land, sea or air. Accessibility is of considerable importance in planning a spill response. The major access categories are outlined in Table 8. It should be remembered that access conditions can change through time depending on beach width, wave conditions, sea levels and weather.

The discussion in the preceding section has focussed on the basic range of shorelines in terms of the substrate. In order to assess the potential impact of oil on the shorelines of Prince Edward Island (Part 6) it is also necessary to describe the local shoreline types that occur in the area. These shoreline types differ from those categorized in Table 5 only in the respect that the backshore areas are treated separately from the beach zone.

TABLE 8. Shoreline Accessibility

LAND ACCESS

1. Roads or tracks that can support heavy equipment or trucks, with direct access to the shore zone or beach.
2. Tracks or trails that provide access to the shore zone for light vehicles.
3. Tracks or trails that provide only pedestrian access.
4. Inaccessible by land.

WATER ACCESS

1. Unobstructed beach or shoreline access for boats and barges.
2. Shallow-water access for small boats only.
3. Inaccessible by water.

AIR ACCESS

1. Flat ground available for helicopter access.
2. Inaccessible by air.

Rock Cliffs

Cliffs occur as a result of bedrock exposures in the coastal zone and are erosional shorelines. On Prince Edward Island the cliffs are unresistant sedimentary rocks that are easily eroded by shore-zone processes; erosion rates greater than 2 m/yr have been reported. The eroded material, which is often sand-size sediments, is transported away from the cliff base by wave or tide-generated currents. Boulder, pebble and cobble bedrock fragments are broken down into finer-grained sediments in the shore zone so that few or no coarse sediments are found downdrift of bedrock cliffs. The cliffs are usually vertical or very steep (Photos 2 and 20, pages 22 and 40).

Unconsolidated Cliffs

Where unconsolidated cliffs occur in the shore zone, erosion rates are usually rapid (Photo 28, p. 82). Cliff retreat can result from slumping or sliding as well as from normal coastal processes. Sediment is supplied directly to the beaches and transported alongshore. The size of the eroded sediments varies depending on the composition of the deposit and can include pebbles, cobbles and boulders of very resistant bedrock fragments. These resistant materials do not outcrop on Prince Edward Island, but were transported to the region and deposited there by the ice sheets. These resistant materials have accumulated to form coarse-sediment (pebble-cobble) beaches at a few locations.

Dunes

On low backshore areas where there is an ample supply of sand-size sediments, the redistribution of the sediments by wind action and the subsequent development of a vegetation cover results in the formation of dunes. The height of a dune system is primarily controlled by the availability of sediments; on Prince Edward Island dune heights up to 20 m are common along the north shore barriers (Frontispiece).

Natural breaching of dunes can occur by overwash (Photo 6, p. 25) but most dunes form a straight barrier that protects the backshore areas from inundation during storms (Photo 25). The stability of a dune system can be seriously affected by pedestrian traffic which can reduce or destroy the vegetation cover (Photo 5, p. 24). The vegetation prevents wind transport of the sand; without this protective vegetation, blowouts (wind-scoured hollows) can form rapidly. Once formed, a blowout can become

Photo 25. Barrier-dune system that encloses Brackley Bay. In this section the straight foredune ridge is undergoing erosion but there is no evidence that the ridge has been breached (6 May 1978).

enlarged by erosion of adjacent vegetated dunes. On barriers or spits further erosion of the blowout could lead to the development of overwash channels during high water levels and possibly to the formation of a new temporary or permanent inlet.

Intertidal Rock Platforms

Outcrops of bedrock in the shore zone are often eroded to form platforms that are exposed at low tides (Photo 26 and Photo 17, p. 37). The bedrock that outcrops on Prince Edward Island is relatively unresistant to the erosive action of waves. On exposed, high-energy coasts eroded fine-grained sediments are usually removed and the platform surface is frequently covered by bedrock fragments and by a coarse-sediment beach in the upper intertidal zone (Photo 26). In sheltered areas where the gradient across the shore zone is very low, the erosion processes can

Photo 26. Bedrock platform exposed in the intertidal zone at low tide near Cable Head (6 May 1978).

produce fine-grained sediments that form a thin veneer on the platform surface. These intertidal sand or mud flats are described below.

Intertidal Sand/Mud Flats

Fine-grained sediments can accumulate on rock platforms or in intertidal zones where the gradient across the shore zone is low. A common characteristic of the intertidal sediments is that they are organized by wave action into a series of low parallel or sub-parallel ridges (Frontispiece and Photo 16, p. 37). These ridges are mobile and frequently change configuration with each tidal cycle. The sediments are generally water-saturated in the lower intertidal zone, and the troughs between the ridges often contain water. The flats do not usually extend to the higher parts of the intertidal zone but give way vertically to beaches, marshes or bedrock exposures.

Sand Beaches

Sand beaches occur on most coasts around Prince Edward Island. The height of the berm is controlled by wave height, increasing as wave heights increase. Wide backshore zones develop only where there is an ample sediment supply (Photo 27 and Photo 5, p. 24). Beach width in the intertidal zone is primarily a function of the tidal range. Erosion and accretion cycles are characteristic of sand beaches and result from variations in wave-energy levels at the shoreline (p. 66-67).

Mixed Beaches

Beaches that have a range of intertidal sediments, usually

Photo 27. Wide sand backshore at Basin Head
(Photo by J.R. Harper; August 1972)

sand and pebbles, or sand, pebbles and cobbles are common adjacent to bedrock exposures or in sheltered environments. Sediment sorting on beaches is a function of shoreline energy levels and where levels are low and a variety of sediment sizes are supplied to the shore zone, the beaches frequently contain a range of material. As energy levels increase the sorting pattern is usually one of pebbles and cobbles adjacent to the high- and low-water levels, with sand and small pebbles in the central intertidal zone (Photo 28). These mixed sediment beaches are also subject to erosion and accretion cycles related to periods of storm-wave activity.

Pebble-Cobble Beaches

Accumulations of coarse-grained sediments are not common on the island as the bedrock fragments are unresistant sedimentary rocks that rapidly abrade to sand or finer-sized sediments. The development of a pebble-cobble beach requires a supply of

Photo 28. Mixed sediment beach (pebbles and sand) at the base of an unconsolidated cliff near Murray Head. The fallen trees indicate active cliff erosion at this location (Photo by J.R. Harper; August 1972).

resistant bedrock fragments from the erosion of unconsolidated deposits and high wave-energy levels to sort the sediment and to remove the sand fraction.

Pebble-cobble beaches usually have a steep, and therefore narrow, intertidal zone. Storm waves tend to push the material up the beach to form a ridge (Fig. 18, p. 69) rather than to erode the beach as is the case for sand beaches (see Owens, 1977, p. 258).

Marshes

In areas sheltered from wave action the accumulation of fine-grained sediments in the intertidal zone is frequently followed by the colonization of vegetation (Photo 29). The vegetation in turn slows current velocities and causes more deposition or trapping of fine-grained sediments. As the process continues a situation is reached where the vegetation surface (or marsh) is only inundated during spring tides or storm surges. This vertical growth of the marsh is usually accompanied by a lateral extension as the vegetation cover extends to adjacent areas (Photo 15, p. 36). The marshes have a flat surface that is interrupted only by tidal creeks that are filled with water at each high tide.

Photo 29. Marshes on the shore of Covehead Bay (6 May 1978).

PART 6 - SHORELINE TYPES AND OIL SPILLS

SYNOPSIS

The impact of stranded oil depends upon: (i) the type of oil, (ii) the volume of stranded oil, (iii) air/water temperatures, and (iv) the shoreline type. The persistence of stranded oil also depends on these four factors and on: (v) the penetration or burial of stranded oil, and (vi) shoreline wave-energy levels.

Each of the major shoreline types that occur on Prince Edward Island is discussed in terms of (a) the impact and persistence of stranded oil, and (b) protection and cleanup methods. The major points of this discussion are summarized in three tables in the final section.

6.1 INTRODUCTION

The impact and persistence of stranded oil, and shoreline protection and cleanup methods are discussed in terms of the shoreline types of Prince Edward Island that are described in Part 5.5. These factors are also briefly discussed for man-made shorelines in the final section.

The role of the shore-zone processes described in Part 5.2 is critical in understanding the impact and persistance of stranded oil. These processes are summarized initially in Part 6.2. The protection and cleanup methods discussed for each of the shoreline types are considered individually in Part 7 and a table that relates recommended cleanup methods to shoreline types is given on page 109.

6.2 THE IMPACT AND PERSISTENCE OF STRANDED OIL

The impact of a spill varies with: (i) the type of oil, (ii) the volume of stranded oil, (iii) air/water temperatures, and (iv) the shoreline type. Although there may exist a wide range of possible combinations of these four factors, the first three are relatively constant for a given spill and only the shoreline type changes significantly.

Similarly, the persistence of stranded oil varies with: (a) the type of oil, (b) the volume of stranded oil, (c) air/water temperatures, (d) the depth of penetration or burial of oil in the shore zone, and (e) the shoreline wave-energy levels. Once again the first three factors are relatively constant for a particular spill and the significant variables are, therefore, (d) penetration and burial (which are related to the shoreline type) and (d) wave-energy levels..

The shoreline type is the primary variable that controls potential impact of stranded oil following a spill. In the following sections (6.3 to 6.12), the expected impact on each of the major shoreline types is described. The persistence of the stranded oil can be estimated by considering the shoreline type and the wave-energy levels (Fig. 20, p. 73 and Table 5, p. 72).

Although wave action is the primary process that controls rates of natural shoreline cleaning, the other processes must be considered as they affect the levels of wave energy and the stranded oil. Table 9 summarizes the discussion given in Part 5.2 in terms of the shoreline processes and rates of natural cleaning.

6.3 ROCK CLIFFS

This section refers to rock cliffs above the high-water mark - intertidal rock exposures are discussed in Part 6.6.

TABLE 9. Factors That Alter The Impact of Littoral Processes on Oil

Factors that REDUCE impact and INCREASE rates of physical breakdown and degradation of oil	Factors that INCREASE impact and REDUCE rates of physical breakdown and degradation of oil
Waves - increasing wave-energy levels - mix or break down oil in breaker, surf and swash zones - use sediments as abrasive tools - redistribute or erode oil on the shore - reflected waves mix or break down oil and may prevent oil reaching the shoreline	Waves - decreasing wave-energy levels - bury oil by beach accretion or by longshore migration of sediments - reduce temperature of oil - throw oil above the normal level of wave activity by the splashing action of breakers
Tides - concentrate wave energy when range is low - concentrate wave energy at high-water and low-water levels when range is high - use sediments as abrasive tools - redistribute or erode oil in the intertidal zone - if tidal range is large, oil layer is thinner as it is deposited over a wider area	Tides - dissipate wave energy over wider vertical band as range increases - spring tides deposit oil above normal level of wave activity - flood tides transport oil into low-energy lagoons or estuaries - redistribute sediments and bury oil in the intertidal zone
Winds - increase rates of evaporation	Winds - redistribute sediments and bury oil on the backshore - generate storm surges and oil is deposited in lagoons (by overwash) or in the backshore - onshore winds trap oil on coast during surge, deposition then occurs above level of normal wave activity when water level lowers
Ice - ice foot prevents oil deposition on the shoreline - ice push breaks up stranded oil - ice foot prevents oil reaching the shoreline	Ice - prevents wave generation and lowers wave-energy levels - ice foot can enclose oil - ice push can bury oil - ice push moves oil above zone of maximum wave activity

IMPACT: Oil tends to coat the exposed, dry, surface areas of rock cliffs when water levels are raised above the highest beach elevations and where the base of the cliffs is not fronted by a beach. Oil may also be splashed on the rock surface above the limits of wave action as waves break against the cliff. In cases where waves are reflected from the cliff, particularly during periods of high-energy wave action, oil may not reach the shoreline.

Most of the rock cliffs on Prince Edward Island are steep or vertical (Photos 17 and 20, p. 37 and 40), so that only a thin layer of oil could adhere to the rock surface. This oil would tend to flow down the cliff and could be trapped on ledges or in hollows. The likelihood of large volumes of oil becoming stranded above the high-water mark during storms is low due to wave reflection. Oil deposited during spring high tides may not be refloated until the next period of spring high tides. This oil could then be redistributed to contaminate adjacent shoreline sections.

PERSISTENCE: Oil that coats the rock surface or that is trapped or collected above the intertidal zone would only be affected by waves at subsequent times of high-water levels or by storm waves. The persistence of this oil, therefore, depends on the frequency of wave action at the level of the stranded oil and on erosion or weathering of the cliff face. As only a thin layer of oil would be deposited on the vertical rock faces, the surface weathering processes, such as rain wash, are effective in removing oil from the friable rock surface. Rates of erosion on bedrock coasts due to marine processes vary considerably but in general are high, up to 2 m/yr. Oil stranded on cliff faces would probably be eroded within a few months. Oil trapped in crevices and hollows would be expected to persist for longer periods.

PROTECTION: The only effective protection methods for this type of coast are offshore containment and removal.

CLEANUP: The primary limitation on the cleanup of rock cliffs is accessibility. If access is possible along the base of the cliff, personnel and equipment could be used to remove stranded oil. Dispersion with low-pressure hoses could be used effectively to remove the oil from the rock surfaces. This method would require containment and removal of the dispersed oil.

High-pressure hoses, steam cleaning or sandblasting could also be used but these would probably be unnecessary as the bedrock outcrops are unresistant and low-pressure hydraulic flushing would be adequate for oil removal. Manual collection of the oil could be employed to remove oil that has collected in pools or crevices.

CLEANUP GUIDELINES: In most cases, cleanup of this shoreline type would not be necessary due either to inaccessibility or to rapid rates of natural self-cleaning. Some action may be required if there is a danger that stranded oil could be refloated to contaminate adjacent shorelines.

6.4 UNCONSOLIDATED CLIFFS

IMPACT: The probability of large volumes of oil becoming stranded on unconsolidated cliffs above the high-water level is low. The slopes of these cliffs are generally steep (Photo 10, p. 29) but rarely vertical, so that oil could be deposited on the cliff during a period of falling water levels or by wave splash. Waves acting on this shoreline type during storm periods may be reflected from the cliff face and this would prevent oil from reaching the shoreline.

PERSISTENCE: This shoreline type is characterized by loosely-bound sediments that are easily eroded either by wave action or by rain wash. In both cases, erosion of the cliff face would result in removal of the oil onto the upper beach or intertidal zone. Natural cleaning of oil stranded on unconsolidated cliffs is likely to be rapid except in sheltered locations where rain wash would tend to cause downward migration of sediment and oil and possible burial of the oil at the base of the cliff. Once the oil is buried, degradation rates would be slow.

PROTECTION: The only effective method of protection would be containment and removal of the oil in the offshore zone.

CLEANUP: Except for manual removal no other cleanup methods can be recommended. Dispersion techniques using hoses would cause erosion of the unresistant cliff face and mixing of the oil with the eroded sediments. Natural cleaning is effective and relatively rapid on this shoreline type.

CLEANUP GUIDELINES: Unconsolidated cliffs are easily eroded and can be unstable. Sediments at the base of the cliff act as a protection against wave action; removal of this material could expose the face to erosion by waves and thereby increase normal erosion rates. Large-scale excavation of the cliff base could cause sliding or slumping by changing the slope angle at the base of the cliff (Photo 30).

6.5 DUNES

IMPACT: The deposition of oil on lowlying dune sections could occur during storm surges. In particular, oil could be carried into the backshore areas through overwash channels (Photo 6, p. 25). Light-grade oil would penetrate dune sands, whereas, the penetration of viscous or semi-solid oils would be restricted to a few centimetres. In the event of contamination during

Photo 30. Beach cleanup at Arichat, N.S. involved removal of intertidal oil. The equipment removed protective material from the base of the cliff and in so doing, cut a notch (arrow) into the cliff. Remedial action was initiated to prevent cliff erosion.

periods of storm waves, the constant movement of the sand could result in burial of the stranded oil.

PERSISTENCE: Natural removal of stranded oil would depend on subsequent periods of high water levels to permit waves to act on the dune system. Surface oil could become buried rapidly by wind-blown sand. In both cases the oil could persist for a long time, particularly if it is buried within the sand.

PROTECTION: Onshore protection for this shoreline type could be effective using dykes constructed by machinery on the backshore or across overwash channels. These dykes would probably be breached during high-energy storm conditions, but would be effective at other times if they were built sufficiently high and wide. The construction of a ditch on the seaward side of the dyke would act to collect oil washed up to the ditch/dyke system.

<u>CLEANUP</u>: The same techniques described below for sand beaches (Part 6.8, p. 96) are applicable to dune areas. Traction is usually lower in these backshore areas and it may be necessary to determine the ability of available equipment to operate on the sections to be cleaned. Individual lumps of tarry oil could be removed manually or could be separated from the sand using a mechanical sieving device. Oiled dune grass could be cropped and little long-term damage is caused to the plants as long as the root systems are not disturbed.

<u>CLEANUP GUIDELINES</u>: For small volumes of oil, manual clean-up methods using rakes or shovels are recommended. Pedestrian or vehicle movement through dunes can severely damage vegetation and thereby initiate dune erosion (Photo 5, p. 24 and p. 78). This damage can be reduced or avoided by using a few selected access routes to minimize the areal extent of the damage or by restricting access and movement across dune areas to sections without vegetation. Mats can be used to reduce vegetation damage and to improve traction if necessary.

6.6 INTERTIDAL ROCK PLATFORMS

<u>IMPACT</u>: Oil is stranded on intertidal rock outcrops as the tide ebbs. As oil does not adhere well to wet surfaces much of the oil would be refloated during subsequent flood tides, except for heavy oils which may not float. The upper parts of the intertidal zone have more time to dry than the lower zones so that

the oil would tend to remain on the higher sections of the exposed rock surfaces. Oil tends to collect in hollows or crevices and is often trapped by intertidal vegetation.

PERSISTENCE: The natural cleaning of intertidal rock exposures is relatively rapid, except in sheltered locations, due to high rates of bedrock erosion by wave action. Stranded oil would therefore be expected to remain for only a few months at the most. Oil trapped in hollows or crevices could persist much longer and could form small pockets of "asphalt" if mixed with sediments (Photo 31).

PROTECTION: There are no effective methods available to completely protect intertidal rock exposures other than offshore containment and removal. If necessary some onshore protection could be afforded in areas where the exposed intertidal zone is not wide

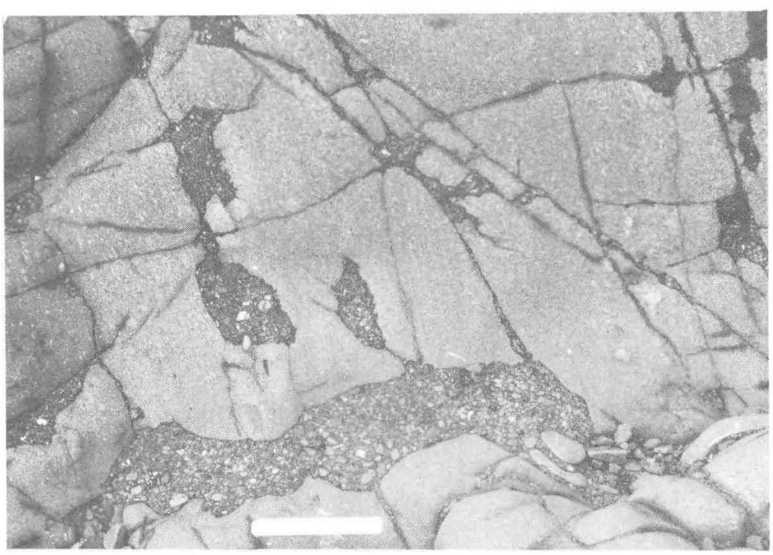

Photo 31. Oil-sediment ("asphalt") in intertidal rock crevices 3 1/2 years after Bunker C oil stranded at this site on Crichton Island, N.S. White scale is 8 cm in length (Photo by J.R. Belanger, Bedford Institute).

by spreading sorbent materials on the rock before the oil is washed ashore. The sorbent-oil mixture would then have to be removed. This may be a difficult operation in some cases, but the sorbent-oil mixture could be flushed with low-pressure hoses onto the adjacent water for collection and removal.

CLEANUP: Natural cleaning rates for oil on the rock surface are high so that cleanup may not be necessary. However, oil that has collected in pools and hollows could be refloated and transported alongshore to contaminate adjacent sections of coast. Low-pressure flushing could remove most of the stranded oil. This operation requires containment and collection of the dispersed oil.

Manual techniques such as pumps or vacuum skimmers can be used to remove oil from tidal pools. If oil has been trapped in seaweed the vegetation can be cropped manually. Cropping should be avoided if possible as the seaweed recovers more rapidly under natural conditions (Eidam, *et al.*, 1975).

CLEANUP GUIDELINES: If there is a danger that refloated oil could contaminate adjacent shorelines, efforts should be made to remove the oil as soon as possible. In cases where this danger does not exist no action is recommended as natural cleaning is rapid in all but sheltered environments. Cleanup of this type of shoreline can be difficult due to the complex nature of the shore zone (Photo 17, p. 37) and the relatively short time available to work in the intertidal zone. In addition, slippery rock surfaces in sections of algal growth can make access difficult.

6.7 INTERTIDAL SAND OR MUD FLATS

IMPACT: These fine-grained intertidal sediments are generally water-saturated, particularly in the lower parts of the intertidal zone (Photo 16, p. 37), so that (a) all except the very light grades of oil would be unable to penetrate the sediments, and (b) much of the stranded oil would be refloated by flooding tides. Heavy oils may not float and could remain where they were deposited. If parallel bars are present, the oil would tend to collect in the troughs between the bars and as these bars frequently change position oil that remains in the intertidal zone would be subject to cycles of burial and exposure.

Intertidal flats are productive biological environments and many of the animals could be affected by smothering or by ingestion of the oil.

PERSISTENCE: Surface oil would be abraded and dispersed by the action of tides and waves, except in cases when a thick layer of heavy oils is deposited. If the oil is buried degradation rates would be slow.

PROTECTION: Many of the intertidal flats are extensive in area (see Frontispiece) so that no practical onshore protection methods are feasible. Where tidal flats occur in a lagoon or estuary that has a relatively narrow entrance, booms could be used to prevent oil from reaching these sheltered environments.

CLEANUP: In most cases removal of stranded oil from intertidal flats would require manual methods. If the bearing capacities are sufficient, for example on relatively dry sand deposits, it may be possible to deploy machinery such as a front-end loader to remove large volumes of oil. Bearing capacities on mud flats are usually very low and in some cases these sediments may not be able to bear the weight of a person. Draglines or clamshells could be used to remove oil, although this equipment is not efficient under most circumstances.

CLEANUP GUIDELINES: If large volumes of the stranded oil are not refloated by the tides, efforts should be made to try to remove the oil before it is buried by the mobile sediments. In general, no action is recommended unless the oil would have an adverse effect on biological populations or if the oil could become refloated to contaminate adjacent shorelines.

Cleanup in this type of shoreline would probably involve extensive manual effort. Care should be exercised to avoid areas of soft sediments. Traffic through stranded oil on soft sands or muds could result in unnecessary further mixing of oil and sediments and could cause burial of the oil.

6.8 SAND BEACHES

IMPACT: Light-grade oils penetrate into sand beaches but most other types of oil remain on the surface or penetrate to only a few centimetres. In low-energy environments or in cases where large volumes of oil are washed ashore, the entire intertidal zone could be contaminated. In other cases oil tends to be deposited in the upper intertidal zone during the first few hours of the ebbing tide. The lower intertidal zone is frequently water-saturated so that most oils, with the exception of heavy oils, are usually refloated during flood tides. If water levels are high due to spring tides or storm surges, the oil can be deposited on the backshore above the limit of normal wave activity (Photo 32).

Sand beaches are subject to continuous changes in response to wave activity. The changes can result in the burial of stranded oil (Figs. 16 and 19, p. 67 and p. 69). With further shore zone changes the oil could be re-exposed and eroded.

PERSISTENCE: The natural dispersion of oil on sand beaches is a function of shoreline energy levels and rates of shoreline change. Redistribution of sediments by wave action can cause burial of the oil. These changes may be due to storm/post-storm or summer-winter erosion and deposition cycles, or to the alongshore migration of rhythmic topography (pages 66 to 69).

On exposed coasts, such as the north shore of Prince Edward

Photo 32. Oil which was stranded on a sand beach in the Straits of Magellan at a time of very high water levels remains largely unaffected by wave action after 2 1/2 years. Solid arrow is the limit of the high spring tides and open arrow is the normal high-water level.

Island, high autumn wave-energy levels erode the beach and would rapidly disperse the oil. On most exposed beaches natural self-cleaning would occur within a few months. In more sheltered locations the oil can form "asphalt pavements" (Photo 24, p. 70) and could persist for years (Fig. 12, p. 56). In some of the very sheltered locations of Chedabucto Bay oil spilled from the *"Arrow"* in 1970 is still in the intertidal zone and is expected to persist for decades. Oil stranded above the normal level of wave action (Photo 32) is dispersed slowly and can be buried by wind-blown sediments.

PROTECTION: Backshore zones can be protected by the use of machinery to construct dykes and ditches at the high-water mark. Dykes would only be successful in the lower intertidal zone if they were constructed so that they would not be overtopped at high tides. Machinery can push sediments up the beach from the intertidal zone rather than using the drier backshore sands as wet sand is most effective for dyke construction.

Sorbents can be placed on the beach before the oil is washed ashore, preferably at low tide. These could be useful for light-grade oils to reduce penetration of the oil into the sediments.

CLEANUP: Several cleanup options are available depending on the volume of oil, the depth of penetration and the bearing capacities of the sediments. For large volumes of oil machinery can be used to scrape oil from the beach surface (pages 122 to 125); manual removal may be more useful if the contamination is light.

The most effective method of mechanical removal, providing there is sufficient traction, is to use a grader to form windrows (Fig. 22, p. 124) which are then removed by a scraper. Elevating scrapers can be used alone. Front-end loaders are less efficient and tracked vehicles are not recommended as these can grind oil into the beach sediments.

If oil removal is not necessary and the beach is on an exposed coast, machinery can be used to push oil into the lower intertidal zone. This action would promote the dispersal and degradation of the oil by wave action. In sheltered areas where removal is not required, machinery can be used to break up the oil cover and thereby promote degradation by exposing a larger surface area of the oil.

Tarry lumps of oil can be removed by using tractor-drawn sieves to separate the oil from the sand.

CLEANUP GUIDELINES: Cleanup operations should not commence until all danger of further oil becoming stranded is past, otherwise it may be necessary to clean the same beach more than once. In all removal operations the objective should be to remove as little sediment as possible. This involves selection of the most suitable and effective method of removal before the oil is buried.

Lowering of the beach elevation, particularly in the upper intertidal zone, can lead to erosion or flooding of backshore areas. If sediment is removed from the beach crest it should be replaced by an equal volume of the same size material to avoid any adverse results. Sediment may be available from backshore areas to replace that removed from the berm (q.v.).

6.9 MIXED SEDIMENT BEACHES

IMPACT, PERSISTENCE AND PROTECTION: In virtually all cases, the impact and persistence of stranded oil and the protection methods are the same as described above for sand beaches because the predominant sediment fraction is sand-size material.

These types of beaches usually occur in more sheltered environments where wave action is insufficient to abrade the bedrock fragments. As a result, the persistence of the oil is often high. In addition, "asphalt pavements" (Photo 24, p. 70) are often formed and would only be eroded slowly in these sheltered environments.

CLEANUP: As this beach type is composed of pebble and cobble sediments, the use of the more effective mechanical oil removal methods may not be possible. The applicable mechanical removal methods are the same as those described below for pebble-cobble beaches except that depth of penetration is usually not as great due to infilling of the void spaces between the coarse particles by sand.

CLEANUP GUIDELINES: This shoreline type occurs most frequently where wave-energy levels are low and, therefore, sediment transport rates are also low. In this respect, it is particularly important to remove as little sediment as possible as natural replacement rates will be slow. Lowering of the beach or berm elevation could lead to backshore erosion or to flooding during periods of moderate or high wave-energy levels.

6.10 PEBBLE-COBBLE BEACHES

IMPACT: The large spaces between individual pebbles and cobbles allow all except the heavy oils to penetrate into the beach sediments. Actual penetration depths depend on the size of the spaces and the viscosity of the oil. Light oils rapidly penetrate into the beach and may be washed through the sediments back into the water. On cobble beaches in Chedabucto Bay penetration depths up to 1.5 m for weathered Bunker C oil were recorded shortly after the oil was stranded.

Oil tends to be deposited in the upper intertidal zone during the high-water slack period and during the first few hours of the ebbing tide. If oil is washed ashore during storm conditions it could be carried over the storm ridge (q.v.) and deposited in backshore areas above the limit of normal wave activity.

PERSISTENCE: Where oil is exposed on the surface of the intertidal beach, rates of abrasion and dispersal are usually high and the beach can be cleaned within months (Photo 33). Oil that has penetrated into the sediments or been deposited on the backshore will be dispersed slowly. Oil on backshore areas can also be subject to burial during subsequent periods of storm-wave activity (Fig. 18, p. 69). If large volumes of oil are washed ashore, resistant "asphalt pavements" can be formed. In this case the ability of the sediment to be moved by wave action and to abrade the stranded oil is greatly reduced.

CLEANUP: Oil removal is difficult on pebble-cobble beaches due to the deep penetration of the oil. In addition, most

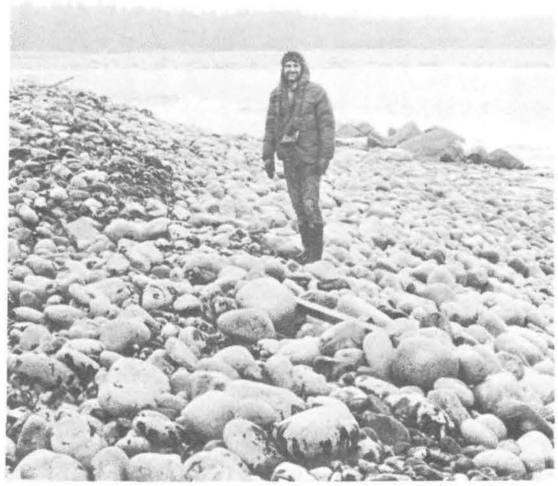

Photo 33. Oil on a pebble-cobble beach at Black Duck Cove, N.S., 3 years after the spill. The intertidal zone (at right) was cleaned naturally within a few weeks, whereas, oil stranded above the high-water mark persisted and was partially buried by clean sediments (photo by J.R. Belanger, Bedford Institute).

machinery cannot operate on these beaches due to poor traction. Although front-end loaders can be deployed, in most instances the method is inefficient as large volumes of sediment must be removed to remove relatively small volumes of oil. Where oil is largely confined to the surface of the beach, a front-end loader can be used successfully if handled carefully. This involves using the bucket to remove only the contaminated sediments rather than trying to use the bucket to excavate the oil.

Oil in the intertidal zone can be dispersed with chemicals and then flushed through the beach. The application of the chemical dispersant would best be carried out at low tide. The dispersed oil would then be partially flushed from the beach during the ebb tide. Low-pressure hoses could be used to increase the flushing rate of the dispersed oil.

In cases where removal of the oil is not required, the contaminated sediments can be pushed down the beach to the lower intertidal zone to allow waves to abrade and disperse the oil. If an "asphalt pavement" has formed, machinery can be used to break up the oil cover to promote rates of weathering and degradation.

Manual removal of surface oil can be employed if machinery is ineffective, either because of accessibility or low traction.

CLEANUP GUIDELINES: Rates of natural sediment replacement are very slow so that any material removed should be replaced by sediment of the same size. Lowering of the beach or storm-ridge could result in backshore erosion or flooding if the sediment is not replaced. In cases where backshore material is available, this sediment can be pushed into the area of sediment removal to prevent waves washing over the top of the beach.

The oil should be removed as soon as possible to prevent surface oil that may become mobile from penetrating into the beach. In addition, oil on backshore areas should be removed before it is buried by subsequent storm-wave action.

6.11 MARSHES

IMPACT: Marsh surfaces are covered with water only during periods of spring high-water levels or storm surges. At other times oil would be restricted to marsh edges or to tidal creeks (Photo 34). As these latter areas are usually water-saturated, oil cannot penetrate the sediments and can be refloated by flood times.

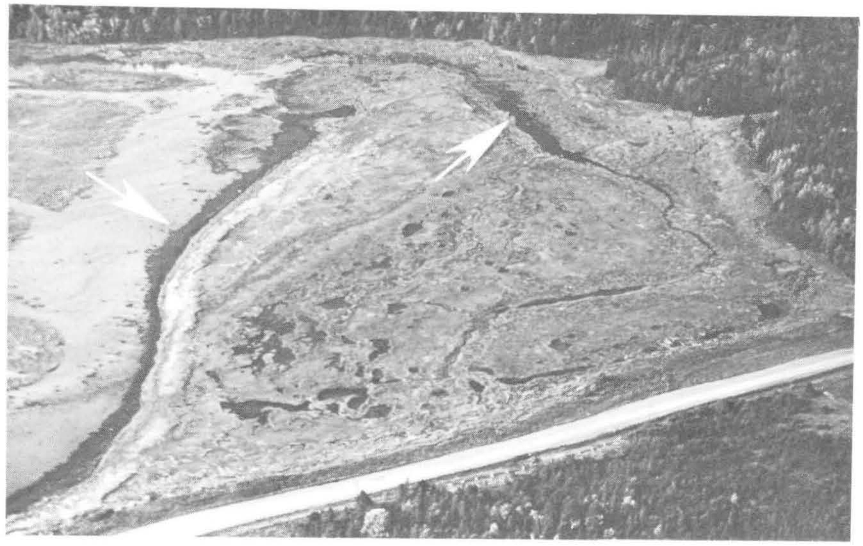

Photo 34. Oil (indicated by the arrows) trapped in a creek and against the marsh edge at high tide, Baie des Chaleurs, October 1974.

Light-grade oils are particularly toxic to the flora and fauna of marsh environments and can penetrate into the marsh sediments. The heavier oils tend to smother the vegetation. The impact of stranded oil varies seasonally and has a lower effect on biological productivity during autumn and winter months (Cowell, 1971). Except in cases of spills from toxic oil or large volumes of heavy oil, marsh environments can usually recover over a 1 to 2 year period (Cowell, 1971).

PERSISTENCE: Levels of mechanical energy in marsh systems are low but rates of biochemical degradation can be rapid if the oil is not buried. Although the oil may persist for several years in a marsh, the impact may not be severe unless the oil is toxic or forms a complete cover on the vegetation.

PROTECTION: The most effective protection for marsh environments is to prevent oil from reaching these areas. If the marsh is in a bay or lagoon that is connected to the sea by an inlet or channel, booms may be effective in containing the oil. Dykes or dams across channels could prevent oil from reaching backshore marsh areas, and during spring tides dykes along the marsh edge can prevent oil being deposited on the marsh surface. Construction of dykes is only possible is sediments are available and if the area is accessible to machinery. Dyke construction should only be carried out if damage to the marsh environment can be avoided.

CLEANUP: The most biologically acceptable cleanup method is the use of low-pressure hoses to flush oil from the marsh surface for subsequent containment and removal (Westree, 1977). Cropping of oiled vegetation can be successful if carried out carefully, and in most cases it is not harmful to plant species (Baker, 1971). Cropping or controlled burning are best carried out in autumn and winter months (Wardley-Smith, 1968; Westree, 1977).

The use of machinery on the marsh surface should be avoided in all cases. Manual removal, by cropping or with rakes and shovels, should be carried out with care to avoid spreading or trampling the oil into the sediments.

CLEANUP GUIDELINES: Machinery should not be used on marsh surfaces as the vegetation can be damaged and the oil can be spread or buried. Similarly, personnel traffic across a marsh surface should be carefully controlled. The use of mats can reduce the level of damage and can serve to restrict access routes to selected locations. Cleanup operations in this environment require close supervision of personnel to prevent more damage than that caused by the oil. Cleanup can be successful without incurring unacceptable damage and it should be planned in consultation with biologists familiar with this sensitive environment.

6.12 MAN-MADE SHORELINES

IMPACT: The distribution of oil on wood, metal or concrete structures is similar to that described above for exposed bedrock cliffs and platforms. The impact of stranded oil is minimal and is primarily aesthetic.

PERSISTENCE: The persistence of oil on man-made structures is largely a function of the local wave-energy levels. On exposed coasts the oil will be dispersed rapidly but in sheltered environments rates of abrasion are slow and an oil stain may persist for several years.

PROTECTION: Man-made structures can be protected by enclosure if currents and wave heights do not negate the effectiveness of booms.

CLEANUP: Oil can be effectively dispersed using high or low-pressure flushing, steam cleaning, sandblasting, or chemical dispersants. The dispersed oil should be contained for subsequent removal. The cleanup of man-made facilities usually presents no problems unless the structure is one of pre-cast concrete blocks. In this case cleanup of the outer surfaces only may be acceptable unless large volumes of oil could be released to contaminate adjacent shorelines.

6.13 SUMMARY

The major points discussed in sections 6.3 to 6.12 have been summarized as three tables. Tables 10 and 11 relate

TABLE 10. The Impact and Persistence of Stranded Oil

SHORELINE TYPE	IMPACT OF OIL	PERSISTENCE
Coasts Without Sediment		
ROCK MAN-MADE	- oil may be reflected - coats exposed dry surfaces - wave splash can throw oil above normal limits of wave action - oil does not easily adhere to wet surfaces - thickness of oil cover decreases as steepness increases - oil collects in rock pools	- oil readily abraded if it is stranded below normal limit of wave activity, except in sheltered sites
Coasts With Sediment		
MUD	- mud has very small spaces between particles and these are usually filled with water, therefore, only very light grades of oil penetrate	- muds are easily transported by waves, therefore, oil can be buried - buried oil degrades very slowly in muds - surface oil may be easily removed by waves because water usually separates the oil from the mud
SAND	- only light oils can penetrate sand - heavy oils rarely penetrate more than 2 to 3 cm - penetration depths are greater during periods of high temperatures - oil is usually deposited at upper limit of wave action	- oil can be easily abraded if it is not buried and if it is within the zone of wave action - possibility of burial is high if beach is subject to wave action during storms - oil/sediment may form an "asphalt pavement", thereby increasing persistence
PEBBLE COBBLE	- as the size of the sediments increases, the depth of penetration of all oils increases - penetration of medium and heavy oils can be as much as 1.0 m - light grades of oil may be washed through the beach and flushed by waves	- buried oil and "asphalt pavements" are very persistent - surface oil is easily abraded by waves and moving sediments
MIXED SEDIMENTS	- spaces between larger particles are filled with smaller-sized sediments, therefore, oils rarely penetrate (except light grades)	- usually low energy environments, therefore, even surface oil persists - "asphalt pavements" are common
MARSHES	- oil is usually restricted to the marsh edges - light oils are more toxic to the vegetation and can penetrate the marsh sediments - impact is less severe in autumn and winter months	- mechanical energy levels are low, but biochemical degradation is rapid if oil is not buried - marshes usually recover naturally unless the oil is very toxic or very large volumes of oil carpet the vegetation

TABLE 11. Onshore Protection Methods and Shoreline Types

SHORELINE TYPE	ONSHORE PROTECTION METHOD(S)
ROCK MAN-MADE	- sorbents may be useful on low angle slopes
MUD	- sorbents could be effective if collection can be achieved without mixing oil/sorbent into uncontaminated muds
SAND	- ditch/dyke system could be used to protect backshore - sorbents could prevent or reduce penetration and facilitate the removal of oil
PEBBLE COBBLE	- no available effective onshore protection - retrieval of sorbents is difficult - ditch/dyke system is too permeable but could stop oil from washing over into the backshore or could be used in conjunction with sorbents
MIXED SEDIMENTS	- can be treated in the same manner as sand/pebble beaches
MARSHES	- ditch/dyke system could protect the marsh edge if the marsh is flanked by sand deposits - dykes across the marsh channels could prevent oil from penetrating into the backshore marsh areas

impact-persistence and onshore protection methods respectively to the major shoreline types. Table 12 indicates the applicability of the various cleanup methods to the shoreline types discussed in the text.

TABLE 12. Cleanup Methods and Shoreline Types

	CHEMICAL DISPERSANTS	HIGH-PRESSURE HOSES	STEAM CLEANING	SANDBLASTING	LOW-PRESSURE HOSES	MIXING	GRADER/SCRAPER	FRONT-END LOADER	BULLDOZER	DRAGLINE/ CLAMSHELL	SUMP/PUMP	MANUAL REMOVAL	MANUAL CROPPING	BURNING/ INCINERATION	BEACH-CLEANING MACHINES
Rock Cliff	X	+	+	+	√	–	–	–	–	–	–	√	–	–	–
Man-Made	+	√	√	+	+	–	–	–	–	–	–	√	–	–	–
Unresistant Cliff	X	X	X	X	X	–	–	–	–	–	–	√	–	–	–
Dunes	X	X	–	–	X	X	√	+	X	X	+	√	+	X	+
Intertidal Rock	X	+	+	+	√	–	–	–	–	–	+	√	+	–	–
Intertidal Sand/Mud	X	–	–	–	–	X	–	+	+	+	–	√	–	X	–
Sand Beach	X	X	–	–	X	+	√	+	X	X	+	√	–	X	√
Mixed Beach	X	X	X	–	X	+	+	+	+	+	+	√	–	X	+
Pebble/Cobble Beach	+	+	+	–	+	+	–	+	+	+	–	√	–	X	–
Marsh	X	–	–	–	√	X	–	X	X	X	+	√	√	+	–

X NOT Recommended – Not Applicable

√ Recommended + Applicable and possibly useful

PART 7 - SHORELINE PROTECTION AND CLEANUP METHODS

SYNOPSIS

Offshore protection can be achieved by the use of booms to contain the oil for collection, by mechanical recovery of the oil from the water surface, or by chemical dispersion of the spilled oil. Onshore protection methods include sorbents, surface treatment agents, and the construction of dykes and ditches on the beach. The available onshore cleanup methods are grouped into dispersion, removal and *in situ* cleaning techniques. Each of the protection and cleanup methods is discussed separately. The major points that relate to the use and applicability of each method are summarized in Tables 13 and 14.

7.1 SHORELINE PROTECTION METHODS

Shoreline protection is most effective when the oil is contained and/or removed directly from the sea surface. Chemical agents can be used to either disperse or collect spilled oil.

Onshore methods can be effective provided that sufficient time and resources are available (Part 8.3, p. 135). The objectives of onshore protection are either to prevent oil adhering to or penetrating into the substrate, and/or to facilitate oil removal from the shoreline. The protection methods are summarized in Table 13.

Offshore Protection

(i) Booms can be very effective in protecting the shoreline by containment or diversion of oil on the water surface (Tsang and Vanderkooy, 1978). As the size of the spill increases, the practicality of containing or diverting all the oil is reduced. Most booms are effective only when current velocities are low (generally <0.5 m/s) and wave heights are small (<25 cm), but new equipment under development will probably be able to contain

TABLE 13. Shoreline Protection Methods

OFFSHORE	METHOD	APPLICABILITY
BOOMS & REMOVAL	- deployed in front of or around the slick to contain or divert oil movement	- currents <0.5 m/s - wave height <25 cm - used to protect bays, harbours, estuaries, or lagoons
DISPERSION AGENTS	- reduce surface tension of oil by application of chemicals - oil is then dispersed more rapidly into the water	- requires permission of regulatory agencies - increases oil mobility, therefore, stranded oil has greater potential to penetrate beach sediments
COLLECTION AGENTS	- increase surface tension of oil by application of chemicals - oil is prevented from spreading	- decreases oil mobility, therefore, stranded oil has a reduced capacity to penetrate beach sediments
ONSHORE	**METHOD**	**APPLICABILITY**
SORBENTS	- applied manually or mechanically to the beach before oil is stranded - oil/sorbent is then removed manually or mechanically, or flushed onto water for removal	- prevents penetration of oil into substrate - sorbent pads preferable to loose-fibre materials for ease of collection - synthetic products have higher sorbtion capacity than natural materials - usually a labour-intensive method
SURFACE TREATMENT AGENTS	- applied to shore zone before oil is stranded - prevents oil from adhering to the substrate	- applicability and effectiveness not yet fully assessed - may be difficult to apply on long sections of shore - oil must be flushed from the shore and agent removed if it does not degrade naturally
HERDERS	- applied along water line before oil is stranded - reduces natural dispersion of oil	- reduces area of shoreline contamination
DYKES AND/OR DITCHES	- ditch up to 1 m deep dug parallel to shore at upper limit of wave action - sediment removed used to build dyke on landward side of the ditch - on pebble-cobble beaches can fill ditch with sorbents to collect oil and prevent oil penetration	- prevents oil being washed onto the backshore - can be constructed mechanically along long beach sections - ditch acts as a collector of oil which can be removed with buckets, hand pumps, or vacuum pumps

oil under more severe conditions (Cranfield, 1978).

Booms can be particularly useful at harbour entrances, across lagoon or river mouths, and across channels and small bays. To protect a sensitive or vulnerable shoreline it may be practical to divert oil towards another section of shoreline for removal. Thus, although contamination at one site may be high, protection would be provided to other shoreline sections where the sensitivity may be greater or where removal may be more difficult.

Shallow tidal channels or creeks can be protected by booms of brush-filled fencing or by construction of an earth dam. If damming the flow through the channel is undesirable, water can be transferred through the dam by a pump or by placing pipes in the dam during construction. Flow can then be controlled by opening or closing valves in the pipe.

(ii) Dispersants on offshore waters could be considered if other protection methods are inapplicable and if sensitive shoreline environments are threatened. In evaluating the use of dispersants, regulatory agency requirements must be satisfied and an assessment of the potential biological impact should be undertaken. Dispersants can be effective provided that the dispersed oil does not reach the shoreline. If the dispersion process is not completed before the oil is stranded, then contamination problems are increased as the dispersed oil will be more mobile and will penetrate the sediments to greater depths than undispersed oil.

(iii) Collecting agents (or "herders") can be spread on oil before it becomes stranded to reduce the spreading of the slick (Berry, 1972). This protection method can reduce the area of shore contamination and the capacity of the oil to penetrate into beach sediments.

Onshore Protection

(iv) Sorbents spread in the intertidal zone before contamination collect oil as it is washed ashore and prevent or reduce penetration of the oil into beach sediments.

Synthetic sorbents are usually more effective than natural organic material (Schatzberg and Nagy, 1971) but are also more expensive. Loose-fibre materials may be useful for collection of oil from pools or hollows but in most situations sorbent rolls or pads are more conveniently deployed and retrieved.

Mechanical spreading of loose sorbents can be achieved with snowblowers (Logan, *et al.*, 1976). A useful retrieval method for loose sorbents is to flush them from the beach onto the water where the oil/sorbent mixture can be collected by a variety of mechanical systems (Miller, *et al.*, 1973; Shaw and Dorrler, 1977; Brunner, *et al.*, 1977).

During the "*Arrow*" spill, peat moss was spread manually and with snowblowers on the shore and then harvested using rakes. The peat had a maximum sorbtion capacity of 17 gms oil/gm peat moss, similar to that of sheet or mat polyethylene fibres (Schatzberg and Nagy, 1971).

Sorbents are most effective when spread on the shore zone at low tide before the oil is washed ashore. The oil and sorbent then mix as the water level rises. The oil-sorbent mixture should be removed as soon as possible so that oil does not drain out onto the sediments or rock surface.

Some limitations of sorbents are that they are less effective in cold temperatures (McMinn and Golden, 1973), and that the method is usually labour-intensive for large spills as it requires spreading, mixing, collection and disposal of the material.

(v) Surface treatment agents are still in the developmental stage, but may prove to be effective and practical in the near future. The method involves coating the substrate with an agent before the oil is washed ashore to prevent oil from adhering to sediment or rock surfaces (Dailey, *et al.*, 1975; Stewart, 1975; Foget, *et al.*, 1977). The oil must be flushed from the shoreline for collection and then removed from the water surface. The agent itself must also be removed if it does not degrade naturally. One agent which may be practical is water. When sprayed over the shore zone the water greatly reduces the amount of oil that is stranded. If ambient temperatures are below the freezing point of the water, spraying of the shoreline would produce a layer of ice that would protect the shore zone. No large-scale field testing of these techniques using water has been undertaken and the applicability and effectiveness is yet to be assessed.

(vi) Ditches (or trenches) and dykes can be constructed on a beach to prevent oil from contaminating the backshore areas. A ditch can be dug parallel to the shoreline near the high-water level. The material excavated can then be used to construct a dyke on the landward edge of the ditch. Oil and water washed up the beach would be collected in the ditch, which acts as a natural sump, so that oil can then be removed with buckets, pumps or vacuum systems. The method is particularly applicable to sand and mixed sediment beaches. As the sediment size increases, oil penetration depths increase and the effectiveness of the system is greatly reduced. However, even on coarse-sediment beaches, a ditch filled with sorbents can contain oil as it becomes stranded and a dyke can protect sensitive backshore areas.

Construction of the ditch-dyke system can be achieved by using trench-cutting machines, motor graders, front-end loaders or bulldozers. In particular, trenching machines can excavate a ditch and cast the sediment to build the dyke simultaneously. If there is insufficient time to construct a ditch-dyke system, graders or bulldozers can be used to quickly build a dyke on the beach by using an angled blade to form a windrow near the high-water level. In cases where only a dyke is built, wet sand pushed up the beach from the intertidal zone can make a higher dyke, and therefore a more effective barrier, than drier back-shore sand.

7.2 SHORELINE CLEANUP METHODS

Shorelines contaminated by oil will clean themselves naturally in time. Where this process is slow, it may be desirable to clean the shoreline, in which case a variety of methods to remove or reduce the volume of oil is available. The selection of the most appropriate method(s) is based on the volume of stranded oil, the shoreline type, the depth of oil penetration, and shoreline accessibility.

The various methods can be conveniently grouped into: (a) dispersion, (b) removal, and (c) *in situ* cleaning. The available techniques are reviewed briefly and information on the applicability and impact of each technique is summarized in Table 14.

Dispersion

(i) Chemical Dispersion. The use of dispersants applied to stranded oil is regulated to low-toxicity products and permission of the regulatory agency in Canada is required (Ruel, *et al.*, 1973; Environment Canada, 1976).

Dispersants increase the oil's mobility by reducing the surface tension of oil so that the dispersed oil can be flushed from the shore zone. The increase in the mobility of the oil can also result in greater penetration of the oil into the beach sediments. Therefore, although dispersants are potentially useful on shorelines with sediment, they are more effective and have less impact on man-made structures.

If used on shorelines, mixing of the oil and dispersant can be achieved by spraying oiled sections at low tide, thereby allowing waves to mix the chemical with the oil as the tide rises. The oil/dispersant emulsion should be flushed from the shoreline with hoses and then removed from the water surface.

(ii) High-Pressure Hoses. This method has proved to be effective in removing oil from the surface of boulders, rock and man-made structures. High-pressure dispersal would not be needed on the coasts of Prince Edward Island as the friable, unresistant rock can be eroded with low-pressure hoses. On cobble or pebble beaches the sediment can be cleaned but the oil is washed into the sub-surface sediments. On sand beaches the sand itself is flushed from the beach.

To be effective this method involves either flushing of the oil onto the adjacent water surface for collection or channelling the oil/water mixture into a ditch or sump for collection (Bender, 1978). Care should be exercised to prevent oil being splashed onto uncontaminated surfaces. The cleaning should begin at the

TABLE 14. Shoreline Cleanup Methods

METHOD	DESCRIPTION	APPLICABILITY	IMPACT
Dispersion			
CHEMICAL DISPERSION	- applied to oil, reduces surface tension	- use requires approval of regulatory agency - may require mixing with oil - oil/dispersant mixture flushed from beach, rock or man-made surfaces	- increased oil mobility can result in penetration of dispersed oil into the sediments - potentially toxic to land and aquatic flora & fauna
HIGH-PRESSURE HOSES	- high-pressure stream of water washes oil from the substrate	- can be effective on rock, boulder, and man-made surfaces, but is expensive - oil flushed onto water surface for removal or channeled to beach collection site	- can damage flora & fauna - can flush oil into sediments - if beach is backed by unconsolidated cliffs, hosing of cliff can cause slumps, falls, or slope failure
STEAM OR HOT-WATER CLEANING	- steam or hot-water washes oil from the substrate	- very effective on rock, boulder, and man-made surfaces - oil flushed onto water surface for collection or channeled to beach collection site - expensive method	- can be very harmful to flora & fauna - can flush oil into sediments
SANDBLASTING	- high velocity sand removes oil from the substrate	- effective but slow method for rock, boulder, and man-made surfaces - can remove oil stains - expensive method	- can be very harmful to flora & fauna - scatters oil and sand - can cause deeper penetration of oil into sediments
LOW-PRESSURE HOSES	- low-pressure stream of water washes oil from the substrate	- effective but slow method for rock, boulder, and man-made surfaces - oil flushed onto water surface for collection or channeled to beach collection site	- biologically preferable to high-pressure hoses, steam cleaning, or sandblasting - can flush oil into sediments
MIXING	A-mechanical equipment such as rakes, discs or harrows used to break up oil cover and mix surface sediments	- accelerates natural cleaning - useful for light grade oils or to break up "asphalt pavements" - increases surface area of exposed oil and increases dispersal and degradation rates	- does not remove oil - can cause burial of the oil
	B-mechanical equipment used to push oil/sediment down beach into the water	- accelerates natural cleaning - wave action disperses and degrades oil - sediment is returned to the beach - applicable for "asphalt pavements" or coarse-sediment beaches	- does not remove oil - should not be used if storm waves are expected before sediment is returned to the beach; could result in waves overtopping the beach and/or causing backshore erosion

TABLE 14. (Cont'd)

Removal			
GRADERS, SCRAPERS	- remove thin layer of oiled sediments - graders form windrows for scraper or front-end loader to remove - scraper removes oil/sediment layer directly	- effective on sand or pebble beaches with low oil penetration depths (<3 cm) - scraper can remove up to 25 cm layer of oil/sediment - some spillage which can be removed manually	- removes sediment from the beach, amount of sediment removed usually not sufficient to affect beach stability
FRONT-END LOADERS	- loader removes material directly from beach to collection sites	- used on beaches with poor traction or for high oil penetration depths (25 cm or more) - high spillage - usually large amounts of uncontaminated sediment are removed - rubber-tired vehicles are preferred to tracked vehicles	- can result in excessive sediment removal that could cause beach or backshore erosion - grinds oil into the beach
BULLDOZERS	- push material into collection sites for removal	- can remove oil/sediment where penetration is 25 cm or greater - not recommended unless other equipment unavailable or traction is too low for other equipment	- can result in excessive sediment removal that could cause beach or backshore erosion - large spillage and grinds oil into sediments
DRAGLINE, CLAMSHELL	- sediment collected in bucket dragged towards equipment, or by crane-operated bucket	- useful where beach access or trafficability is poor	- can result in excessive sediment removal that could cause beach or backshore erosion
SUMP COLLECTION AND PUMP REMOVAL	- sump excavated and used to collect oil which is then removed by pump or vacuum system	- useful for large spills with oil washed ashore over a period of days	- does not remove all the oil from the beach
MANUAL	A-oil scraped from the substrate B-oil collected with buckets, shovels, rakes, forks, etc. (with or without sorbents) C-cutting of oiled vegetation	A/B useful for areas inaccessible to equipment or small spills A/B/C labour intensive methods; slow rate of oil removal C-oil/vegetation collected in containers for removal	A-selective oil removal, not all oil is removed C-labour intensive method; pedestrian traffic can disturb marsh vegetation and can cause oil/sediment mixing
In Situ Cleaning			
BURNING (A) INCINERATION (B)	A-oil ignited, usually with ignition agents -continued burning may require wicking agents B-incineration machines use heat source to burn oil	A-seldom completely successful -useful for oil on surface of ice -can be used in marshes with appropriate biological advice -oil residues remain B-useful for sand, pebble, and cobble beaches -sediment returned to beach after incineration	A-can cause heavy air pollution -can increase the penetration of oil into the sediments -could damage root systems of marsh vegetation B-little or no impact
BEACH CLEANING MACHINES	- cleaner picks tar lumps from the beach	- useful on beaches with tar balls	- little sediment removal

farthest point from the collection area and systematically flush the oil downslope for collection.

In locations with a cliff of unconsolidated sediments, care must be exercised to avoid disturbance to the base of the cliff. If the cliff is unstable, a situation that may not always be readily apparent, washing of the basal sediments could cause slope failure and slumping.

(iii) Steam or Hot-Water Cleaning. The method is similar to high-pressure flushing except that it removes oil more effectively, is more expensive, and is more harmful to flora and fauna. The advantage of the method is that, in addition to the mechanical energy introduced by flushing, the temperature of the oil is raised and the oil, therefore, becomes more mobile and flows downslope. The method is particularly applicable for most man-made surfaces but would be unnecessarily expensive for the unresistant rock outcrops on Prince Edward Island.

(iv) Sandblasting. The use of sand to abrade oil from the substrate is particularly effective in removing all oil, including stains, from contaminated surfaces. However, the method also removes all flora and fauna, and it is an expensive and slow process. Once blasting is complete the sand-oil mixture must be removed for disposal. The method is applicable for most man-made structures and could be used for rock surfaces, although in the latter case low-pressure hoses would be adequate and less expensive.

(v) Low-Pressure Hoses. Similar in operation to, but slower than, the high-pressure hose system, this method is biologically preferable and can be used in marsh environments without incurring damage to the vegetation (Westree, 1977). The method is applicable for man-made structures, rock surfaces and marshes. It may be useful to disperse oil on pebble-cobble beaches but can cause flushing of oil into the sediments.

(vi) Mixing. The objective of this method is to use machinery to break up the oil cover on beaches in order to increase the rates of evaporation, degradation and dispersion. The method does not involve the removal of oil and is, therefore, primarily applicable in situations where sediment removal may result in an unstable beach, on low-energy beaches where an "asphalt pavement" has formed, or on low-priority non-recreational beaches. Two basic techniques can be used:

(A) The first mixing technique involves the use of rakes, discs, harrows, or bulldozers to break the oil cover, to increase the exposed surface area of the oil, and to leave the oil to degrade naturally. It is particularly effective for light-grade oils that evaporate readily upon exposure, provided that the use of equipment does not create a potentially hazardous situation (by the ignition of highly volatile oils such as avgas or diesel). To avoid burial of oil, which would reduce the rates of degradation, the depth of disturbance should not exceed the depth of the oil penetration. The method is applicable on any type of beach and particularly useful in low-energy, sheltered beach environments where sediment removal is inadvisable or unnecessary, and on beaches where the sediments and oil have formed an "asphalt pavement".

(B) The second mixing technique involves use of machinery to push contaminated sediments from the beach into the lower intertidal zone. The purpose is to allow normal wave action to abrade and disperse the oil and to return the sediment back onto the beach (Owens, 1977; Bender, 1978). The method is applicable on all types of beach and again is useful where sediment removal is inadvisable or when an "asphalt pavement" has formed.

The method is best applied on exposed beaches where levels of wave activity are relatively high so that waves can clean and return the sediments rapidly. The operation should not be implemented if storm or high-water level conditions are expected before the beach sediments are returned. The operation temporarily reduces the effectiveness of the beach to protect the backshore, so waves could overtop the beach and cause backshore inundation or erosion.

Removal

(vii) Graders and Scrapers. The removal of surface oil from sand beaches can be achieved effectively and efficiently by the use of graders and scrapers (Sartor and Foget, 1970). This equipment can also be used on mud or pebble shores where bearing capacities of sediments are favourable. In all cases, the primary limitations are trafficability and, for the grader, a maximum oil penetration in the order of 2.5 cm (Fig. 21). Elevating scrapers, either motorized or towed, can remove sediment to greater depths (up to 25 cm).

The grader is the most efficient equipment as it removes the

SIZE OF AREA	TYPE OF OIL	DEPTH OF PENETRATION	TYPES OF BEACHES		
			FINE SAND	COARSE SAND	GRAVEL
LARGE	HEAVY	SHALLOW, 1cm to 2.5cm	GRADER and ES or FFL	GRADER and ES or FFL	--
		MODERATE, 2.5cm to 25cm	ES	ES	ES
		DEEP, 25cm+	WFEL*	WFEL	WFEL
	LIGHT	--	BEACH CLEANING MACHINES		
SMALL	HEAVY	--	MANUAL REMOVAL OR WFEL*		
	LIGHT	--	MANUAL REMOVAL, RAKE		

ES - Elevating Scraper WFEL*- Wheeled Front-end Loader, firm gr. only
FFL - Forced Feed Loader Tracked front-loader for low bearing cap. soils

Figure 21. Method and equipment for cleanup of sand and gravel beaches (adapted from Der and Ghormley, 1975).

least uncontaminated sediment. The recommended technique is to form windrows with a 50° blade angle (Fig. 22, Table 15). The windrows are then removed by the scraper. If scrapers are not available a front-end loader can be used to remove the windrows, but spillage is greater and the operation is slower. Spillage occurs in any of the techniques but it can be recovered by manual pick-up. If graders are unavailable, scrapers can be used to remove the contaminated material directly without forming windrows. On beaches with poor trafficability, traction can be increased by reduction of tire pressures or by installation of flotation tires (Sartor and Foget, 1970).

(viii) Front-End Loaders. A front-end loader can be used if graders or scrapers are unavailable, if beaches have poor traction, or if oil penetration is greater than 25 cm. The front-end loader can be used on all but boulder beaches but the equipment

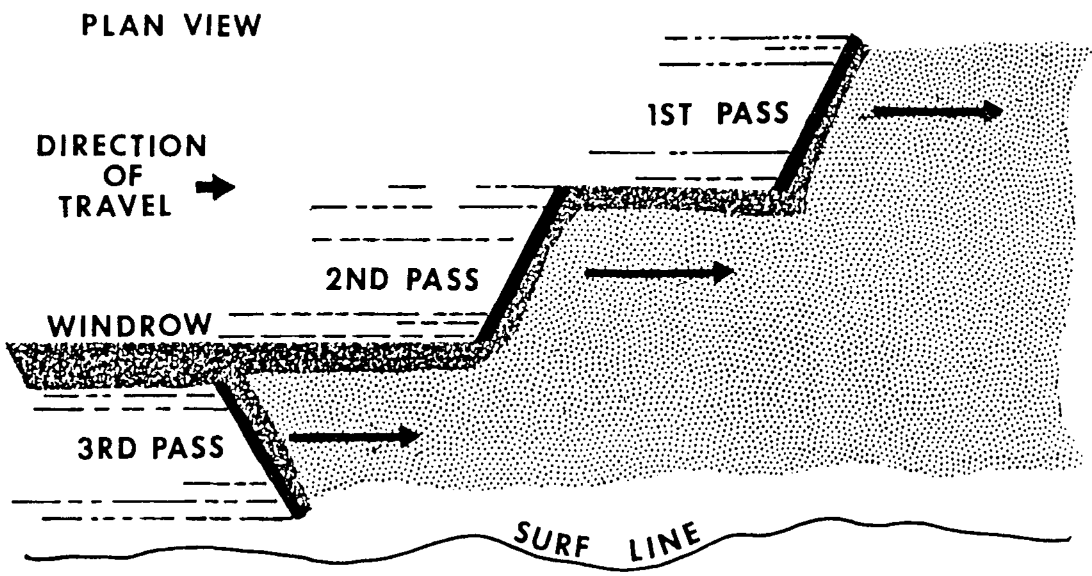

Figure 22. Sequence of windrow formation for removal of surface oil from sand beaches by a motorized grader (from Sartor and Foget, 1970).

TABLE 15. Recommended Cleanup Procedures For Equipment on Sand Beaches (from Sartor and Foget, 1970)

Equipment	Method of Operation
A. Combination of motorized grader and motorized elevating scraper	Motorized graders cut and remove surface layer of beach material and form large windrows, which motorized scrapers pick up and haul to disposal area for dumping or to unloading ramp-conveyor system for transfer to dump trucks. When large amounts of debris are present, a screening system is used to separate beach debris, such as kelp, from sand.
B. Motorized elevating scraper	Motorized elevating scrapers, working singly, cut and pick up the surface layer of beach material and haul it to disposal area for dumping or to unloading ramp-conveyor system for transfer to dump trucks. When large amounts of debris are present, a screening system is used to separate beach debris, such as kelp, from sand.
C. *Combination of motorized grader and front-end loader	Motorized graders cut and remove surface layer of beach material and form large windrows, which front-end loaders pick up and load into following trucks. Trucks remove material to disposal area or to conveyor-screening system for separation of large amounts of debris from sand.
D. *Front-end loader	Front-end loaders work singly to cut and pick up surface layer of beach material and load it into following trucks. Trucks remove material to disposal area or to conveyor-screening system for separation of large amounts of debris from sand.

*Use C and D only when motorized elevating scrapers are not available. Operation of front-end loaders on oil-contaminated beaches should be kept to a minimum.

generally involves high spillage rates and the removal of large amounts of uncontaminated sediments, as this machine is designed for digging rather than for removing thin layers of sediment. Spillage can be reduced if the bucket is filled to only one-quarter capacity. Rubber tires are greatly preferred over tracks as the tracks tend to grind oil into the sediment. When front-end loaders are used alone in a beach cleanup operation, the use of a multi-task bucket is preferable.

(ix) Bulldozers. This equipment is not recommended unless other machines are unavailable. If used, a bulldozer can push material up the beach for later collection, however, the use of this equipment causes excessive removal of uncontaminated sediments. The vehicle tracks grind oil into the beach and spillage around the blade is high. Spillage can be reduced by using an angled rather than straight blade.

(x) Dragline or Clamshell. In situations where the bearing capacity of the sediments is extremely low, this equipment can remove contaminated sediment. The operation is slow and inefficient and should only be considered if other options are impractical. Apart from the relative inefficiency of the operation, this technique also involves large-scale removal of uncontaminated sediments.

(xi) Sump Collection and Pump Removal. Excavation of a sump on sand, pebble, or mixed sediment beaches to collect oil is applicable for large amounts of mobile oil (O'Sullivan, 1978). The sump should be located in the intertidal zone in order to permit oil to collect. A pump system or vacuum truck is used to remove the oil/water mixture from the sump (*e.g.*, Ruby, *et al.*, 1977).

(xii) Manual. Manual removal can be effective for spills involving small amounts of oil or in locations inaccessible to or unsuitable for machinery. Oil can be scraped or scrubbed from rock or man-made surfaces, and oil particles or contaminated sediments can be removed from beaches with shovels, rakes, forks or buckets. This removal can be carried out with sorbent materials used to collect mobile oil (see p. 114). If vegetation is contaminated, manual cutting may be effective (Vandermeulen and Ross, 1977). In marsh environments care must be exercised to avoid damaging plant root systems and to prevent grinding oil into the sediments.

Manual methods of scraping, removal or cutting are labour-intensive operations. The efficient use of manpower requires good organization. In marsh environments the labour force should be carefully briefed and close supervision may be necessary to prevent damage to the environment.

Sorbent materials have been designed largely for oil removal from water surfaces but can also be used on shorelines. Pads or rolls of synthetic sorbents are very effective but more expensive and usually less readily available than natural organic materials. Loose-fibre sorbents are labour-intensive as they must be spread, mixed with the oil, and removed for disposal. One method of harvesting loose-fibre sorbents from rocks, coarse-sediment beaches or marshes is to use low-pressure hoses to flush the material onto water surfaces for collection.

In Situ Cleaning

(xiii) Burning and Incineration. Direct cleaning of shorelines can be undertaken by burning if the stranded oil is of a suitable character. An ignition agent may be required to obtain sufficiently high temperatures; a wicking agent may also be necessary to maintain combustion (*e.g.*, Ruby, *et al.*, 1977). The method is of particular use for pools of oil or for oil on the surface of ice. However, the burning process can result in deeper penetration of oil into the sediments and can produce residues which may be difficult to remove. The method also causes heavy air pollution that may be undesirable (Coupal, 1976). Few attempts at burning have been completely successful (Der and Ghormley, 1975). Suitable types of oil spills in marsh environments can be successfully burnt in autumn or winter months, provided that the root systems of the vegetation are not damaged.

Several incineration techniques are in the developmental stage. These techniques basically involve: (i) the transfer of contaminated material into a kiln, (ii) incineration, and (iii) replacement of the clean material on the beach. The equipment is being designed to be portable and to be able to handle coarse as well as fine-grained sediments.

(xiv) Beach Cleaning Machines. Although several types of equipment have been developed to remove, clean and replace contaminated sediments, the only techniques that have proven to date to be cheap, portable and efficient involve either sieving devices for removal of tar lumps (Cormack and Jeffrey, 1975; Wardley-Smith, 1976, p. 185) or rotary brushes to spike the tar lumps (Wardley-Smith, 1968). Although effective on sand or pebble beaches, the equipment is frequently not readily available. Sediment/oil pick-up and sieving devices can be built with little difficulty and the equipment can be towed behind a tractor or front-end loader.

The beach cleaning machines referred to in Figure 21 have been designed to collect, wash and replace contaminated sand-size sediments. The machines utilize a variety of methods to separate the sediment and the oil, but to date the techniques and equipment developed have not proven to be cheap, portable and efficient.

PART 8 - SHORELINE SENSITIVITY AND RESPONSE PRIORITIES

SYNOPSIS

The sensitivity of a section of shoreline to a spill is frequently related to the shoreline type and to the shore-zone sediments. When this index of shoreline sensitivity is applied, low wave-energy and vegetated shorelines are the most sensitive to spills, and coasts without sediment are the least sensitive. In practical terms, an assessment of shoreline sensitivity must also involve an estimation of the degree to which stranded oil affects and alters: (1) normal shore-zone processes (both ecological and geological), (2) man's normal use of the shore zone (recreational, cultural and commercial), and (3) possible damage that could be caused by shoreline cleanup operations. The most critical factors in determining the sensitivity or vulnerability of a shoreline section to spilled oil are related to shore-zone ecology and to man's use of the shore zone.

Shoreline protection is most effective when oil can be collected and removed before becoming stranded. Protection operations are feasible if: (a) the location and movement of a slick are known, (b) sufficient time is available to implement the operations, and (c) sufficient equipment and personnel are available. The decision to implement a protection operation involves an assessment of the probable impact of the oil and of the shoreline sensitivity and the feasibility of the operation. Protection priorities can be based on shoreline sensitivity, with the most vulnerable shoreline sections designated as the highest priority sites.

Cleanup of oiled shorelines is not required when the level of contamination is acceptable or when oil would be removed naturally in an acceptable time period. As more damage may be caused by the cleanup operations than results from the spilled oil, consideration must be given to the impact of the methods to be employed. Damage to vegetation can be critical in marsh and dune systems, and sediment removal can cause beach retreat and backshore erosion in locations where natural sediment replacement is inadequate.

8.1 INTRODUCTION

The response decisions that follow an oil spill in coastal waters are based initially on developing operational procedures to minimize the effect(s) of the spilled oil. If oil is on the shore, decisions related to cleanup are concerned initially with: (a) whether or not cleanup operations are necessary, and (b) the selection of the most appropriate techniques, which involves both consideration of the effectiveness of oil removal and the potential impact of the techniques on the shore zone.

The development of these response decisions for protection and cleanup also involves the assessment of the relative sensitivity of shoreline sections, and where the oil is expected to wash ashore or where oil has become stranded. In this context sensitivity is defined as the impact or effect of the spilled oil on normal ecological and geological processes and on man's normal use of the shore zone. The latter can involve recreational, cultural and commercial activities.

In this section shoreline sensitivity is briefly discussed (Part 8.2) and operational priorities and planning for shoreline protection (Part 8.3) and cleanup (Part 8.4) are reviewed.

8.2 SHORELINE SENSITIVITY

The sensitivity of a section of shoreline can be defined by the impact of stranded oil on:

(a) the normal shoreline processes (geological and biological),

(b) man's normal use of the shore zone (cultural, recreational and commercial), and

(c) unique shore-zone features (cultural and biological).

Shoreline type, wave-energy level, and the volume of oil are critical in determining the persistence of stranded oil, but are not sufficient parameters for defining shoreline sensitivity. Normal shoreline processes and man's use of the shore zone are of critical importance. In certain instances the impact of stranded oil may be severe. For example, high-use recreational sand beaches contaminated in winter months may be cleaned rapidly by natural processes or by cleanup operations with little or no impact and damage to the ecology or to man's normal activities. However, a spill on the north shore of Prince Edward Island in the height of summer tourist season would severely impact the economy of the island as well as man's normal use of the shore zone. Similarly, a spill in a migratory wildfowl habitat during breeding season could cause serious damage while a spill in the same area at another time of year may have little or no impact. Between these extremes are a great range of sensitivity levels.

As an initial framework, the major shoreline types of Prince Edward Island have been ranked in terms of sensitivity in Table 16 (see also Gundlach and Hayes, 1978). The shoreline types have been slightly modified from those discussed in Part 5.5 to include an assessment of shoreline energy levels. This modification is important because oil tends to collect and to be more persistent in sheltered locations and because sheltered environments are usually more ecologically sensitive.

This ranking in Table 16 is intended only as a general guide to the impact of oil; within each shoreline type it is necessary also to consider the effects of the oil and of the cleanup programme in terms of:

1. the type of oil spilled,
2. the persistence of stranded oil, and
3. the cleanup effectiveness.

<u>The type of oil spilled</u> can determine the severity of impact. Light, volatile oils are more toxic than heavy or tarry

TABLE 16. Sensitivity of Shoreline Types

INCREASING SENSITIVITY ↑

I.	Marshes Lagoons
II.	Sheltered Rocky Coasts Sheltered Beaches
III.	Dunes Mud Flats
IV.	Pebble/Cobble/Boulder Beaches Sand Beaches
V.	Exposed Rock or Man-Made Structures

oils and would invariably have a greater initial ecological impact. On sandy or rocky shores where ecological sensitivity is generally not high, the impact of light oils may not be severe. Similarly, the impact of light oils on a marsh is much less severe in autumn or winter months than in spring or summer.

The oil persistence increases as the volume of stranded oil and the penetration or the degree of burial increases, and as the level of wave energy at the shoreline decreases. If small amounts of light oil are stranded on an exposed coast, natural dispersion may be sufficiently rapid that the economic and cultural impact is low. Such would be the case on low-amenity shores in unpopulated regions. However, even small volumes of oil that would normally disperse rapidly may greatly affect man's normal use of a recreational beach in a park or recreational area during summer months.

The shoreline sensitivity can also be considered in terms of the effectiveness of natural cleaning or cleanup operations. If the shore zone can be cleaned easily and effectively by nature or by man, then the impact of the oil is greatly reduced.

Superimposed on the shoreline type, the oil and the cleanup parameters, are the effects of the spill. It is then necessary to consider:

4. ecological sensitivity,
5. geological sensitivity, and
6. cultural-economic sensitivity.

Ecological sensitivity is a function of the degree to which normal biological processes are damaged or altered. Important factors in determining ecological sensitivity are:

(a) natural recovery potential,

(b) presence of rare or endangered species,

(c) timing of the spill relative to breeding or growth seasons,

(d) possible adverse effects of cleanup operations, and

(e) economic value (commercial and recreational) of impacted species.

Definition of ecological sensitivity should be undertaken by qualified personnel, preferably with a local knowledge of the area affected, or potentially affected, by the oil.

The most important aspect of geological sensitivity relates to the removal of contaminated sediment from the shore zone. Erosion and beach retreat will result if beach stability is affected because of sediment removal. If the backshore area has been developed for either housing or recreation, those properties could then be exposed to wave action. Similarly, because a beach acts as a buffer to wave action at the base of cliffs, removal of sediment can permit waves to act directly on the cliff and cause cliff retreat.

Damage to dunes or marshes can be caused during a cleanup programme by the use of vehicles in the backshore area. In these cases the destruction of vegetation by machinery incurs both geological and ecological damage. This damage can be more severe than the impact of oil alone.

Normal shoreline processes, sediment transport and beach changes can be altered by oil if an "asphalt pavement" is formed. Although this impact is important in terms of local sediment transport and oil persistence, it is rarely a significant problem. However, in certain circumstances the presence of this impermeable ramp, rather than a permeable beach, can cause higher wave run-up than is normal on a beach. This could allow waves to overtop a beach and to erode backshore areas that would normally be above the limit of wave action.

The degree to which cultural or economic activities are sensitive to an oil spill varies considerably. The impact of oil stranded in a major recreational area during summer months may severely affect normal activities. In this context, a recreational sand beach may be a very sensitive shoreline type during summer months, whereas, the same section of shoreline may have a much lower sensitivity in the remaining seasons. The cultural-economic factors to be considered include:

(a) special or unique cultural features,

(b) marinas or harbours,

(c) parks or recreational areas,

(d) commercial or recreational activities (*e.g.*, fishing), and

(e) seasonal changes in man's activities.

From the foregoing discussion, it is evident that an assessment of shoreline sensitivity involves a series of interrelated factors (Fig. 23). The basic shoreline sensitivity given in Table 16 is presented only as a very general guideline to the problem of the impact of oil. Definition of shoreline sensitivity in terms of a scale or ranking system is both complex and difficult, and is not attempted in this report.

8.3 SHORELINE PROTECTION PRIORITIES AND PLANNING

Prevention of oil from reaching sensitive shoreline sections or environments is possible provided that:

(a) accurate predictions of the movement or of locations where the oil will be stranded are available,

(b) sufficient time is available to implement protection operations,

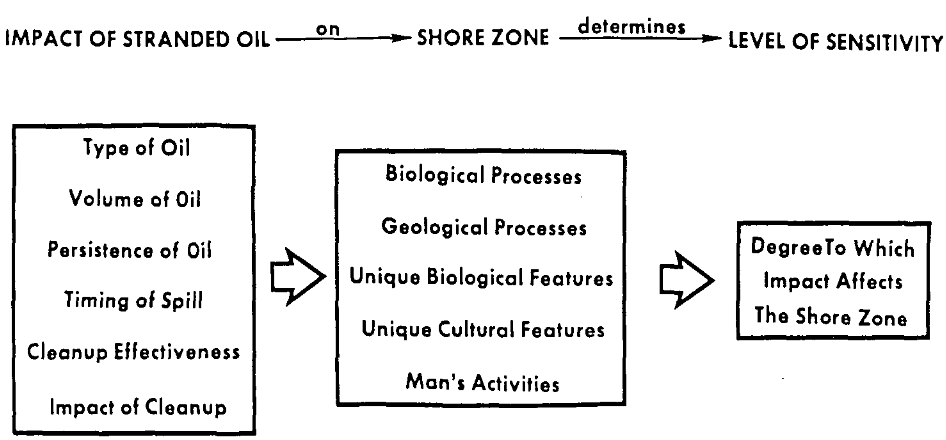

Figure 23. Factors that affect the level of shoreline sensitivity.

(c) environmental conditions are favourable, and

(d) equipment, materials and manpower are available.

In almost all cases, protection of the shoreline by removal of oil from the water surface is more efficient and easier than shoreline cleanup. In the case of small spills, offshore oil removal can be very effective, but the problems of containment and removal of the oil increase as the size of the spill increases.

The decisions related to protection operations involve consideration of: (i) whether or not it is necessary or beneficial to prevent oil from reaching the shore zone (shoreline sensitivity), (ii) the deployment of available resources to protect those sections identified as sensitive (protection priorities), and (iii) the practicality and logistics of protecting those shore sections (operational feasibility). In cases where shoreline protection is required or is desirable, and it is evident that all of the spilled oil cannot be contained offshore, a system of defining protection priorities must be prepared. These decisions related to priorities involve assessment of the impact of stranded oil on different shoreline sections and consideration of the logistical requirements for each site to be protected.

The priorities could be defined either: (a) in relation to the spill movement, so that the sections nearest the oil would be afforded protection first, or (b) according to the level of shoreline sensitivity. In the first case (a), the assignment of priorities is relatively simple and is largely a problem of logistics. The assignment of priorities in the second case (b) is more difficult as it requires the consideration of a variety of factors. Table 16 (p. 132) indicates the relative sensitivity of shoreline types to oil spills. This can provide an initial ranking of priorities. Superimposed on this ranking are local factors for each shoreline section (Fig. 23, p. 135), in particular, the presence of unique biological features (ecological preservation areas, wildlife sanctuaries or breeding areas, productive commercial areas, etc.) and the cultural/recreational use of the shoreline (marinas, parks, archeological sites, bathing beaches, shore-front cottages or hotels, etc.). Consideration of these ecological, cultural and economic factors is of greater importance than the actual vulnerability of the shoreline type to oil spills. For example, protection of sand beaches adjacent to urban communities or within parks would receive a higher priority than sheltered beaches or mud flats in unpopulated, inaccessible areas which have no unique features.

It is not possible to develop a practical ranking system for protection priorities that can be applied universally. Ideally, each shoreline section should be investigated and relevant information should be collected prior to a spill.

8.4 SHORELINE CLEANUP PRIORITIES AND PLANNING

The cleanup of oil-contaminated shorelines requires: (i) a knowledge of the impact of the oil (shoreline sensitivity), (ii) a review of the relative merits of natural recovery versus clean-up (sensitivity to cleanup methods), and (iii) an assessment of cleanup practicality and logistics (operational feasibility).

The development of a response plan initially involves an assessment of the impact of the oil on particular shoreline sections. In this context, information should be obtained on the shoreline sensitivity to stranded oil. The damage caused by oil contamination of the shoreline is usually on impact, so that in most cases, once the oil is stranded there is usually no necessity for an immediate and rapid response. The exceptions to this would be situations where: (a) the continued presence of oil constitutes a severe impact, such as marsh environments actively used by migrating wildfowl or recreational shore sections during the vacation season, or (b) the oil could become buried within the beach sediments due to natural penetration or to the movement of sediments by winds or waves.

The initial decision to clean up, based on shoreline sensitivity, involves answers to two fundamental questions: (1) is the level of oil contamination acceptable, and (2) would cleanup operations cause more damage than allowing the oil to disperse naturally? The first question involves the desirability of removing stranded oil in terms of biological, recreational and commercial factors. If the presence of oil does not interfere with normal shore-zone processes or man's use of the shore zone, the contamination may be acceptable. This first question also involves an assessment of oil persistence, as natural cleaning may be effective within an acceptable time period.

In cases when it is decided that cleanup operations are required or preferable to natural recovery, then an assessment must be made of the effectiveness and the feasibility of cleanup operations. If available techniques to remove the oil cannot meet the objectives of the operation (*e.g.*, not all the oil can be removed), the cleanup decision should be reconsidered. Similarly, if a cleanup method is proposed but the operations would involve ecological or geological damage to the shore zone, then it would be necessary to consider the relative merits of other less effective and/or efficient methods or natural recovery.

The selection of cleanup methods is controlled primarily by the volume of oil and by the shoreline type. In particular, the shoreline sediments and geomorphology determine depths of oil penetration, equipment accessibility and equipment trafficability. The available methods are described in Part 7.2(p. 116) and the applicability and/or limitations of each method to the basic shoreline types are discussed.

PART 9 - CHECKLISTS

9.1 INTRODUCTION

The development of spill response operations requires the collection of data and information on the character of the oil and the affected shorelines. The checklists presented in this section have been designed to assist in the information-gathering process. They present questions relevant to: (a) an evaluation of shoreline protection and cleanup requirements, and (b) the applicability and impact of the available cleanup techniques.

The text of this report provides the basic information that would be required to complete this series of checklists. The primary purpose of this section is to explain the objectives of each checklist and to provide a cross-reference for text information that is relevant to the checklists.

Information on the spill itself must be gathered at the time of the event. When a spill occurs there is usually little time or resources to undertake shoreline surveys and to compile relevant shoreline information. Local surveys can be undertaken as part of spill preparedness operations so that relevant information would be immediately available to the On-Scene Commander. In particular, information on shoreline sections that would have a high protection or cleanup priority would be of great value in the initial response decisions as an immediate response could greatly minimize the effects of a spill.

9.2 SPILL INFORMATION CHECKLIST

Most of the data required to complete this checklist (#1)

CHECKLIST #1. SPILL INFORMATION

1. <u>OIL ON WATER</u>

Source of Spill: ____________________

Is oil still being spilled?

YES - Spill Discharge Rate: ____________________

- Estimated Duration of Spill: ____________________

- Estimated Final Spill Volume: ____________________

NO - Volume of Spill: ____________________

Type of Oil: ____________________

Is oil flammable or otherwise hazardous to personnel? YES/NO

Will the oil be stranded? YES/NOT KNOWN/NO

*Where will the oil be stranded: ____________________

*Requires spill movement prediction information not contained in this report.

2. <u>OIL ON SHORE</u>

Has the spill ceased? YES/NO

Is there a danger of more oil being washed ashore? YES/NO

Oil Viscosity: Low(fluid) ___ Moderate ___ High(semi-solid) ___

Oil Flammability: Very Dangerous ___ Potentially Flammable ___ Low Risk ___ Inert ___

DO THIS FOR EACH SECTION

Section Name or Identification: ____________________

Surface Area Covered by Oil: ______%

Thickness of Surface Oil: ______cm

Distribution Across Shore Zone: ____________________

Maximum Depth of Oil Penetration: ______cm

Estimated Volume of Stranded Oil on Beach Section: ____________

is self-explanatory. Some of the information-gathering may involve estimates rather than accurate numbers, but the checklist can be updated as further information is received.

The volume and character of the stranded oil should be recorded for each section of shoreline and for each shoreline type. As different measurement units are in current use some of the relevant conversion factors are given in the Appendix (p. 166). An estimate of the volume of oil is obtained by multiplication of: (1) the width of the zone of stranded oil, by (2) the average thickness of the stranded oil (both on the surface and within the sediments) and by (3) the length of the shoreline section.

9.3 SHORE-ZONE CHARACTER CHECKLIST

The characterization of a section of coast for spill response decisions requires information or data (Checklist #2) on shore processes, wave-energy levels, sediment availability, sediment type, and accessibility.

The substrate (q.v.) (or shoreline type, pages 77 to 83) is probably the single most important factor for determining impact and response. The absence of sediment or the predominant sediment size controls the depth of oil penetration and, to a large extent, the persistence of oil. The sediment size (Table 7, p. 75) and oil penetration depth are also primary controls on the effectiveness and applicability of available cleanup methods.

The substrate type can be determined by visual observations. On beaches with more than one size of sediment the types should be listed in descending order of abundance (*e.g.*, cobbles and

CHECKLIST #2. SHORE-ZONE CHARACTER

1. BEACH SEDIMENTS AND MORPHOLOGY

	Substrate	Sediment Size(s)
Foreshore	________	________
Berm	________	________
Backshore	________	________

Debris: Cover on berm ____% On backshore ____%

Intertidal Beach Width: ____m

Backshore Beach Width: _____m

Shore-zone Sediment Transport Direction: ________________________

Estimate of Sediment Availability: Very Scarce: ___
Scarce: ___ Abundant: ___

2. SHORELINE EXPOSURE AND ENERGY LEVELS

Maximum Fetch (km) >100 ___ 50-100 ___ <50 ___

Tides: Range: ____m; DIURNAL/SEMI-DIURNAL: SPRING/NEAP

Coastline Straightness: Straight ___ Irregular ___ Indented __

Degree of Exposure: Open ___ Partly Sheltered ___
Completely Sheltered ___

Presence of Ice Foot: Absent ___ Present ___

Relative Exposure/Energy Level: (from Table 5, p. 72) ___________

Seasonal Energy Level: (see text, p. 9, 71-73)
High ___ Intermediate ___ Low ___

3. SHORELINE ACCESS (see Table 8, p. 76)

Heavy Vehicles: Land Access: Existing ___ Required ___
Seaborne Access: YES/NO

Light Vehicles: Land Access: Existing ___ Required ___
Seaborne Access: YES/NO

Pedestrians: Land Access: YES/NO
Seaborne Access: YES/NO
Aerial Access: YES/NO

sand) or by location if there is an across-beach zonation (*e.g.*, sand - foreshore: cobbles and sand - berm: dunes - backshore). These location definitions are explained in the Appendix (Fig. 24, p. 162). The basic shoreline types and sediment size grades are given in Tables 6 and 7, pages 74 and 75.

The presence of debris lines or logs can hamper cleanup but can also be an indicator of the maximum upper limit of wave action. If debris lines are above the spring high-tide level this indicates that the shore is subject to periods of high waves, and, therefore, high wave-energy levels.

Estimates of the shore-zone sediment transport directions and sediment availability should be made if possible. In the absence of qualified scientists to provide this information, reference can be made to Figure 8 (p. 18), to the text description of the shoreline (Part 3), and to Table 4 (pages 44 to 45).

An estimation of relative wave-energy levels at the shoreline can be obtained by defining fetch and shoreline exposure (pages 71 to 73). This estimate must take into account the large seasonal variation in wind velocities and, therefore, wave heights (p. 9). On a general basis, this seasonal variation can be accounted for by regarding the period from November to April as "high-energy"; from June to August as "low-energy"; and May, September, and October as "intermediate-energy".

Tidal information can be obtained from published sources (*e.g.*, Canadian Hydrographic Service, 1975a). It is important to determine the stage of the spring-neap tidal cycle (p. 62) as this may affect the distribution of stranded oil.

The accessibility to the shore zone is an important characteristic for spill response operations and this information (based on Table 8, p. 76) is included in the shoreline checklist.

9.4 SHORE-ZONE SENSITIVITY CHECKLIST

The assessment of sensitivity for a given section of shoreline (p. 130) can involve a large number of factors (Fig. 23, p. 135). In the first section of the checklist (#3) the expected persistence of the oil can be estimated from: (1) the type and volume of oil, (2) the depth of oil penetration, and (3) the levels of wave-energy that can act on the stranded oil (pages 53 to 58 and 86 to 106). The effectiveness and impact of the cleanup methods are derived from Checklist #5.

The character and persistence of the oil and the possible effects of the cleanup operation determine the degree to which: (a) normal shore zone processes (biological and geological), and (b) man's use of the shore are altered (pages 133 to 135). These effects, given in the second part of this checklist, determine the degree of sensitivity. In most cases, the assessment of the potential or actual effects may require advice and information from biologists and geologists familiar with the shore-zone sections in question.

The estimated effects of the spill or the cleanup programme are of particular importance in the development of operational strategies, especially in the definition of protection and cleanup priorities.

CHECKLIST #3. SHORE-ZONE SENSITIVITY

IMPACT FACTORS

Type of Oil: ____________________________

Is oil on shore?

YES - Volume Stranded (from Checklist #1): ____________

NO - Volume of Spill: ____________________

Expected Persistence of Oil: Days ___ Months ___ Years ___ Decades ___

Month of Year: ________

Can cleanup be effective? (from Checklist #5) YES/NO

Would cleanup have an impact? (from Checklist #5) YES/NO

If YES, describe: ____________________________

____

SHORE-ZONE CHARACTER

Shoreline Type (from Table 6, p. 74): ________________

Rare or Endangered Biological Species: Absent ___ Present ___

Natural Biological Recovery Potential: <1 Yr. ___ Years ___ Decades ___

Natural Geological Recovery Potential: <1 Yr. ___ Years ___ Decades ___

Recreational Use of Shore Zone:
None ___ Low ___ Moderate ___ High ___ Very High ___

Commerical Use of Shore Zone:
None ___ Low ___ Moderate ___ High ___ Very High ___

Biological Impact of Oil:
None ___ Low ___ Moderate ___ Severe ___ Critical ___

Impact of Oil on Rare or Endangered Species:
None ___ Low ___ Moderate ___ Severe ___ Critical ___

Biological Impact of Cleanup:
None ___ Low ___ Moderate ___ Severe ___ Critical ___

Geological Impact of Cleanup:
None ___ Low ___ Moderate ___ Severe ___ Critical ___

9.5 SHORELINE PROTECTION CHECKLIST

Checklist #4 provides guidelines for decisions to implement a protection operation (pages 135 to 137). The initial decision whether or not to protect a section of shoreline can be answered in the first three questions. Question #3 can be answered following the evaluation of the shoreline sensitivity from questions #4 to 8. Shoreline protection would probably be required if the answer to any one of questions #4 to 8 is "YES". Question #8 is included as it is important to evaluate whether or not cleanup would be effective and whether or not protection is more efficient and more effective than cleanup operations. The feasibility of protection can be evaluated in questions #9 to 11. If any one of the answers to these questions is "NO", then the protection operation should be reconsidered.

9.6 SHORELINE CLEANUP INFORMATION CHECKLIST

The information checklist (#5) for cleanup decisions provides a framework for operational planning (pages 137 to 139). The initial set of information on the nature of the stranded oil, the degree of contamination and the shore-zone character is obtained from checklists #1 and #2. The possible burial of oil by sediments (pages 64 and 65 to 70) must be considered as this could affect cleanup priorities.

Several of the answers required in Part B can be obtained from checklist #3. If any of the answers in Part B are "YES", then a cleanup operation for that section of the shoreline should be considered provided that <u>all</u> the answers to the questions in

CHECKLIST #4. SHORELINE PROTECTION

	YES	NO
1. Will the oil become stranded:		
2. Would the shoreline be cleaned naturally in an acceptable period of time?		
3. Would the section of shore zone be seriously affected by the impact of oil?		
IMPACT OF STRANDED OIL		
4. Would the oil seriously endanger flora or fauna?		
5. Would the impact on flora and fauna be long-term?		
6. If cleanup is necessary, would this adversely affect beach stability (*e.g.*, by sediment removal)?		
7. Would the presence of the oil adversely affect man's use of the shore section?		
8. Would protection be more effective than cleanup?		
PROTECTION FEASIBILITY		
9. Is sufficient time available to implement the protection operation?		
10. Would the method(s) be effective?		
11. Are sufficient equipment, materials and manpower available?		

METHODS

12. What is (1) the most applicable method(s)? ______________________

____

(2) the most applicable alternative(s)? ______________

____

Part C and D are also "YES". If the evaluation of the selected method(s) yields a "NO" to any of the questions in Parts C and D, then alternative methods of cleanup would be considered. In all cases, the danger of possible recontamination must be considered as the benefits of cleanup may be nullified if a shoreline becomes re-oiled.

CHECKLIST #5. SHORELINE CLEANUP INFORMATION

A. OIL AND THE SHORE ZONE

Type of Oil: ______________________________

Depth of Penetration: ______________________________

Volume of Stranded Oil (from Checklist #1): ____________________

Shoreline Type: ______________________________

Shore-Zone Sediments (see Checklist #2): ____________________

Shore-Zone Exposure and Wave-Energy Levels (see Checklist #2): ___

____

Is ice present in the shore zone? YES/NO

Is there a likelihood that the oil will be buried? YES/NO

B. CLEANUP OR NATURAL RECOVERY?

Expected Persistence of Oil:
Days ____ Months _____ Years ____ Decades ____

Would continued presence of oil be undesirable in terms of:

(a) Biological Processes YES/NO

(b) Recreational Activities YES/NO

(c) Commercial Activities YES/NO

Is the level of contamination unacceptable? YES/NO

Would oil migrate onto other shoreline sections? YES/NO

Is immediate cleanup necessary? YES/NO

C. CLEANUP FEASIBILITY

What is the most effective/efficient cleanup method for the shoreline section? ______________________________

Are satisfactory equipment and sufficient manpower available? YES/NO

CHECKLIST #5. (Cont'd)

Is the shoreline accessible for equipment and/or personnel? (see Checklist #2) YES/NO

Can the equipment operate effectively in the shore zone? YES/NO

Would the degree of cleanup be satisfactory? YES/NO

If the most preferred cleanup method is unfeasible or would incur damage (see "D" below), what is the next suitable alternative method? ______________________________

____

D. CLEANUP DAMAGE

Would the level of biological damage be acceptable? YES/NO

Would the level of geological damage be acceptable? YES/NO

Impact of Cleanup on Unique Cultural Features:

None ____ Low ____ Moderate ____ Severe ____ Critical ___

Impact of Cleanup on Recreational Activities:

None ____ Low ____ Moderate ____ Severe ____ Critical ___

Impact of Cleanup on Commercial Activities:

None ____ Low ____ Moderate ____ Severe ____ Critical ___

NOTES:

PART 10 - CONCLUSIONS

1. The shoreline types of Prince Edward Island range from exposed, high-energy barrier beach or cliffed coasts to sheltered, quiescent lagoons or estuaries. The beaches of the island are an important recreational and economic resource and, therefore, would be highly sensitive to a large coastal oil spill.

2. There is a marked contrast in wave-energy levels around the island which would affect expected degradation rates of stranded oil. Rates of natural self-cleaning would be slow in the many sheltered (low-energy) shoreline sections, but would be rapid on the exposed (high-energy) coasts.

3. Shore-zone processes are significantly affected by the presence of shorefast and/or sea ice for periods up to 4 months each year at a time when wave-energy levels would otherwise be at a maximum. The presence of ice could hamper cleanup operations in winter months.

4. Compared to many other sections of Canada's coasts, cleanup of stranded oil would be easier in some respects as most of the sensitive shoreline areas are readily accessible. In addition, the sand beaches, which are the most important recreational feature on the island, could be cleaned effectively and rapidly using available techniques.

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APPENDIX

DEFINITION OF TERMS

ASPHALT: Refers to the heavy fractions of oil that have a high boiling point (see Table 17, p. 163).

BACKSHORE: That part of a beach above the high-water mark that extends landward to the limit of storm-wave activity (see Fig. 24).

BEACH: An environment of unconsolidated sediments in the coastal zone between the low-water mark and the landward limit of storm-wave activity (see Fig. 24). The upper limit is usually marked by vegetation, dunes or a cliff.

BEACH FACE: Upper part of the foreshore, between the low- and high-water marks that is exposed to swash action. Usually the beach face has the steepest slopes (up to 40°) in the beach zone (see Fig. 24).

BERM: A zone above the beach face that is nearly horizontal and is above the limit of normal wave action (see Fig. 24).

BERM CREST: The seaward limit of the berm (see Fig. 24).

CRUDE OIL: Naturally occurring undistilled or unrefined oil (see Table 17).

DIURNAL TIDES: A tidal cycle with one high and one low tide each day.

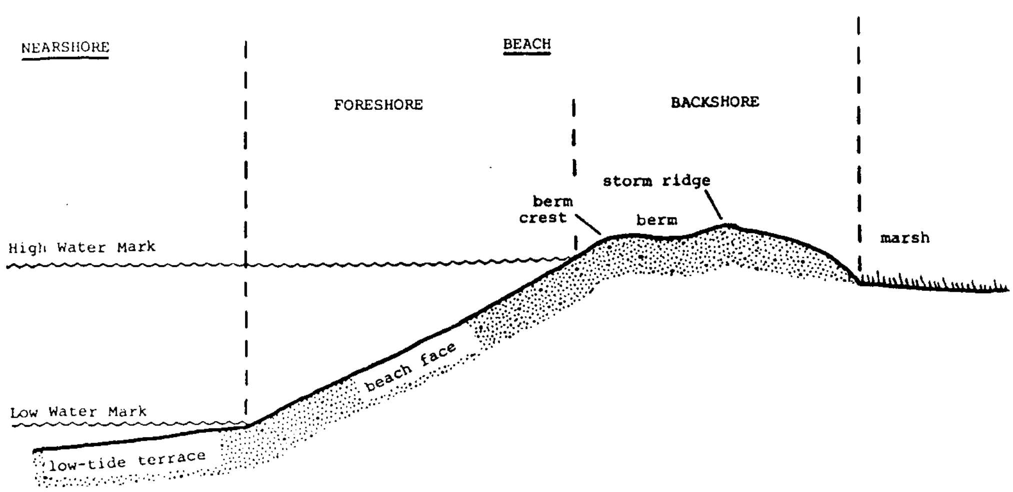

Figure 24. Beach features and subdivisions.

TABLE 17. Classification and Components of Crude Oil (from Whitehead, 1976)

Boiling Point Range °C	-200 · -10 · 0 · 30 · 150 · 200 · 250 · 350 · 380 · 520 · 1000+
General Classification	← Gases → ← Light Fraction → ← Middle Fraction → ← Heavy Fraction → ← Residue →
Main Components	← Gases → (*dry* … *wet*); ← Gasolines → (*light* … *heavy*); ← Fuel Oils →; ← Asphaltenes →; ← Gas Oils →; ← LPG →; ← Kerosines →; Naphthas; ← Lubricating Oils →
Hydrocarbon Range	← C_4 and lower → ← Pentane Plus → ← Liquid → ← Solid → (C_1, C_4, C_5, C_8, C_{14}, C_{16}, C_{60})
US Bureau of Mines Correlation Index	Paraffinic-Paraffinic · Paraffinic-Naphthenic · Naphthenic-Paraffinic · Naphthenic-Naphthenic
Base Classification	Paraffinic (Light) · Mixed (Aromatic) · Naphthenic (Heavy) · Asphaltic
Typical API Gravity Range	38° – 47° · 37° – 30° · 25° – 15°
Specific Gravity	0.835 – 0.800 · 0.840 – 0.876 · 0.900 – 0.970

Note: The classifications shown in this table are intended to be representative, and no precise demarcations are implied.

EMULSION: A mixture of two fluids that do not usually mix, in this report this term refers either to a water-in-oil or an oil-in-water mixture.

ESTUARY: The lower reach of a river that is affected by tides or where fresh and sea water mix.

FETCH: The area of open water over which waves are generated by wind.

FORESHORE: That part of the shore zone between the high- and low-water marks (see Fig. 24).

HEAVY FRACTION: Hydrocarbon compounds that have a very high boiling point (>350°C) (see Table 17, p. 163).

HIGH-WATER MARK: The higher limit of the tidal water level. Mean high-water mark or the mean high-tide mark is the higher limit averaged over a time period. Spring high-water mark or spring high-tide mark is the higher limit of spring tides. Neap high-water mark is the higher limit of neap tides.

ICE FOOT: A feature that is formed by the accumulation of ice that results from freezing of wave spray and swash in the littoral zone (Photo 1, p. 13).

INTERTIDAL ZONE: See Foreshore.

LIGHT FRACTION: Hydrocarbon compounds with a boiling point below 150°C (see Table 17, p. 163).

LOW WATER-MARK: The lower limit of the tidal water level. Mean low-water mark or the mean low-tide mark is the lower limit averaged over a time period. Spring low-water mark or spring low-tide mark is the lower limit of spring tides. Neap low-water mark is the lower limit of neap tides.

MARSH: (salt marsh) A flat, vegetated area at or above the high-water mark that is flooded by spring tides or during storm surges.

MEAN HIGH-WATER MARK: See High-Water Mark.

MEAN LOW-WATER MARK: See Low-Water Mark.

NEAP HIGH-WATER MARK: See High-Water Mark.

NEAP LOW-WATER MARK: See Low-Water Mark.

NEAP TIDES: Tides that occur when the gravitational pull of the sun is at right angles to and, therefore, opposes the pull

NEAP TIDES (Cont'd): of the moon. Tidal range is reduced during neap tides. These tides occur twice each month, during the first and last quarter of the moon (*e.g.*, Charlottetown, Fig. 3, p. 10).

NEARSHORE ZONE: That part of the shoreline seaward of the low-water mark that is within the zone of wave-generated processes.

OIL: A liquid mineral compound of hydrocarbons, with minor amounts of other substances that is insoluble with and lighter than water. The physical and chemical properties of naturally-occurring (crude) oils vary considerably (see Table 17, p. 163).

POUR POINT: The lowest temperature at which an oil will flow (in crudes these can vary between -26°C and +50°C).

SEDIMENTARY ROCKS: Rocks formed by the deposition of sediments in layers by wind, river, ice or marine processes.

SEMI-DIURNAL TIDES: A tidal cycle with two high and two low tides each day.

SIGNIFICANT WAVE HEIGHT: The average height of the highest one-third of the waves.

SPRING HIGH-WATER MARK: See High-Water Mark.

SPRING LOW-WATER MARK: See Low-Water Mark.

SPRING TIDES: Tides that occur when the gravitational pull of the sun is in the same direction and, therefore, reinforces that of the moon. High tides are higher and low tides are lower than usual. Spring tides occur twice a month at the new and full moon (*e.g.*, Charlottetown, Fig. 3, p. 10). The highest spring tides occur twice a year at the spring and autumn equinoxes, when the sun is overhead at the equator.

STORM RIDGE: A ridge formed in the backshore above the high-water mark by wave action during storms. The ridge is changed only by subsequent storm waves (see Fig. 24).

STORM SURGE: During storms the water level can be raised above the normal high-water mark as water is piled against the coast by onshore winds.

SUBSTRATE: The material(s) of which the shore zone is made.

SWASH: The rush of water up a beach face that follows breaking of the wave.

TIDAL RANGE: The difference in elevation between high- and low-water marks.

VISCOSITY: The property of a fluid that tends to resist relative motion or flow within the fluid.

VOLUME: The standard unit for volumes of oil is generally the U.S. barrel. However, other commonly used units and the conversion factors are:

Barrels

1 barrel (U.S.)	= 42 U.S. gallons
	= 35 imperial gallons
	= 159 litres
	= 0.159 cu. metres
1 barrel (U.K.)	= 36 imperial gallons
	= 163.7 litres
	= 0.16 cu. metres

Gallons

1 U.S. gallon	= 3.785 litres
	= 0.024 U.S. barrel
	= 0.833 imperial gallon
1 imperial gallon	= 4.546 litres
	= 0.038 U.S. barrel
	= 1.201 U.S. gallon

Tons

1 metric ton	= 1000 kg*
1 long ton	= 1016 kg*
1 short ton	= 907.2 kg*

*The volume-weight conversions involve consideration of the density (or specific gravity) of the oil. In these conversions a specific gravity of 1 (= a density of 1.0 kg/litre) is used. The specific gravity of oils varies in the range from 0.80 to almost 1.0.

WAVE-CUT NOTCH: A notch at the base of a coastal cliff eroded at or near the upper limit of wave action.

WINDS (DOMINANT): Those winds which over a time period (usually a year) have the highest velocities. The direction of the dominant winds may differ from that of the prevailing winds.

WINDS (PREVAILING): Those winds which occur with the highest frequency.