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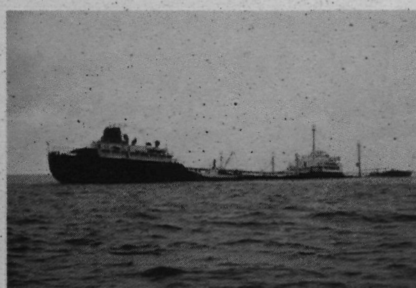

Chedabucto Bay 1992 Shoreline Oil Conditions Survey

Long-term Fate of Bunker C Oil from the ***Arrow*** Spill in Chedabucto Bay, Nova Scotia

Report EPS 5/SP/2
March 1994

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Long-term Fate of Bunker C Oil from the *Arrow* Spill in Chedabucto Bay, Nova Scotia

E.H. Owens,
B.E. McGuire, and
B. Humphrey

by

Woodward-Clyde Consultants
Seattle, Washington

for the

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Gary Sergy
Manager, Western Regional Office
Technology Development Directorate
Environmental Protection
Environment Canada
4999-98 Avenue
Edmonton, Alberta
T6B 2X3

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Abstract

A field survey was conducted from June to September 1992 to locate and document any residual oil on the shores of Chedabucto Bay, Nova Scotia. The grounding of the tanker Arrow *in February 1970 resulted in the release of more than 11 × 10^6 litres (L) of Bunker C fuel oil. This oil was stranded over an estimated 305 km of shoreline in the Chedabucto Bay area, but less than 50 km of shoreline were treated during subsequent response operations. Previous random visits to the site have indicated that oil is still present in some areas, but that much of the coastline has been cleaned through natural processes over the years. A systematic ground survey, however, has documented the presence of oil on 13.3 km of shoreline in Chedabucto Bay. Heavy oiling is restricted to 1.3 km, concentrated primarily in the Black Duck Cove and Lennox Passage areas. Some of this residual oil has been identified as coming from the* Arrow *based on circumstantial evidence; however, chemical analysis identifies one sample from Black Duck Cove as probably being* Arrow *oil.*

Natural weathering accounts for the removal of the majority of the oil from Chedabucto Bay. Where oil remains, it occurs as a thin stain on bedrock or coarse sediments (pebbles, cobbles, and boulders) or as a resistant oil-sediment asphalt-like mixture. Areas in the low wave-energy environments of Haddock Harbour and Inhabitants Bay that were observed to be heavily oiled in the spring of 1970, and were not cleaned, are now virtually free of oil. These areas have a plentiful supply of fine-grained suspended sediments that may have contributed to clay-oil flocculation weathering as described recently for Prince William Sound, Alaska. The presence or absence of oil residues in Chedabucto Bay can be explained in terms of the physical, biophysical, and biological processes that act upon stranded oil. Oil remains on the shore when it is:

- *outside the zone of physical wave action (including sheltered lagoons) required to move sediments and/or abrade the oil;*

- *in areas of nearshore mixing where fine sediments are not present to weather the oil through biophysical processes (clay-oil flocculation and biodegradation); and*

- *weathered on the surface, forming a crust that prevents biodegradation processes from being active.*

Résumé

On a effectué un levé sur le terrain de juin à septembre 1992 pour localiser et décrire les hydrocarbures résiduaires présents sur les rives de la baie Chedabucto, en Nouvelle-Écosse. L'échouement du pétrolier Arrow *en février 1970 a causé le rejet de plus de* 11×10^6 *L de mazout lourd. Ce mazout s'est répandu sur plus de 305 km de littoral dans la région de la baie Chedabucto, mais moins de 50 km de littoral ont été traités au cours des interventions ultérieures. Des visites au hasard faites précédemment sur le site ont indiqué qu'il y avait encore des hydrocarbures à certains endroits, mais que la majeure partie de la côte avait été nettoyée par les processus naturels au cours des ans. Cependant, un levé systématique au sol a permis d'établir la présence d'hydrocarbures sur 13,3 km de littoral dans la baie Chedabucto. Seule une bande 1,3 km a été sévèrement mazoutée, et elle se trouve principalement dans les régions de l'anse Black Duck et du passage Lennox. On a établi que certains de ces hydrocarbures résiduaires provenaient de l'*Arrow *à partir de preuves indirectes; l'analyse chimique indique en outre qu'un échantillon provenant de l'anse Black Duck est probablement du pétrole de l'*Arrow.

L'altération naturelle est responsable de l'élimination de la majeure partie des hydrocarbures déversés dans la baie Chedabucto. Lorsqu'il reste encore des hydrocarbures, ils se trouvent sous forme soit de minces taches sur l'assise rocheuse ou les sédiments grossiers (galets, cailloux et blocs), soit d'un mélange résistant d'hydrocarbures et de sédiments semblable à du bitume. Dans certaines zones de Haddock Harbour et de la baie Inhabitants où l'énergie de la houle est faible, on avait observé un mazoutage sévère au printemps de 1970; ces zones, qui n'ont pas fait l'objet d'opérations de nettoyage, sont maintenant pratiquement exemptes d'hydrocarbures. On y retrouve en abondance des sédiments fins en suspension qui peuvent avoir contribué à l'altération par floculation argile-hydrocarbures, telle qu'observée récemment dans la région du détroit du Prince-William, en Alaska. La présence ou l'absence de résidus d'hydrocarbures dans la baie Chedabucto peut s'expliquer en fonction des processus physiques, biophysiques et biologiques qui agissent sur les hydrocarbures échoués. Les hydrocarbures demeurent sur le rivage lorsqu'ils sont :

- *à l'extérieur des zones (y compris les lagunes abritées) où l'action physique de la houle est suffisante pour déplacer les sédiments et abraser les hydrocarbures;*

- *dans les zones littorales de mélange où il n'y a pas de sédiments fins pour altérer les hydrocarbures par des processus biophysiques (floculation argile-hydrocarbures et biodégradation);*

- *altérés à la surface où ils forment une croûte qui empêche l'activité des processus de biodégration.*

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Executive Summary

This report presents a description of the activities related to and a summary of the information generated by a field survey carried out in Chedabucto Bay, Nova Scotia, for Environment Canada from June to September 1992. The objective of the survey was to locate and document any residual oil on the shores of Chedabucto Bay. The grounding of the tanker Arrow *in February 1970 resulted in the release of more than 11 × 10^6 L of Bunker C fuel oil. This oil was stranded over an estimated 305 km of shoreline in the Chedabucto Bay area. A subsequent spill from the tanker* Kurdistan *in March 1979 affected some eastern sections of the study area, but, unless otherwise stated, the residual oil described in this report is considered to have come from the* Arrow.

Regional Survey

During the first phase of the field program, 249 km of the coastline of Chedabucto Bay were surveyed on foot over a 25 day period from June to August 1992. The field data collected can be summarized as follows:

- *the total length of shoreline on which oil or oiled sediments were documented was 13 302 m, or 5.37% of the shoreline surveyed;*
- *868 m (6.5% of the total oiled shoreline) is described as having a "heavy" oil cover (based on width and distribution parameters); 77% is described as having either a "light" or "very light" oil cover;*
- *1336.5 m (10% of the total oiled shoreline) falls within the "heavy" oil category (based on width, distribution, and thickness parameters); 83% falls within either the "light" or "very light" oil categories;*
- *275 m (2% of the total oiled shoreline) falls within the "pooled" thickness category; 83% falls within either the "coat" or "stain" thickness categories;*
- *2547 m (19% of the total oiled shoreline) is described as having an "asphalt pavement" character; and*
- *only one of the 129 segments with documented oil occurs in an area of high wave-energy; whereas 114 segments (88% of the total*

number of segments with documented oil) occur in areas of low wave-energy.

Oil was stranded over more than 300 km of the shoreline of Chedabucto Bay in 1970, but 22 years later, these shores are virtually free of oil. The residual oil can be described as a scattered, light oil stain, with a few localized patches of larger amounts of oil. Those segments with large amounts of residual oil are concentrated in the sheltered Black Duck Cove and Lennox Passage areas.

Detailed Site Surveys

The second phase of the field program, in September 1992, involved site visits to areas where oil had been documented during the systematic ground survey to describe in detail the character and distribution of the residual oil and to collect samples for chemical analyses. The site locations and key activities or observations are summarized below.

Eastern Rabbit Island. *This open, sheltered beach (fetch generally less than 5 km) in Lennox Passage has a relatively continuous asphalt pavement in the upper intertidal zone covering an area of approximately 600 m^2. Transects were surveyed for oil distribution and substrate character along a 64.5 m length of shoreline. Samples of oil were collected, one of which appeared to be relatively shiny and mobile, but which was shown to be very weathered.*

Black Duck Lagoon (South). *This very sheltered area of lagoon (spit backshore) shoreline, on the outer coast of Chedabucto Bay, with heavy oiling is characterized by weathered, pooled oil in a pebble/cobble matrix. Transects were surveyed for oil distribution and substrate character along a 66.4 m length of shoreline. The pavement in the survey area covered approximately 230 m^2, but a much larger area (990 m^2) was characterized by coarse (pebble-cobble) sediments with oil-filled surface pore spaces. Analysis of a sample collected from an area of pooled interstitial oil in the upper intertidal zone showed that the oil was relatively unweathered and is probably* Arrow *oil. Other samples collected in this area were very weathered, even though some had a shiny or fresh appearance.*

Black Duck Lagoon (North). *This site on the back lagoon (mainland) shoreline has pooled oil and asphalt pavement (approximately 864 m^2 in area) and is partially covered by sediments and marsh vegetation. Transects were surveyed for oil distribution and substrate character along a 113 m length of shoreline. Oil was* *observed on both sides of the study site, but the survey did not attempt to document all of the oiled area because of thick vegetation cover and time limitations.*

Inhabitants Bay - Western Lennox Passage. *This is a sheltered, low wave-energy environment that was originally heavily oiled, was not cleaned or treated, but is now essentially free of surface or subsurface oil. There are considerable amounts of suspended sediments in the nearshore waters of this area and it is hypothesized that the presence of the clay fraction prevented the formation of a weathered surface oil layer, thus allowing physical and biophysical processes to remove the oil from the shoreline.*

Beach - Headland Environments of North and West Chedabucto Bay. *These are exposed shorelines upon which only occasional, small scattered patches of oil residues were observed.*

Arichat Harbour. *This sheltered shoreline was treated in 1970 by mechanical reworking of the heavily oiled beach sediments, without sediment removal. The residual oil present today throughout this segment is characterized as a 2 m wide continuous band of hard "asphalt balls" in the upper half of the intertidal zone. The balls are 3-10 cm in diameter and occur with a frequency of four or five balls per square metre.*

Source of Oil Residues

The oiled shorelines with asphalt pavement and heavy oil category residues located during this survey are known to have been initially oiled as a result of the Arrow *spill. Furthermore, these locations have been visited on more than one occasion (1973 and 1982) and the sequential observations support the contention that the present residues are from the* Arrow.

All of the samples that were collected, except one, were weathered to the point that they were an unresolvable complex mixture, including resins and asphaltenes. One sample of pooled oil collected on the lee side of Black Duck Spit is probably Arrow *oil, based on the chemical analyses performed. The existence after more than 22 years in pools on a beach of what is apparently original* Arrow *oil, with characteristics similar to the same oil stored in a sealed container, is astounding. This oil has remained almost unweathered as it was stranded on a cobble beach, which was originally heavily oiled, where a weathered crust formed on the top and bottom of the pooled oil layer to seal it from biophysical weathering. The other oil samples are also believed to be* Arrow *oil, based on circumstantial* *evidence, but the analyses conducted were not able to positively identify the source of the oil. The traces of these samples provide very little information and show that present techniques (gas chromatography) are rarely capable of characterizing very old oil or providing meaningful data on weathering.*

Oil Residues in 1992

The Bunker C oil that spilled from the Arrow *in 1970 washed ashore over an estimated 305 km of shoreline in Chedabucto Bay. Approximately 50 km of shoreline were cleaned or treated in relatively accessible locations. The oil that remained after the cleanup operations has been weathered and abraded so that by the time of the 1992 survey only a few scattered pockets of oil residue remained. The majority of the residual oil is concentrated in 10 segments in the Black Duck Cove and Lennox Passage areas. At these locations, asphalt pavement and pooled oil were documented. Elsewhere, the residual oil is characterized as small amounts of a thin stain or coat on bedrock or coarse sediments.*

Natural Shoreline Cleaning on Exposed Shorelines

Oiled shorelines subject to the action of waves on exposed and moderately exposed coasts have been cleaned primarily by physical abrasion. In these areas, the presence of oil residues is restricted to small amounts of thin, scattered oil on the higher parts of the beach, above the limit of most wave activity.

Natural Shoreline Cleaning on Sheltered Shorelines

The majority of the segments that have documented oil residues occur in low wave-energy environments and the few sites with heavy oiling conditions probably account for over 90% of the residual oil by volume. However, a key finding of this study is that many of the originally heavily oiled shorelines in low wave-energy environments are now free of oil. It is significant that near the spill location, oil was found on only 18 of the 111 segments in the sheltered Inhabitants Bay and Haddock Harbour areas. These initially heavily oiled coastlines received little cleanup treatment in 1970. Natural cleaning on these low wave-energy shorelines cannot be attributed reasonably to physical abrasion. These waters have considerable amounts of fine sediments in suspension and the process of clay-oil flocculation is believed to have prevented the formation of a hard weathered surface on the stranded oil. This process allowed continuous surface weathering and removal to proceed through the *biophysical combination of flocculation and biodegradation (oxidation).*

The presence and absence of oil residues on the coastline of Chedabucto Bay, 22 years after the Arrow *spill, can be explained by the physical weathering and biological degradation processes that act to remove stranded oil from the shorelines. The direct effects of physical abrasion and hydraulic pressures resulting from wave action on exposed shorelines provide an effective and rapid mechanism for the removal of oil from exposed, high and moderately high wave-energy environments. The relative importance of physical and biological processes varies geographically in areas where wave action is not the dominant removal process. Thus, oil has been removed from some sheltered, low wave-energy environments, but remains in substantial quantities in other sheltered locations.*

Other Comments

This project has underlined the concept that the total length of oiled shoreline alone is a poor measure of the actual oiling conditions. An estimation of oiling conditions, in terms of the oil cover (distribution) or thickness, is crucial to presenting an accurate picture of the degree of oiling.

The concept that single-line transects are inadequate for describing surface or subsurface oil conditions is further validated by this study. The substrate character and oil distribution and character are highly variable at each of the three detailed mapping sites. Surveys that have one transect per unit or segment are adequate only for uniform oiling conditions on uniform substrates, but this is not common on mixed shorelines, such as those oiled as a result of the Arrow *and* Exxon Valdez *spills.*

The value of detailed video and audio documentation for areas with complex oiling conditions became clear during the interpretation phase of this project. Still photographs and field notes or mapping are of prime importance in this type of study, but considerably more information can be recorded and archived through the careful and systematic use of video techniques.

In the Black Duck Cove area, the growth of thick vegetation covers, both grasses and fucoids, is evident based on comparisons of photographs taken and field observations made at the site over the 22 year period. These plants have grown on coarse-sediment beaches in a sheltered area, where oil remains in 1992, on what would otherwise have been an infertile substrate.

Conclusions

1) *Oil is present on 13.3 km of shoreline in Chedabucto Bay. Heavy oiling is restricted to 1.3 km, concentrated primarily in the Black Duck Cove and Lennox Passage areas. Some of this residual oil has been identified as coming from the* Arrow *based on circumstantial evidence; however, chemical analysis identifies one sample from Black Duck Cove as probably being* Arrow *oil.*

2) *Relatively little cleanup was carried out in 1970; only about 50 km of the more than 300 km that were oiled were treated. Natural weathering accounts for the removal of the majority of the oil from Chedabucto Bay. Where oil remains, it occurs as a thin stain on bedrock or coarse sediments (pebbles, cobbles, and boulders) or as a resistant oil-sediment asphalt-like mixture.*

3) *Areas in the low wave-energy environments of Haddock Harbour and Inhabitants Bay that were observed to be heavily oiled in the spring of 1970, and were not cleaned, are now virtually free of oil. These areas have a plentiful supply of fine-grained suspended sediments that may have contributed to clay-oil flocculation weathering as described recently for Prince William Sound, Alaska.*

4) *The most heavily oiled area is in Black Duck Lagoon, where asphalt pavement and pooled interstitial oil remain in three distinct areas of predominantly coarse sediments (cobbles and pebbles).*

5) *Resistant "asphalt balls" remain on the beaches of Arichat Harbour, where oiled sediments were reworked by the action of a bulldozer.*

6) *The presence or absence of oil residues in Chedabucto Bay following the* Arrow *spill can be explained in terms of the physical, biophysical, and biological processes that act upon stranded oil. Oil remains on the shore when it is:*

- *outside the zone of physical wave action (including sheltered lagoons) required to move sediments and/or abrade the oil;*

- *in areas of nearshore mixing where fine sediments are not present to weather the oil through biophysical processes (clay-oil flocculation and biodegradation); and*
- *weathered on the surface, forming a crust that retards change and protects the oil inside from those same weathering and oceanographic processes.*

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Introduction

1.1 Oil Spills in the Chedabucto Bay Area

There are two known sources of residual oil in the Chedabucto Bay area: the *Arrow*, a tanker that became grounded within Chedabucto Bay in 1970, and the *Kurdistan*, which broke apart offshore in 1979. Both of these accidents involved the release of Bunker C oil.

The *Arrow* spill began on 4 February 1970 after the tanker became grounded at Cerberus Rock, 6.5 km from the north shore of Chedabucto Bay. Nearly 11.4×10^6 L (72 000 bbl) of Bunker C fuel oil were released from the vessel during its subsequent breakup and sinking on 8 February. Most of the oil was released during the first 24 hours, but smaller amounts continued to leak from sunken sections until late March, when cargo salvage operations were concluded.

Oil was stranded on nearby shores within a matter of hours and slicks were transported as far away as Sable Island to meander on the waters of the region for a period of many weeks. Oil was stranded as late as mid-April on shorelines previously free of oil. The oil was washed ashore, to various degrees, over an estimated 305 km of the 604 km of shoreline in Chedabucto Bay (Task Force - Operation Oil, 1970b), of which only approximately 50 km were cleaned during Operation Oil (March-August 1970) (Task Force - Operation Oil, 1970a). In addition to the 78 beaches cleaned by the Department of Public Works (MacKay, 1970), earlier cleanup operations had been initiated by the Canadian Armed Forces and a number of limited-scale test studies were conducted (for example, using chemical agents and crushed limestone powder).

The *Kurdistan* broke in two in pack ice on 15 March 1979 in the Cabot Strait area, north of Cape Breton Island. Approximately 8.6×10^6 L (54 000 bbl) of Bunker C oil were spilled, spreading along the northern half of the east coast of Nova Scotia, mostly outside of Chedabucto Bay. A survey carried out on 19-20 April 1979 revealed scattered, thick viscous oil at 16 locations along the northeast and east shorelines of Chedabucto Bay (Fowler and Noll, 1979). This oil was patchy in distribution and was removed from those areas where it was located. Although it is unlikely that large quantities of *Kurdistan* oil remained in the study region, the possibility exists that some of the oil observed during the 1992 survey of the Chedabucto Bay coastline may have come from the *Kurdistan*. However, unless otherwise stated, the residual oil described in this report is considered to have come from the *Arrow*.

1.2 Program Purpose and Scope

The 1970 *Arrow* spill was well documented at the time of the incident (Drapeau, 1970; MacKay, 1970; Owens, 1970, 1971a,b; McLean and Betancourt, 1973; Buckley *et al.*, 1974). However, since a series of initial follow-up studies (e.g., Owens and Drapeau, 1973; Thomas, 1973, 1977, 1978; Rashid, 1974; Owens and Rashid, 1976; Vandermeulen and Gordon, 1976; Keizer *et al.*, 1978), no systematic surveys have been carried out to establish the existence, character, and distribution of residual oil on the shoreline. Similarly, no detailed or ground surveys have been conducted since the initial *Kurdistan* cleanup operations in 1979, which concentrated on locating and removing the obvious oil that was stranded. Therefore, the extent of any residual oil has been a matter of conjecture.

Conventional wisdom suggests that natural processes (biological, chemical, and physical) have removed any oil that was not removed during initial cleanup operations. Reconnaissance surveys (e.g., a Petro-Canada/Woodward-Clyde videotape survey conducted in 1982) have indicated that, with a few localized exceptions, the coastline of the region is free of oil. In the case of the *Arrow* spill, this implies that some 255 km of shoreline oiled by the heavy Bunker C oil have been cleaned through these natural processes. To confirm this hypothesis, a systematic ground survey was conducted from June to August 1992, followed by more detailed site surveys at two locations (Black Duck Cove/Lagoon and Rabbit Island) in September 1992. Data from these surveys provide an up-to-date, systematic, and detailed analysis of oiling conditions in the area.

Section 2

Methods

2.1 *Systematic Ground Survey*

The intent of the first phase of the field program was to survey the coastline of Chedabucto Bay in a systematic manner, including the coastline of Isle Madame and other islands in the bay, between St. Peters Island on the north shore and Black Duck Cove on the southeast shore (Figure 1). The survey was conducted between 15 June and 19 August 1992. It was carried out primarily on foot, but access was gained by boat where land access from the backshore to the shoreline was not practical along sections of Inhabitants Bay and nearby. Based on map interpretation, air photo interpretation, and field observation, the study area included an estimated 305 km of shoreline, 248 km of which were covered by the ground survey.

Areas not surveyed included those where:

- no data existed indicating oiling following the two spills;
- data existed indicating no oiling following the two spills; and
- access was not practical during the survey period due to inclement weather or the unavailability of a support boat from the Canadian Coast Guard.

All ground surveys were conducted during the lower half of the tidal cycle, beginning 3 to 4 hours before low tide and ending 3 to 4 hours after low tide. The cumulative amount of time spent in the field surveying was 24.5 days; however, approximately 5 days of this time was spent backtracking (i.e., returning to the starting point following completion of a segment). The average amount of time spent surveying per day was 7.5 hours. Based on these numbers, an average of 17 segments were surveyed each day, or an average of 10.1 km of shoreline.

2.2 *Shoreline Segmentation*

Shoreline segments were predefined based on knowledge of shoreline variables and were indicated on topographic maps. Segments were assigned an alphanumeric identifier (Appendix A) prior to the field survey based, in part, on a prominent local feature or landmark. In all, the study area was divided into 505 segments, 419 of which were surveyed. Of those surveyed, 129 segments were found to have residual oil.

Segments varied in length from 75 m to 4.4 km. Three hundred and fifty (69%) of the segments were in the range of 300 to 1000 m. Segment boundaries and site locations were located in the field using topographic maps and, where necessary, a hand-held Global Positioning System (GPS) unit.

2.3 *Ground Survey Documentation*

Documentation procedures followed those presented in the Atlantic Coast SCAT Manual (see also Environment Canada, 1992). Where no oil was encountered within a segment, only general geologic and geomorphic data were recorded on the Shoreline Oiling Summary (SOS) form. Where residual oil was observed, data were

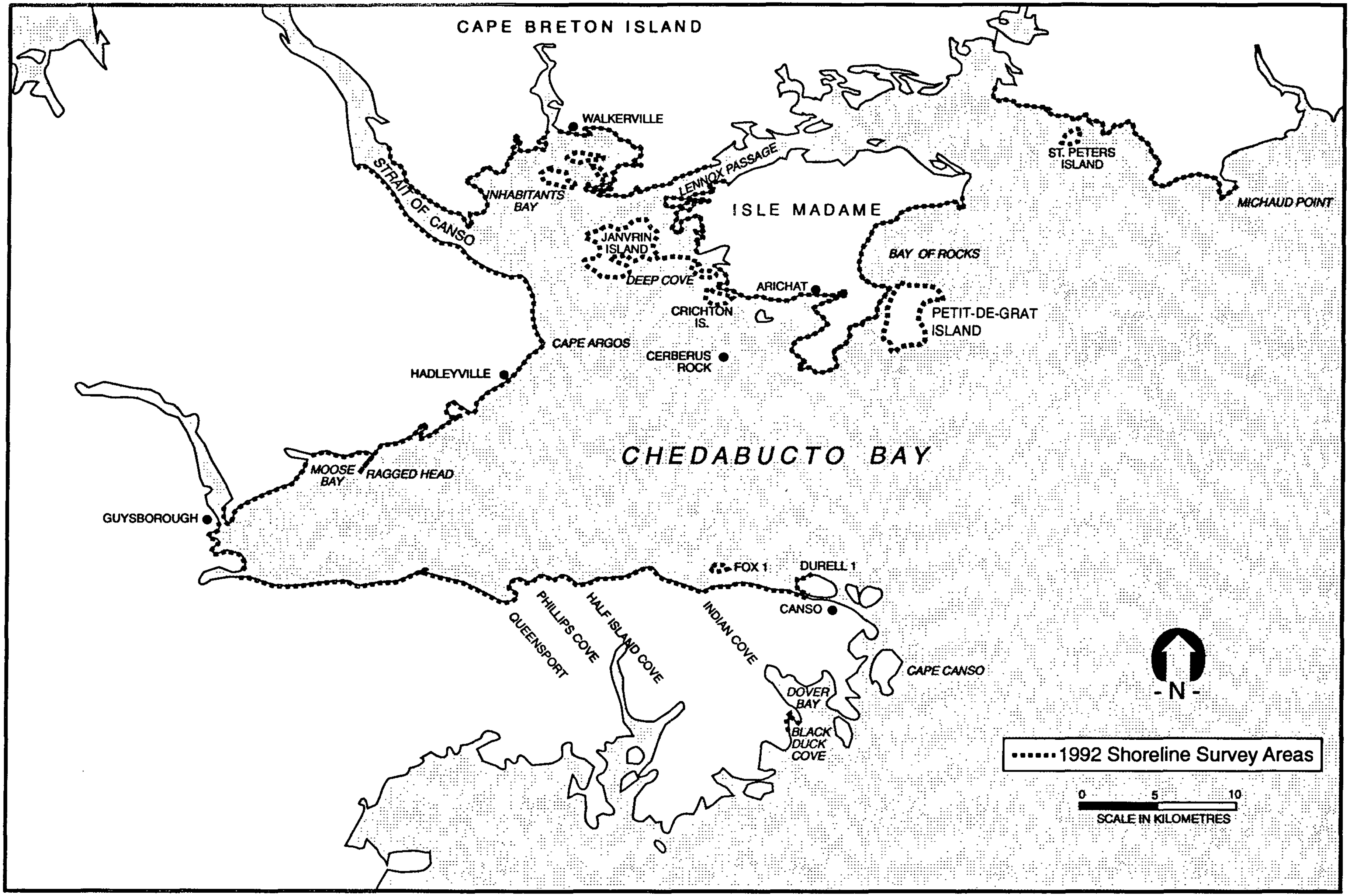

Figure 1 Chedabucto Bay Survey Area

collected following Shoreline Cleanup Assessment Team (SCAT) procedures. These included:

- completion of an SOS form;
- a sketch of the segment and of the surface oil distribution;
- colour slide photography; and
- 8 mm colour videotape documentation.

The information used to complete the SOS form is based on a definitive set of terms that describe the character of the oil on the shoreline (Environment Canada, 1992). This set of terms and definitions is intended to provide an accurate description of the stranded or residual oil with respect to the:

- width of the oiled area;
- extent of surface area with oil (distribution);
- thickness of the surface or subsurface oil layer; and
- character of the oil.

This data set provides a detailed description of exactly where and how much oil remains on the shoreline within each segment.

An example of a completed SOS form and a sketch for that and adjacent segments are shown in Figures 2 and 3 respectively. Data from all forms and sketches, as well as definitions of terms used to describe the shoreline and oiling conditions, are summarized in Appendix A.

2.4 Site Study Documentation

The second phase of the field program involved a number of visits to representative oiled locations and more detailed studies at locations where residual oil had been observed during the systematic ground survey. This phase was conducted over a 5 day period (9-13 September 1992) and involved the following activities:

9-9-92 Site inspection and sample collection at Black Duck Lagoon (BD-1 and BD-2).

10-9-92 Ground site visit to west Point Michaud (PM-15).
Aerial inspection with ground visits at Oyster Point (SC-2, SC-3, and SC-4), Ragged Head (GY-21A), Queensport (CA-28), and Rabbit Island (LP-12).

11-9-92 Detailed mapping at Rabbit Island (LP-12).
Ground (boat) site visits to north Rabbit Island (LP-6), MacNamaras Island (IN-69), Tongue Point (LP-13), and Inhabitants Bay (IN-31, IN-33, and IN-34).

12-9-92 Detailed mapping at Black Duck Lagoon (BD-1 and BD-2).

13-9-92 Ground site visits to Janvrin Island - Deep Cove (JI-22, JI-23, HH-32, and HH-33) and Arichat Harbour (AR-13).

The three detailed site studies (LP-12, BD-1, and BD-2) involved:

- mapping the distribution of surface oil;
- digging trenches or pits to establish the presence or absence of subsurface oil;

SHORELINE OILING SUMMARY (SOS) FORM

Page_____of_____

1. GEN

Segment ID: BD 6	Survey Date: 18/7/92	Survey Time: 10:25 to 11:25 AST / (ADT)	Tide Level ____ to ____
Surveyed from: (Foot) / Boat / Helicopter		Weather: Sun / (Clouds) / Fog / Rain / Snow	

2. CREW

Crew No: -	Operations: ______ for ______
OG: B. McGuire	Provincial: ______ for ______
ECO:	Federal: ______ for ______
ARCH:	Land Manager: ______ for ______

3. SHORE

Overall Classification for UITZ: Select One	Sediment Beach:	Sediment Flat:
Bedrock: Cliff_____ Platform_____	Boulder-Cobble ✓ Sand_____	Boulder-Cobble_____ Sand_____
Manmade: Permeable_____ Impermeable_____	Pebble-Cobble_____	Pebble-Cobble_____ Mud_____
Marsh/Wetlands_____	Sand-Gravel_____	Sand-Gravel_____
Secondary Shore Type: Pebble - Cobble Beach	Backshore Type: Low Relief (Wooded)	

4. LAND

Predominant Substrate: Artificial(permeable Y/N) ___% Rock ___% Rock & Sediment ___% Sediment 100% Organics/Fines ___%

Slope Low 100 % Medium _____% High _____% Vertical _____% | Wave Exposure: (Low) Medium / High

Total Estimated Segment Length: 400 m | Total Estimated Length Surveyed: 400 m

Access Restrictions:

5. OIL

Total Pavement: 350 sq.m by 1.0 cm	Debris/Amount:
Patties / Tarballs — bags	Logs_____ Vegetation_____
Oiled Debris? Yes/(No)	Rubbish_____ Other_____

6. SURFACE OILING

LOC	AREA LENGTH m	AREA WIDTH m	DIST	THICKNESS PO	CV	CT	ST	FL	CHARACTER FR	MS	TB	TC	SR	AP	NO	DB	ZONE SU	UI	MI	LI	SHORE SLOPE V H M L	SURFACE SEDIMENT TYPE
F	50	10	B	X										X			X	X			L	B,C,P

Distribution (DIST): C = 100-91%; B = 90-51%; P = 50-11%; S = 10-1%; T = <1%

Photo Roll # CHB·1 Frames 25, 27-30

7. SUBSURFACE OIL

PIT NO.	PIT ZONE SU	UI	MI	LI	PIT DEPTH cm	OILED ZONE cm-cm	CLEAN BELOW (Y / N)	SUBSURFACE OIL CHARACTER AP	OP	PP	OR	TR	NO	WATER LEVEL cm	SHEEN COLOR*	SURFACE-SUBSURFACE SEDIMENTS

* SHEEN COLOR: B = BROWN; R = RAINBOW; S = SILVER; N = NONE

8. OG COMMENTS

Figure 2 Shoreline Oiling Summary (SOS) Form: Segment BD-6.1

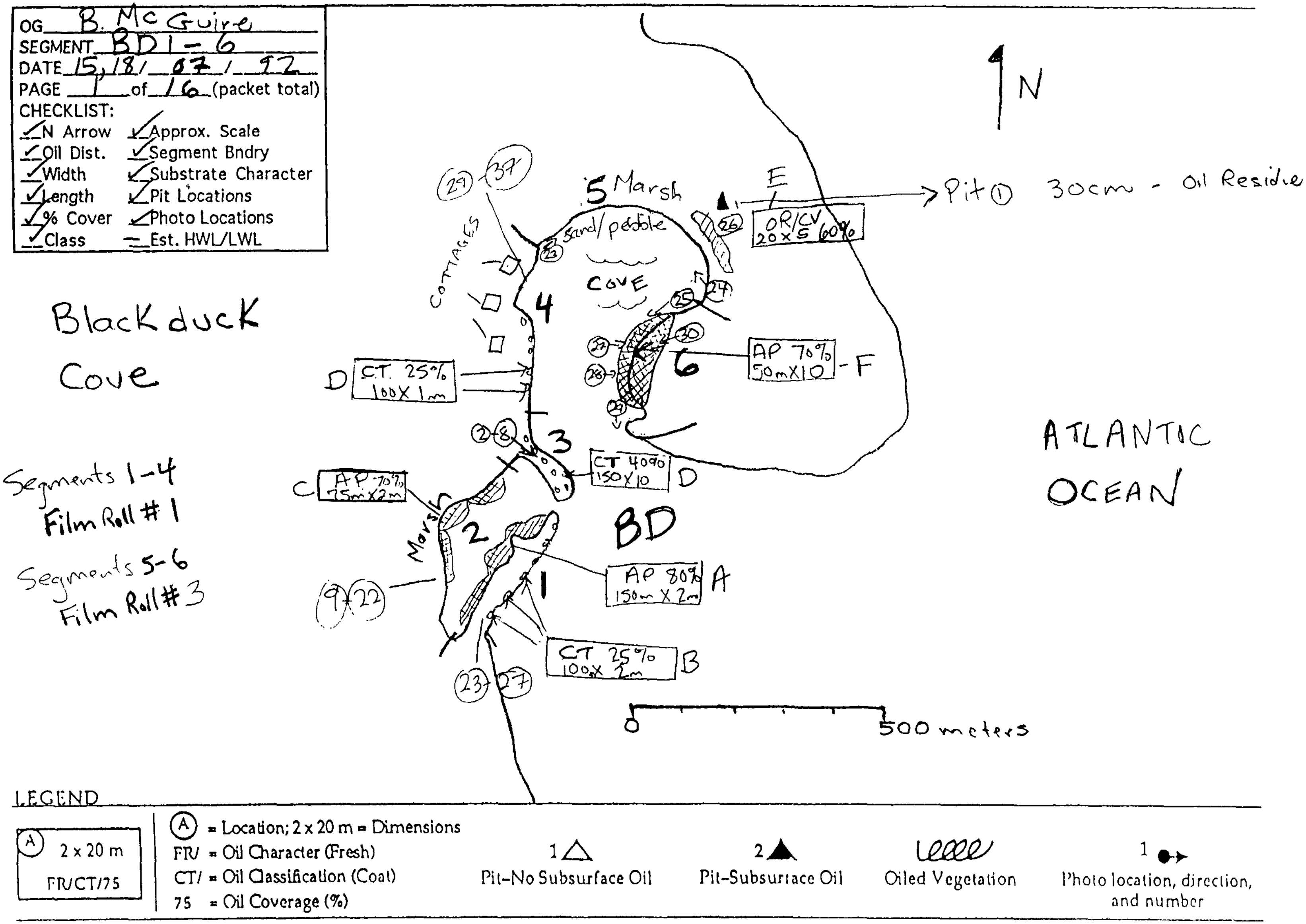

Figure 3 Shoreline Sketch Summarizing Oiling Conditions in Segments BD-1 to BD-6

- collecting samples for GC/FID and GC/MS analyses; and
- completing full photo/video documentation.

2.5 *Sample Collection and Analysis*

Fourteen samples were collected for chemical analyses. All samples were collected using a clean trowel and each sample was immediately placed in clean, screw-top jars.

2.5.1 Sample Collection

The following is a description of the locations from which the samples discussed in this report were collected. The sample locations are indicated on the figures cited, which are presented in Section 4.

Sample 1: Black Duck Spit

- seaward side of spit, very exposed (Figure 7)
- 2 m below storm ridge crest
- above mean high-water level and below highest high-water level
- surface layer of mobile, clean, cobble-pebble sediments, 20-30 cm thick
- sample collected from 15 cm thick zone of pebble-cobble sediments
- sediments in 2-15 cm diameter range, with black stain and film
- clean coarse sand in cobble-pebble sediments below

Sample 2: Black Duck Spit

- lee (lagoonal) side of spit, very sheltered (Figures 7 and 8)
- above mean high-water level and below highest high-water level
- asphalt pavement, 2-3 cm thick, over clean sand substrate
- no fresh oil evident, but centre of pavement had some black shiny and sticky residues

Sample 3: Black Duck Spit

- lee (lagoonal) side of spit, very sheltered (Figures 7 and 8)
- upper intertidal zone, downslope of sample 2
- asphalt pavement patch, up to 5 cm thick, over dry, coarse sand

Sample 4: Black Duck Spit

- lee (lagoonal) side of spit, very sheltered (Figures 7 and 8)
- middle intertidal zone, downslope of sample 3
- asphalt pavement, internally tacky, 2-3 cm thick, over dry, coarse sand

Sample 5: Black Duck Lagoon

- lower intertidal zone, on lagoonal flats (Figures 7 and 8)
- downslope of sample 4 on a low rise area
- soft asphalt patch over wet, very fine sand-silt sediments with eel grass

- rainbow and brown sheen left on water surface in sample hole after sample collected

Sample 6: Black Duck Spit

- lee (lagoonal) side of spit, very sheltered (Figures 7 and 8)
- above mean high-water level and below highest high-water level
- sediments dominantly white, well-rounded cobbles in 20-30 cm diameter range
- surface of cobbles clean, oil pooled in large pore spaces between cobbles
- surface crust of dull, black weathered oil
- below surface crust, "pure" oil, honey-like consistency, flowed on disturbance of cobbles

Sample 7: Black Duck Lagoon

- landward side of lagoon, mainland shore, upper intertidal zone (Figure 7)
- thickly vegetated marsh grasses
- soft pavement over fine organic sediments, marsh grasses growing through oil pavement

Sample 8: Rabbit Island

- middle to upper intertidal zone (Figure 6)
- moderately exposed site in terms of wave-energy levels
- subsurface sample collected at 2-5 cm depth in sand-cobble sediments
- oil was free-flowing upon disturbance
- rainbow and brown sheen appeared immediately on water surface in sample hole

Sample 9: Rabbit Island

- upper intertidal zone, 3 m upslope of sample 8 (Figure 6)
- asphalt pavement over clean sand-cobble sediments
- surface very weathered, light brown colour, due to presence of sediments in the oil

Sample A: Black Duck Lagoon

- landward side of lagoon, mainland shore (Figure 7)
- upper intertidal zone, south of sample 7
- thickly vegetated marsh grasses
- soft pavement over fine organic sediments, marsh grasses growing through oil pavement

2.5.2 Sample Analysis

Samples were analyzed to establish if the apparent oil collected during the survey came from the *Arrow*. This was accomplished by determining the composition of the oil and comparing it with a sample of "original" *Arrow* oil and analytical results from earlier studies (Keizer *et al.*, 1978; Humphrey and Vandermeulen, 1986).

The analyses were conducted by the Emergencies Science Division of Environment Canada at the Environmental Technology Centre in Ottawa. The analytical protocol used was developed by the Emergencies Science Division and involved a gas chromatography method using both flame ionization and mass spectrometer detectors (GC/FID and GC/MS). The protocol is summarized in Figure 4 and is described in Wang (1993) and Wang and Fingas (1993).

The analyses performed for this study included a sample of "original" *Arrow* oil stored in a tin at the Environment Canada laboratory in Halifax.

Earlier studies on oil from the *Arrow* spill reported GC/FID results (Keizer *et al.*, 1978; Humphrey and Vandermeulen, 1986). In both cases, the analysis of an "original" oil was reported, based on analytical procedures similar to those used in this study. The sample of "original" oil used by Keizer *et al.* (1978) was probably taken from the same tin as the sample used here, but the sample used in 1985 by Humphrey and Vandermeulen (1986) was a different sample.

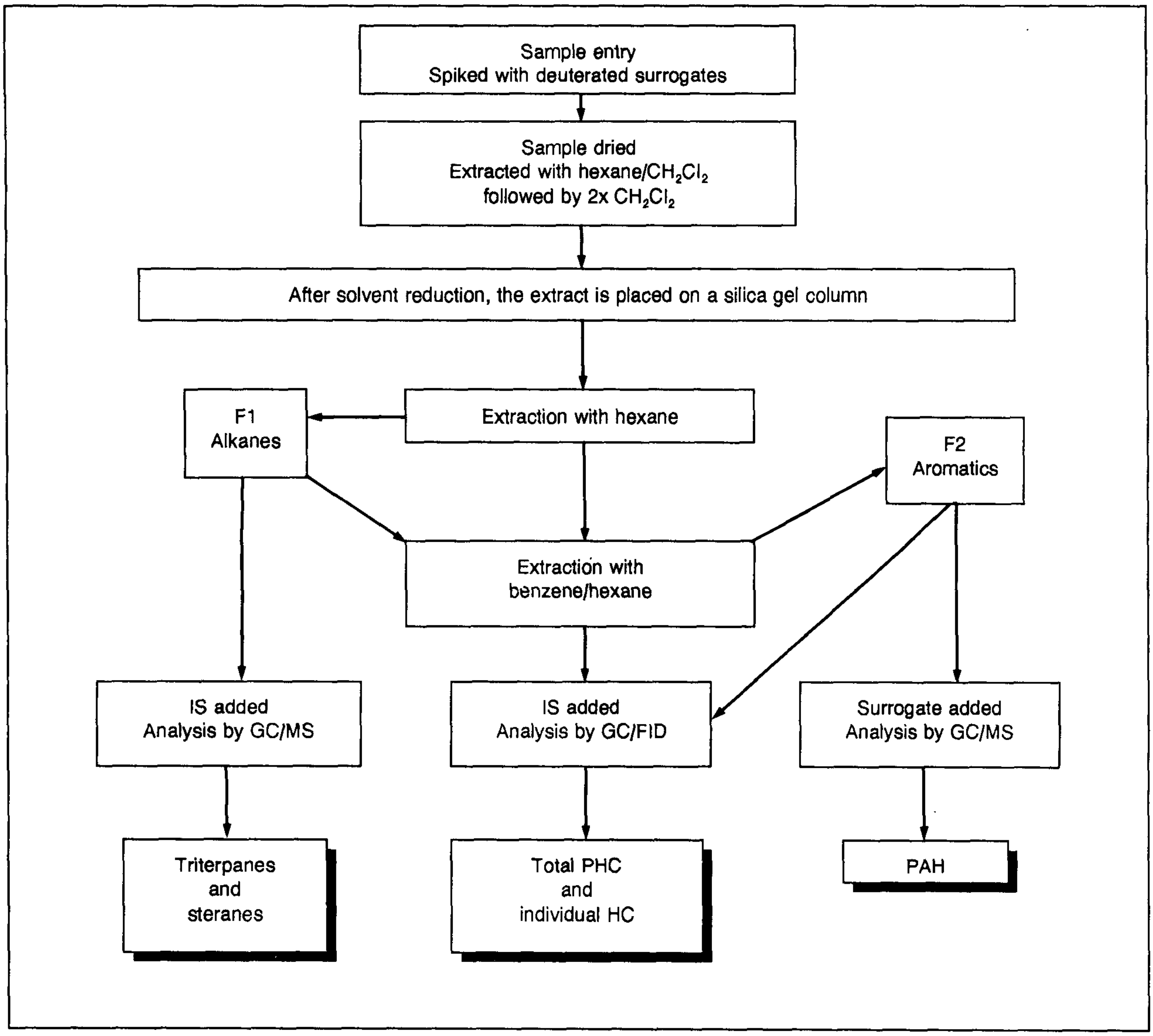

Figure 4 Analytical Protocol

Results of the Systematic Ground Survey

This section discusses the field data collected as part of the systematic ground survey conducted between 15 June and 19 August 1992 by B. McGuire. A brief outline of terminology and definitions used on the Shoreline Oiling Summary (SOS) form is presented in Appendix A; a more complete set of definitions and a description of SCAT field procedures is given in the Environment Canada SCAT manuals for Atlantic Canada (1993) and for British Columbia (Environment Canada, 1992). An example of the field data sheet (SOS form) and a site sketch from one set of segments are provided in Figures 2 and 3 respectively.

The ground survey focussed on recording the presence of surface oil residues. Pits were dug where oil was thought to be present. Not all of the data recorded on the SOS forms and sketches were analyzed for this report due to the large amount of information generated by this relatively simple surveying technique. The information of most interest for each oiled area within a segment was entered into a spreadsheet (Appendix A) and included the:

- location of the oil (by tidal zone);
- length of the oiled area;
- width of the oiled area;
- distribution of the oil (percent cover);
- thickness of the oil or oil layer; and
- character of the oil.

This information was then used to define the:

- oil cover (a two-dimensional descriptor), and
- oil category (a three-dimensional descriptor).

Data on the physical character of each segment included the:

- wave exposure;
- beach/shore-zone slope;
- sediment type(s);
- segment length; and
- length of the segment surveyed.

3.1 Length of Oiled Shoreline and Distribution of Oil

The total length of shoreline on which oil residues were observed, in one form or another, was 13.3 km. These residues were distributed in 129 of the 419 segments surveyed (Table 1), which represents a very scattered distribution throughout Chedabucto Bay. However, the majority of the heavily oiled segments are clustered in the Black Duck Cove and Lennox Passage areas. All of the observed oil was located in either the upper intertidal zone or the supratidal zone.

Table 1 ***Arrow* Survey Data Summary, 1992**

TOTALS			
Length of shoreline	304 725 m	Number of segments	505
Length surveyed	247 575 m	Number of segments with oil	129
Length oiled	13 302 m	Percentage of length surveyed that is oiled	5.37
Summary of Wave Exposure for Oiled Segments		Thickness	Length (m)
High	1 segment	Pooled	275
Medium	42 segments	Cover	1 956
Low	86 segments	Coat	1 296
		Stain	9 776
		Character	Length (m)
Distribution (No. of Segments)	Length (m)	Asphalt pavement	2 547
Continuous (1)	2.5	Surface oil residue	10 754
Broken (24)	1 683.0	Tar balls	2
Patchy (39)	4 011.5		
Sporadic (65)	7 605.0	Oil Cover (No. of Segments)	Length (m)
Trace (0)	0.0	Heavy (10)	868.0
		Moderate (24)	2 227.5
Width (No. of Segments)	Length (m)	Light (29)	2 378.5
Wide (4)	235	Very light (66)	7 828.0
Medium (16)	2 143		
Narrow (101)	10 389	Oil Category (No. of Segments)	Length (m)
Very narrow (8)	535	Heavy (24)	1 336.5
		Moderate (15)	977.0
		Light (20)	2 091.0
		Very light (70)	8 897.5

3.2 Amount and Character of Residual Oil on the Shoreline

Although the percentage of oiled shoreline was relatively high (5.37% of the shoreline surveyed), more than 80% of the observed oil fell into the "light" and "very light" oil categories (Table 1). Only 235 m of shoreline had "wide" (>6 m in width) oiled areas, and these were concentrated in four segments.

Oil thicknesses fell predominantly (73%) into the "stain" category (<0.01 cm thick). Only 2.2 km of oiled shoreline (16.5%) had thicknesses in the "cover" (>0.1 cm and <1.0 cm) or "pooled" (>1.0 cm) categories.

The majority of the oil had a thickness that fell within the "stain" category. Such oil is very weathered, with little of the lower molecular weight fractions remaining. At the few locations where "pooled" oil or "asphalt pavement" was found, the surface of the oil was observed to be very weathered and often very light grey in colour. In some of these locations, however, observation of the subsurface oil revealed that it was relatively "fresh" in appearance and also still mobile.

3.3 Discussion

The systematic ground survey was successful in that it has provided an accurate picture of the distribution and character of oil residues in Chedabucto Bay. This oil can be attributed to the *Arrow* spill on the basis that the locations where most of the heavier oiling was observed correspond with the locations where heavy oiling was observed following the spill and during subsequent surveys in 1973 and 1982. Oil was not reported in these locations during surveys conducted following the *Kurdistan* spill.

Conclusions based on the systematic ground survey can be summarized as follows:

1) Oil was observed on 30% of the shoreline segments surveyed, although these segments accounted for only 5.37% of the total shoreline length surveyed.

2) The residual oil can be described as a scattered, light oil stain, with a few localized patches of larger amounts of oil. Although the oil was scattered over a large area of Chedabucto Bay, the majority of it was found in sheltered areas and was located in the upper intertidal zone or the supratidal zone on coarse-sediment (pebble-cobble) beaches.

3) With respect to the oiled areas observed, 78% fell into the "narrow" (width) category; 87% into the "sporadic" or "patchy" (distribution) categories; and 73% into the "stain" (thickness) category.

4) In terms of oiled areas observed with larger amounts of residual oil, <2% fell into the "wide" (width) category; <1% fell into the "continuous" (distribution) category; and 2% fell into the "pooled" (thickness) category.

5) Almost 60% of the oil cover (width + distribution) fell into the "very light" category, and 67% of the oil category (width + distribution + thickness) fell into the "very light" category. By contrast, 6.5% of the oil cover fell into the "heavy" category, and 10% of the oil category fell into the "heavy" category.

Section 4

Results of the Detailed Site Surveys

The objective of the detailed site studies was to examine the long-term fate and persistence of residual oil in the area and to compare the observations and data with those from similar coastal environments with oil residues. The shoreline segments described in this section are known to have been oiled as a result of the *Arrow* spill, except in the vicinity of Point Michaud (PM-15), which may have been oiled as a result of the *Kurdistan* spill.

4.1 Eastern Rabbit Island (LP-12)

This sheltered site in Lennox Passage (Figure 5) was surveyed on 11 September 1992. The shores of Rabbit Island were initially heavily oiled as a result of the *Arrow* spill, probably on several occasions, but the site was not cleaned as part of the Department of Public Works' cleanup program. It is not known if other, earlier, treatment activities were carried out at this site, but reconnaissance observations in May 1970 revealed an almost continuous band of heavily oiled sediments in the lower, middle, and upper intertidal zones (Owens, 1971a). Considerable amounts of weathered surface oil were photographed throughout the area during aerial reconnaissance in 1973 (Owens and Rashid, 1976). In 1982, oil was photographed as a weathered residual pavement at several sites in the area of Rabbit Island during ground stops that were part of an aerial videotape reconnaissance survey of the region (Woodward-Clyde Consultants, 1982). As of September 1992, there remains a relatively continuous asphalt pavement, several metres wide in places, in the upper intertidal zone of that part of the island selected for detailed study.

The study site is characterized by predominantly coarse, angular and subangular sediments with occasional bedrock outcrops. The beach has a low-angle slope and is backed by a narrow band of vegetation with no storm ridge. These features are characteristic of a beach that is reworked by only limited wave action on an open coast, but in a sheltered fetch location. Maximum fetch is generally on the order of less than 5 km and there is a very narrow fetch window to the southwest of approximately 10 km. The site is not likely to receive refracted waves from the open bay or ocean as it is sheltered by Janvrin Island (Figures 1 and 5).

A total of 50 cross-beach transects were surveyed for oil distribution and substrate character along a 64.5 m length of shoreline (Figure 6; Table 2) and two samples (Figure 6, sample locations 8 and 9) were collected from the upper intertidal zone asphalt pavement.

Sample 9 was collected 3 m upslope of sample 8 in the upper half of the asphalt pavement, which has a light-brown weathered surface (Appendix C, Plate 1). This colour is due partially to the light colour of the sediments embedded in the pavement. The pavement is continuous and varies in thickness between 3 and 5 cm. Visible surface oil covers only 5% of most sections; the remainder is composed of clean sediments exposed on the surface of the asphalt.

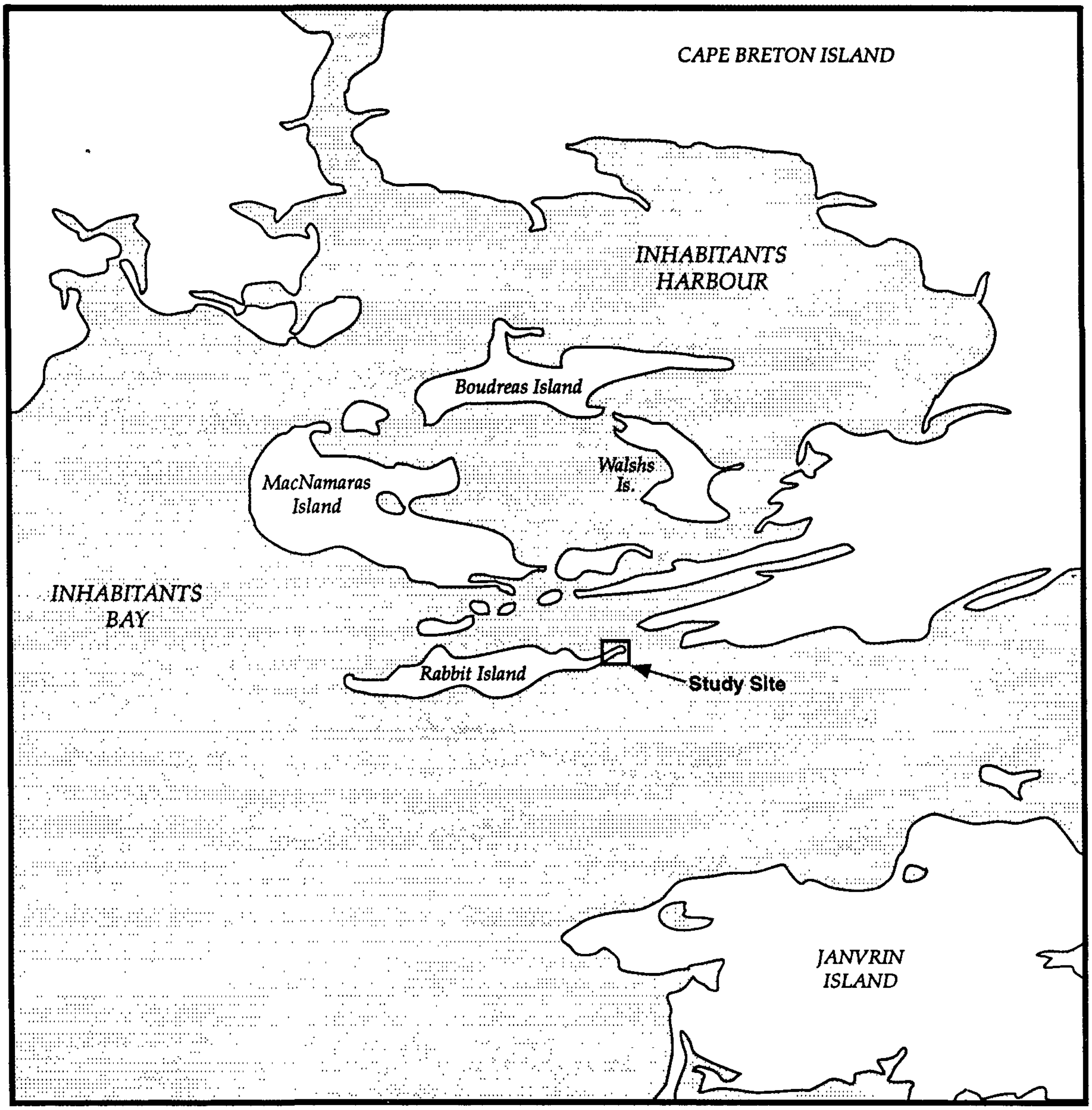

Figure 5 Eastern Rabbit Island Study Site

Sample 8 was collected from the lower half of the pavement. Still in the upper intertidal zone, it has a weathered surface, but below this crust the oil is relatively fresh in appearance, black in colour (Appendix C, Plate 2), and flows within seconds after being exposed and disturbed. Water in pits that were dug for sample collection accumulated brown oil on the surface. Elsewhere, a rainbow sheen was visible in disturbed areas or where water drained from the pavement area. Daytime air temperatures had been greater than 20°C over a period of several days immediately prior to the site survey.

The beach sediments at this site are evidently mobile. At the time of the survey, a small ridge was migrating up the beach in the upper intertidal zone. Within this ridge of clean sediments, buried deposits of residual oil were found.

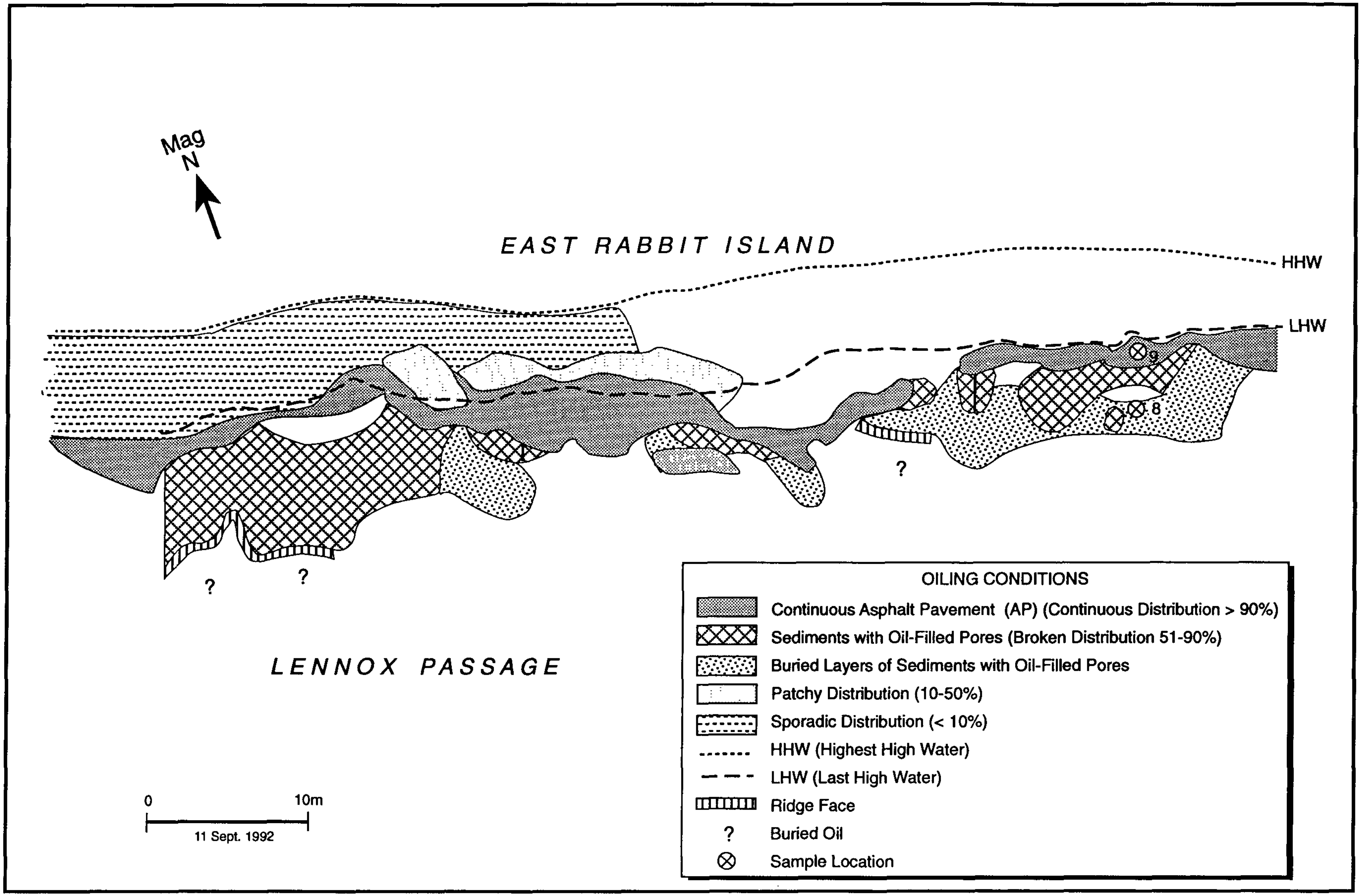

Figure 6 Oiling Conditions, Eastern Rabbit Island Study Site (11 September 1992)

Table 2 Detailed Study Site Oil Distribution Summary

Rabbit Island (LP-12)	
Continuous asphalt pavement	600 m^2
Broken (51-90%)	580 m^2
Patchy (10-50%)	152 m^2
Sporadic (<10%)	460 m^2
Total surface	1792 m^2
Buried pooled oil	380 m^2
Black Duck Cove (BD-1)	
Continuous asphalt pavement	228 m^2
Cover with *Fucus*	40 m^2
Patchy (40-50%) + pooled oil	200 m^2
Patchy (10-20%) + pooled oil	520 m^2
Total surface	988 m^2
Buried pooled oil	168 m^2
Black Duck Cove (BD-2)	
Continuous asphalt pavement	864 m^2
Broken (51-90%)	64 m^2
Patchy (10-50%)	164 m^2
Total surface	1092 m^2
Buried pooled oil	72 m^2

4.2 Black Duck Spit (south shore of the lagoon) (BD-1)

The pebble-cobble beaches on the back side (very sheltered lagoon shore) of the Black Duck Cove spit (Figure 7) were initially heavily oiled as a result of the *Arrow* spill (Owens, 1970, 1971a). This site was the subject of detailed field measurements and observations in 1973 (Buckley *et al.*, 1974; Owens and Rashid, 1976; Owens, 1978). A ground stop was made at this location in July 1982 (Woodward-Clyde Consultants, 1982) and the oiled shorelines were photographed. They were also photographed and videotaped from the air at this time.

As of September 1992, extensive areas in the upper intertidal zone remain oiled along a 100 m section of this segment as (1) pooled (OP) weathered oil that fills the interstices of well-sorted cobbles or pebbles, or (2) an asphalt pavement (AP) of weathered oil and sediments in areas of mixed sand/pebble/cobble beach material (Figure 8).

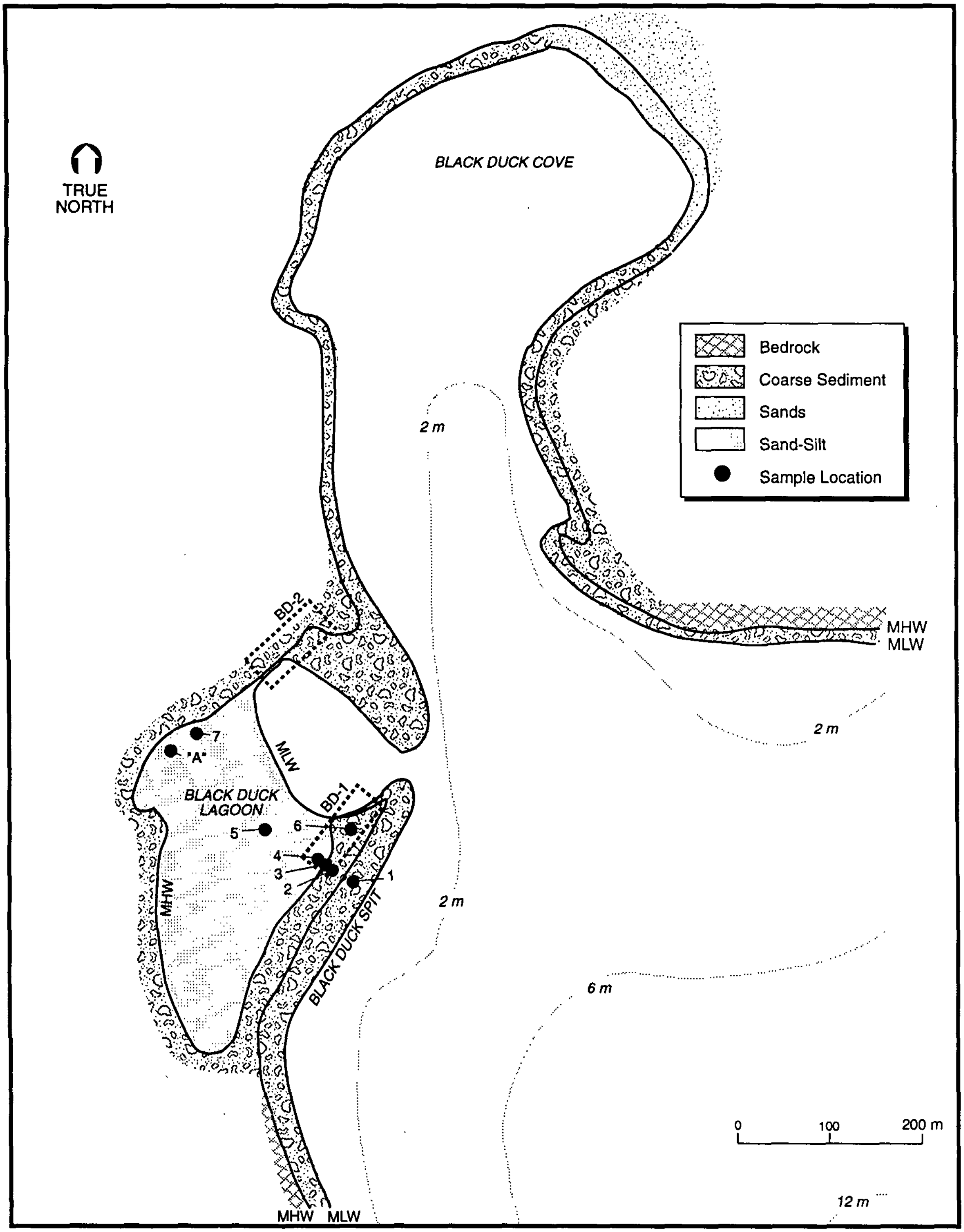

Figure 7 **Black Duck Lagoon and Spit Study Sites**

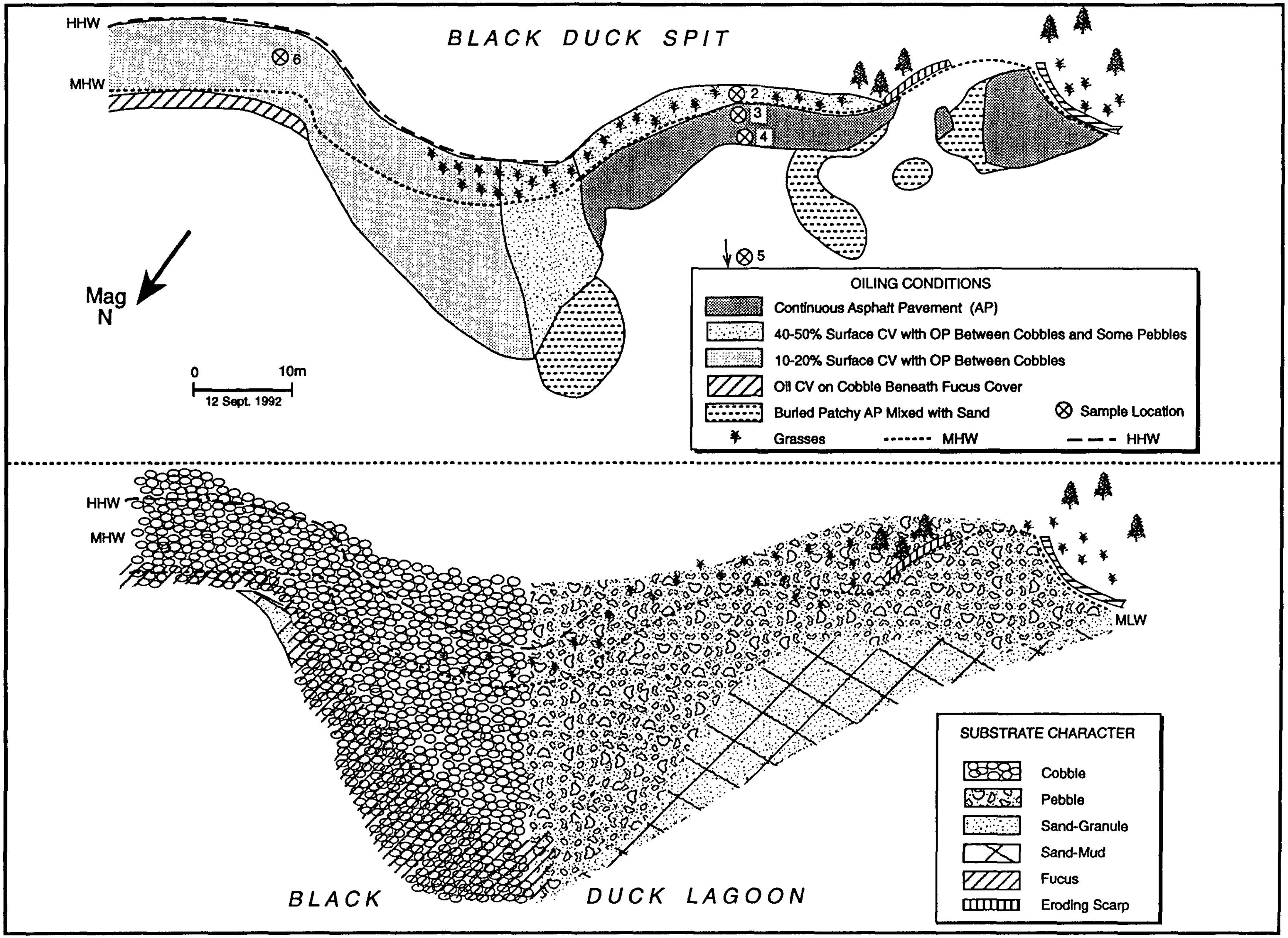

Figure 8 Oiling Conditions and Substrate Character at the Black Duck Spit Study Site (12 September 1992)

On 12 September 1992, 22 radial transects were surveyed for oil distribution and substrate character along a 66.4 m length of the spit's (lagoon backshore) shoreline. Rebar was set at the end and intermediate points of the surveyed section to facilitate future relocation of the transects. Five samples were collected (9 September 1992) along a line from the upper intertidal zone asphalt pavement to the fine-grained lower intertidal zone (Figure 7); a sixth sample was collected from an upper intertidal area adjacent to one of the transect origin stakes (Figures 7 and 8). Observations made at several locations on the spit outside the actual mapped area are also included in the discussion presented here.

The top of the intertidal zone on the ocean side of the spit has a mobile surface layer of clean, 30-40 cm diameter, white cobbles. Below this is a 20-30 cm thick layer of relatively immobile pebbles with some cobbles and granules that have a weathered coat or stain of oil (Appendix C, Plate 3). This layer is not cemented by oil and appears to be washed through by water during spring tides and storms. Sample 1 (Figure 7) was collected from a large pit at this location. Below the oiled layer is clean coarse sand with pebbles. The sand has no visible oil, but the uppermost layer of pebbles has a coat or stain on the top half with a clean lower half. These observations indicate that the depth of reworking on this upper section of the beach-face slope, above the normal high-water level but below the ridge crest, is shallow, perhaps limited to only one or two layers of mobile sediments.

Some pebbles and cobbles have been thrown over the ridge crest by storm wave action that characterizes this very exposed beach. Approximately one in every 30 or 40 clasts in this zone has a coat or stain of oil, and the cover on each clast ranges from 5 to 30%. As the sediments are white in colour, the oiled clasts stand out clearly. Observations of the oiling conditions in September 1992 revealed a significant reduction in the amount of surface oil compared with that observed in May 1973 at the same location [for May 1973 photographs, see Buckley *et al.* (1974, Figure 17) and Owens (1978, Figure 5)]. In 1973, the oil had a patchy (11-50%) to broken (51-90%) distribution of oil cover (0.1-1.0 cm thick) and was being buried on the seaward margin by clean sediments moved up the beach by wave action. Physical reworking and abrasion by infrequent, but energetic, storm wave action have been effective in reducing oil coverage on the sediments of the ridge crest.

Detailed mapping was carried out in an area of heavy residual oiling that covers approximately 100 m of the upper intertidal zone and supratidal zone on the lee side (lagoon shore) of the spit. This location is a very low wave-energy environment that is completely sheltered from open-ocean waves. The shallow sill at the entrance to the lagoon (Figure 7) absorbs refracted wave energy; therefore, physical energy in this system is restricted to the tidal rise and fall of the water level and to small waves generated in the lagoon (maximum fetch less than 250 m).

The oil in this study site is associated with pebble-cobble sediments. Relatively little oil is present in the adjacent sand and finer sediments that mark the change from the back beach of the coarse-sediment spit to the tidal flats of the lagoon (Figure 8). Four distinctly different oiling conditions exist in this site as a result of the different sediment sizes present:

- a deep layer of oil in the pores of the coarsest (cobble) sediments in the upper intertidal and supratidal zones of the northeastern half of the study area; this oil has a weathered surface crust, but appears shiny and fresh below;

- a deep layer of oil in the pores of the pebble sediments in the upper intertidal and supratidal zones of the central-southwestern backshore half of the study area; this oil has a weathered surface crust, but appears shiny and fresh below;

- more weathered oil, which has cemented sediments in the mixed pebble-cobble sediments (asphalt pavement (AP) zone in Figure 8) (Appendix C, Plate 4); and

- a scattered, and sometimes partially buried, surface layer of asphalt on the finer (sand-granule) sediments of the middle to upper intertidal zone.

4.2.1 Cobble Area

In the most northeasterly portion of the study site, in the upper intertidal zone, the white, well-rounded cobbles have a mean diameter on the order of 20-40 cm and no fine fractions are present. The surface cover is approximately 80-90% unoiled, giving the appearance of a clean beach from a distance or if one looks along the beach from a low angle (Appendix C, Plate 5). However, the pore spaces are completely filled with shiny, black to dark brown, mobile oil free of any sediment (sand or granules) (Appendix C, Plate 6). It was not possible to determine the thickness of this oiled cobble layer, but in two locations it was found to be at least 20 cm deep. Sample 6 (Figure 7) was collected from this area. This section of the study area contains a large amount of oil relative to the surface area due to the large pore spaces that exist between the well-rounded and well-sorted cobble sediments. These pore spaces were filled with oil in 1970, to a minimum depth of 20 cm, and the oil and sediments have not been disturbed since that time. The tops of the oiled cobbles, which had an oil coat (0.01-0.1 cm thick) or cover (0.1-1.0 cm thick) in 1970, have been cleaned to expose the white sediments. However, a surface crust was formed as a result of weathering where the oil was exposed in the intervening voids and this asphalt-like crust has protected the underlying oil from degradation. The beach sediments of this area have not been moved since the oil was initially stranded in 1970. Grasses have grown on some upper sections of the oiled area near the highest high-water (HHW) level (Figure 8).

In 1970 and 1982, oil was observed on the steep section of the back beach at the east end of the study site (labelled "oil CV on cobble beneath *Fucus* cover" in Figure 8). This section, in the vicinity of the mean high-water (MHW) level, has a 3 m wide and 1 m high face, which was heavily oiled in 1970 and 1973, with no vegetation. In 1992, this section was characterized by a thick and continuous layer of attached *Fucus*, within which it was possible to find oil on the sediment surface. This *Fucus* zone extended to the low-water level at the time of the 1992 survey, to the junction of the cobble sediment and fine-grained, low-tide flats. These observations support the contention that the oil has acted as a base for attachment and growth of the *Fucus* on what would otherwise have been an infertile substrate.

4.2.2 Pebble Area

To the south and west of the predominantly cobble area, the sediments are finer, generally 5-10 cm in diameter, but again white in colour and well rounded. The surface of this portion of the study site has a surface oil cover of 50-60%, the remainder being the clean top surface of the white sediments. The character of the oil-sediment mixture in this portion does not differ significantly from that in the cobble area, except for the surface appearance, which appears more oiled in the pebble area than in the cobble area. This is simply a function of the different ratio between the area of the tops of the clean pebble sediments and the area of the intervening voids. As with the oiled cobble sediments, the beach sediments in this area have not been moved since the oil was initially stranded in 1970 and grasses have grown on the upper sections of the oiled area between the mean and highest high-water levels (Figure 8).

4.2.3 Pavement Area

The southwestern portion of the coarse-sediment zone of the study site has an asphalt pavement of predominantly pebble sediments mixed with granules and some cobbles (Appendix C, Plate 4). The pavement is up to 15 cm thick, has 50-90% clean surface in the upper half of the band and 10-50% clean surface in the lower half. The lower edge of the pavement is abrupt, occasionally a scarp feature, at the junction of the coarse back-beach sediments and the sands of the upper part of the low-tide flats. Photographs taken in 1973, 1982, and 1993 indicate that this pavement area is very stable and is only slowly being abraded by water action along its lower edges.

There is a clear distinction between this pavement area and the cobble and pebble areas. Where the well-sorted, immobile coarse sediments exist without finer (sand and granule) fractions, the oil remains as a residue that fills the open pore spaces between the clasts. Where the sediments exist as a mixture of coarse (pebble-cobble) and finer (sand-granule) fractions, a pavement-like feature has formed [described as a "tar conglomerate" in Buckley *et al.* (1974)]. This pavement could have formed as a result of simple oil penetration and weathering *in situ* or could have involved physical mixing of oil and sediment, as was the case in Arichat Harbour.

4.2.4 Asphalt Areas

A scattered, and sometimes partially buried, surface layer of asphalt on the finer (sand-granule) sediments of the middle to upper intertidal zone remains in parts of the upper intertidal zone, below the mean high-water level (Figure 8). The presence of this residual oil is recorded in photographs taken in May 1970, May 1973 (Owens and Rashid, 1976, Figure 13), and July 1982 (Woodward-Clyde Consultants, 1982). In areas adjacent to an overwash channel, which is the dominant geomorphological feature in the western end of the study site, the pavement rests on the surface of the sands in the upper parts of the low-tide flats. In this area, the pavement is not continuous and provides a 60-80% cover in some parts. The oil is a discrete layer up to 5 cm thick on the surface, but has been buried by sand in some parts; when the pavement is broken, the oil in the middle of the pavement has an odour and is shiny and tacky. Samples 2, 3, and 4 (Figures 7 and 8) were collected from this area.

Downslope of the asphalt pavement, on the low-tide flats, isolated and small patches of asphalt were observed, and some sheen was observed in disturbed areas. Sample 5 (Figures 7 and 8) was collected on a rise in this part of the lagoon. Evidence of recent clam digging was observed in many parts of the lagoonal flats.

4.3 Black Duck Lagoon (north, mainland shore) (BD-2)

This site on the north side of the lagoon (Figure 7) was heavily oiled as a result of the *Arrow* spill (Owens, 1970, 1971a). The site is a coarse-sediment beach that gives way downslope to the fine-grained tidal flats of the lagoon. Site visits were made on various occasions in 1970 and in May 1973 (Owens and Rashid, 1976). A low-altitude photographic overflight was also conducted in July 1982 (Woodward-Clyde Consultants, 1982). Initially, the area was heavily oiled with surface deposits of pooled weathered oil that were more than 20 cm thick in places on the low-angle slopes. These thick deposits were still evident during the May 1973 visit (Buckley *et al.*, 1974, Figure 18; Owens, 1978, Figure 6a).

Eleven cross-beach transects were surveyed for oil distribution and substrate character along a 113 m length of the back lagoon (mainland) shoreline on 12 September 1992. Rebar was set at the end points of the surveyed section to facilitate future relocation of the transects.

Extensive areas in the upper intertidal zone remain oiled along much of this segment as (1) pooled weathered oil that fills the interstices of well-sorted cobbles or pebbles (approximately 55 m^2), or (2) an asphalt pavement of weathered oil and sediments in areas of mixed sand/pebble/cobble beach material (approximately 215 m^2) (Figure 9).

In the western part of the segment, the oiled areas have a thick cover of vegetation, which made locating and describing the oil difficult. In this area, it was not possible to accurately document the full extent of the remaining oil. The vegetation cover becomes more dense west of the study site boundary (profile 1) and oil was found virtually everywhere that observations were made along the length of this shore. The grasses during the September visit were more than 1 m in height in places and provided an almost complete cover in most areas, with isolated nonvegetated sediment or sediment/oil patches. The thick and almost continuous vegetation cover in this area, to the west and south of the section that was mapped, made a systematic mapping program impractical in the time available. In more open patches, oil could be seen as a pavement layer or an asphalt layer on sand. At one location, *Fucus* was observed attached to pebbles and cobbles embedded in the surface of a pavement area as well as to asphalt directly. Four samples were collected (9-9-92 and 12-9-92) from the upper intertidal zone in this area to the south of the study site.

The appearance of this section of shoreline in 1992 was markedly different from that recorded in the summer of 1970, when little or no vegetation was observed on the heavily oiled, coarse beach sediments of this shoreline. By the spring of 1973, flowers were observed growing through the oil layer on this beach (Owens, 1977, photo 94). It is conjectured that the presence of the oil provided a base for plant growth on a section of shoreline that otherwise would have been a relatively infertile substrate.

The study site lies between the end of the thickly vegetated area (Appendix C, Plate 7) and a low sill that almost closes the entrance to the lagoon at low tide (Figure 7). The site is characterized by an area of upper intertidal zone surface oil that extends alongshore to the northeast to the sill ridge. This section has a beach-face slope of coarse (cobble-pebble) sediments that gives way downslope to a middle and low-tide flat area of mixed sand and pebble/cobble sediments with *Fucus* (Appendix C, Plate 8). The junction of the beach face and the flat has a sand lens that has buried the surface oil over some of the section. Oil was observed on some upper sections of the flats, but in sections where oil was found it was also

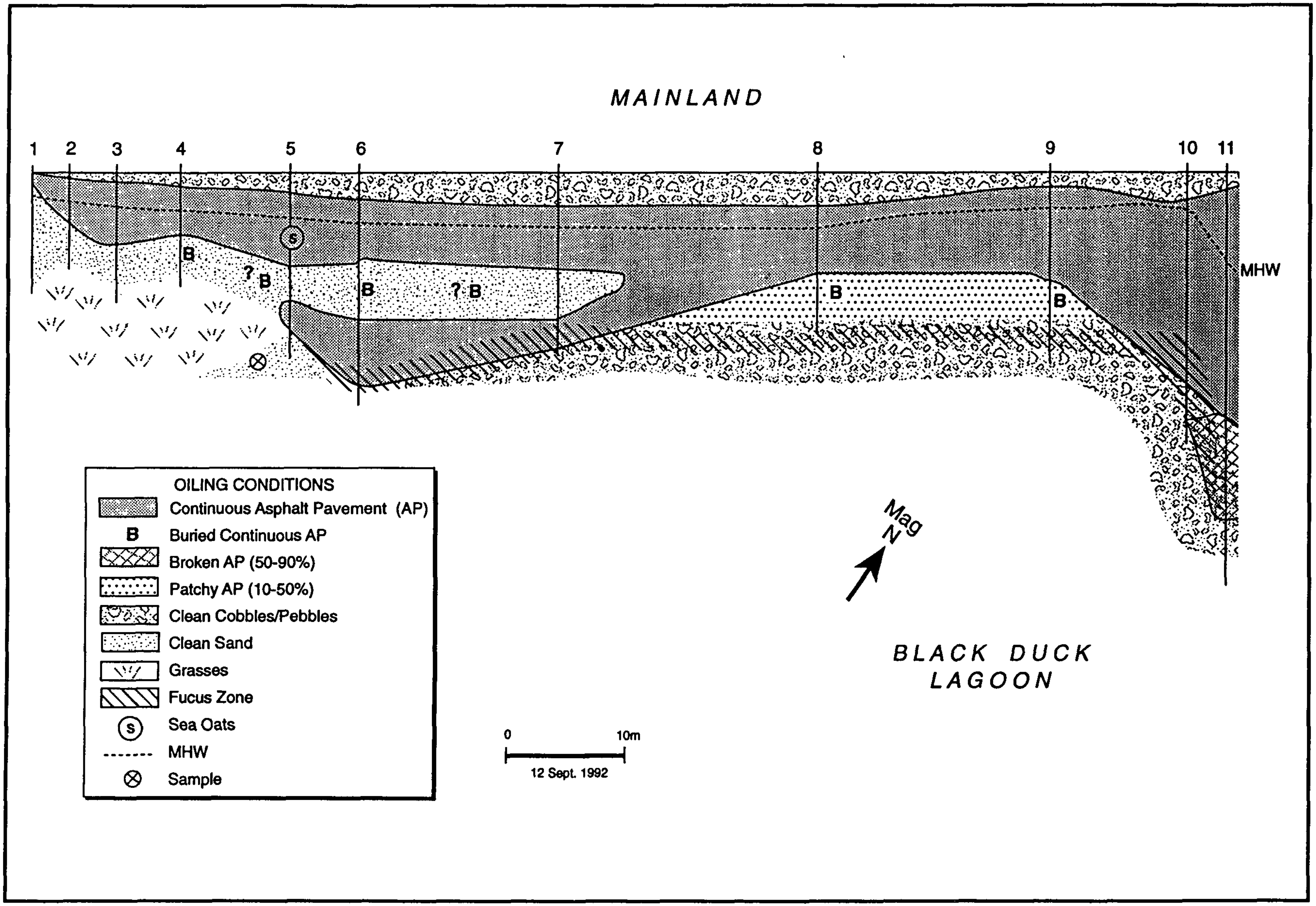

Figure 9 Oiling Conditions and Substrate Character at the Black Duck Lagoon Study Site (12 September 1992)

partially buried by sand and by a cover of *Fucus*.

On the upper half of the beach face, the surface sediments are predominantly cobbles with scattered boulders and secondary pebble and granule/sand components (Appendix C, Plate 8). From a distance, the surface appeared to be relatively clean. The sediments are white and the oil was largely restricted to infilling of the pore spaces between large clasts. The level of the oil surface between the clasts was lower than the beach surface so that when viewed alongshore the beach had a predominantly white appearance. However, a vertical view at any point on the beach face would indicate that between 30 and 50% of the surface had an oil cover. The sediments were cemented in place and the oil in the pores was black or dark brown and became relatively mobile upon being exposed and disturbed. The lower half of the beach face, below the mean high-water level, had more sand and in some sections it was observed that this sand lens had buried the lower sections of the pavement.

4.4 Other Site Visits

4.4.1 Sheltered, Low Wave-energy Environments of Inhabitants Bay - Western Lennox Passage

11-9-92 Rabbit Island (LP-6 and LP-12), MacNamaras Island (IN-69), Tongue Point (LP-13), and Inhabitants Bay (IN-31, IN-33, and IN-34)

13-9-92 Janvrin Island - Deep Cove (JI-22, JI-23, HH-32, and HH-33)

This area of Chedabucto Bay was one of the most heavily oiled as a result of the *Arrow* spill in 1970, but very little cleanup activity was carried out in Inhabitants Bay and Lennox Passage. Wave-energy levels are low in this sheltered location in the northern back bay of Chedabucto Bay and the fetch is generally less than 5 km; therefore, wave action would not be expected to contribute to physical abrasion of the oiled sediments. In the absence of wave energy, the natural removal of stranded oil is attributed to a combination of ice scour and/or abrasion, flocculation by suspended sediments, and biodegradation.

Ice action is a potential mechanism for oil weathering as this area experiences ice-foot formation and pack ice during most winters for periods up to several months. Processes associated with flocculation (Jahns *et al.*, 1991; Bragg and Yang, 1993) are also a potential mechanism for oil weathering as there are large amounts of suspended clay material due to the continuing natural erosion of glacial till at the shoreline. These suspended sediments frequently result in red discolouration of nearshore waters. Although biodegradation has been shown to be effective under certain circumstances (Hoff, 1992), it is not considered to be a primary mechanism for removing large quantities of stranded Bunker C oil by itself. However, in the presence of clay-oil flocculation processes, biodegradation can proceed as oil-eating bacteria oxidize the exposed unweathered surface of the residual oil.

4.4.2 Exposed Beach - Headland Environments of North and West Chedabucto Bay

10-9-92 West Point Michaud (PM-15), Oyster Point (SC-2, SC-3, and SC-4), Ragged Head (GY-21A), and Queensport (CA-28)

On exposed shorelines, occasional small patches of oil were found during the systematic ground survey. These scattered residues were generally very weathered, often mixed with sediment, and almost always associated with bedrock outcrops. Where present, these residues probably amounted to less than 1 L per segment.

4.4.3 Arichat Harbour (AR-13)

This beach segment is a sheltered, low wave-energy environment that was initially heavily oiled as a result of the *Arrow* spill, probably on several occasions. The beach is a thin (one or two clasts thick) layer of angular to subrounded pebble-cobble sediment mixed with granules and some sand. This layer of sediments rests on a cohesive clay (till) platform that is the eroded remnant of an unconsolidated, vegetated backshore cliff between 2 and 10 m in height.

The cleanup history of this segment between Lenoir Forge and the government jetty is important to understanding the current (1992) distribution and character of residual oil. The beach is very close to the spill site and was heavily and repeatedly oiled. On 30 April 1970, a bulldozer moved along the upper intertidal zone at the base of the till cliff. It pushed oiled sediments along the beach and at the same time cut into the base of the cliff, leaving a low (0.5-1 m) scarp. It finished pushing through to the west end of the segment on 2 May. To prevent creating unstable conditions as a result of undercutting the unconsolidated backshore till cliff, the intertidal sediments were pushed from the intertidal zone to the base of the cliff along the length of the segment on 2-3 May (Owens, 1970). No further mechanical sediment removal occurred.

The beach was visited on 13 September 1992 and the residual oil that was observed throughout the segment was characterized as a 2 m wide continuous band of hard "asphalt balls" (Appendix C, Plates 9 and 10) in the upper half of the intertidal zone. The balls were 3-10 cm in diameter and occurred with a frequency of four or five balls per square metre.

The oil that remained on the intertidal sediments after the activities of 2-3 May 1970 must have adhered to and mixed with the pebbles, granules, and sand to form aggregate "asphalt balls" that were shaped by small waves, probably less than 10 cm breaker height. These balls weathered and hardened and became resistant to physical abrasion and biochemical erosion. The wave energy at this site is insufficient to abrade these balls at anything but a very slow rate.

4.5 Results of Sample Analyses

The total hydrocarbon content of each sample, as determined by GC/FID analysis, is listed in Table 3. Both the amount of extractable material from and the petroleum hydrocarbon (PHC) content of the sample are listed. The former provides an indication of the total amount of oil-like material in the sample, whereas the latter is useful for determining if the extracted material has a petroleum origin or a natural origin. In addition, the content and ratios of the steranes and triterpanes are presented. These compounds are relatively immune to degradation and may be used as marker compounds for specific oils.

Only the original *Arrow* oil and sample 6 showed identifiable alkanes in the GC/FID analysis. All other samples had traces resembling that illustrated in Figure 10. Such traces contain very little information, making it difficult to identify the source. Analyses of the original oil and sample 6, on the other hand, provide much more information. Figure 11 is the trace of the original oil

Table 3 Quantitative Analytical Results

	Arrow	S-A	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
TSEM ($mg \cdot g^{-1}$)	830	100	3.0	190	120	73	5.2	500	76	300	35	1.0
PHC ($mg \cdot g^{-1}$)	420	33	0.45	51	51	33	2.2	230	32	13	9.0	0.18
Aliphatics (% of PHC)	56	72	73	74	72	60	51	64	62	64	62	50
Aromatics (% of PHC)	44	28	27	26	28	40	49	36	38	36	38	50
PHC/TSEM	0.51	0.33	0.15	0.27	0.43	0.45	0.42	0.46	0.42	0.04	0.26	0.18
PAH ($\mu g \cdot g^{-1}$ TSEM)	810	140	55	40	200	190	86	560	79	8.9	70	130
Ts/Tm	0.42	0.40	0.45	0.40	0.41	0.45	0.39	0.39	0.42	0.41	0.44	ND
C29 Hopane	100	170	19	120	150	150	130	150	170	170	100	25
C30 Hopane	110	210	23	140	170	160	140	160	200	190	120	35
C29/C30	0.91	0.81	0.83	0.86	0.88	0.94	0.93	0.94	0.85	0.89	0.83	0.71
C23 Triterpane	270	270	5	300	310	340	340	390	490	440	390	51
C24 Triterpane	130	130	8.1	150	140	170	170	190	240	210	190	46
C23/C24	2.08	2.08	0.62	2.00	2.21	2.00	2.00	2.05	2.04	2.10	2.05	1.11

Note: TSEM, total extractable material; PHC, petroleum hydrocarbon; PAH, polynuclear aromatic hydrocarbon; TS, 18a(H),21b(H)-22,29,30-trisnorneohopane; and TM, 17a(H),21b(H)-22,29,30-trisnorhopane). See Appendix B for additional explanation of these terms.

Source: Wang (1993).

analyzed in this study and, for comparison purposes, Figures 12 and 13 are digitized traces of analyses of earlier *Arrow* oil samples.

A careful comparison of these three traces of *Arrow* oil indicates that the 1993 and 1978 traces are very similar, with the 1993 sample appearing slightly more weathered (lower amounts of low-boiling alkanes and an unresolvable complex mixture shifted to heavier components). The 1985 sample, which came from a different source, appears less weathered than the 1993 and 1978

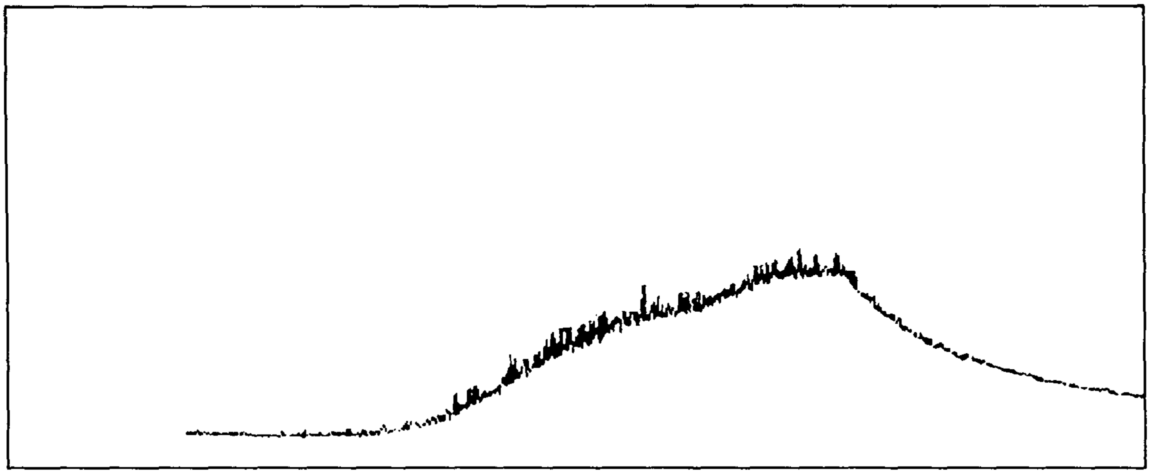

Figure 10 Degraded Hydrocarbon Trace (sample "A," Figure 7)

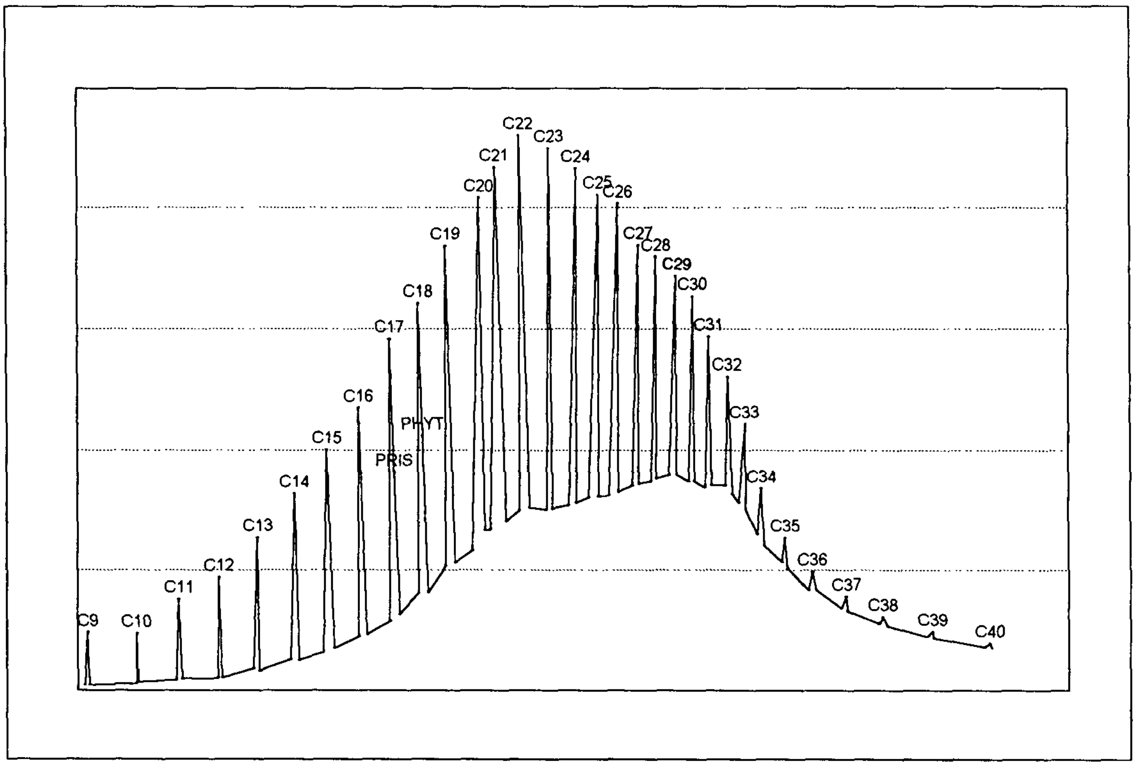

Figure 11 Original *Arrow* Oil Trace, 1993 Analysis

samples. In all cases, instrument responses could be different, so only general patterns may be considered.

Figure 14 is the trace for sample 6. It closely resembles the trace of the original *Arrow* oil sample analyzed at the same time and using the same technique.

A more specific comparison of the original *Arrow* oil sample and sample 6 can be made by examining the individual alkane patterns. Each identifiable component is determined separately, so the effect of the unresolvable complex mixture is removed. Figure 15 compares the patterns of the original *Arrow* oil sample (1993 STD) and sample 6 (S6)

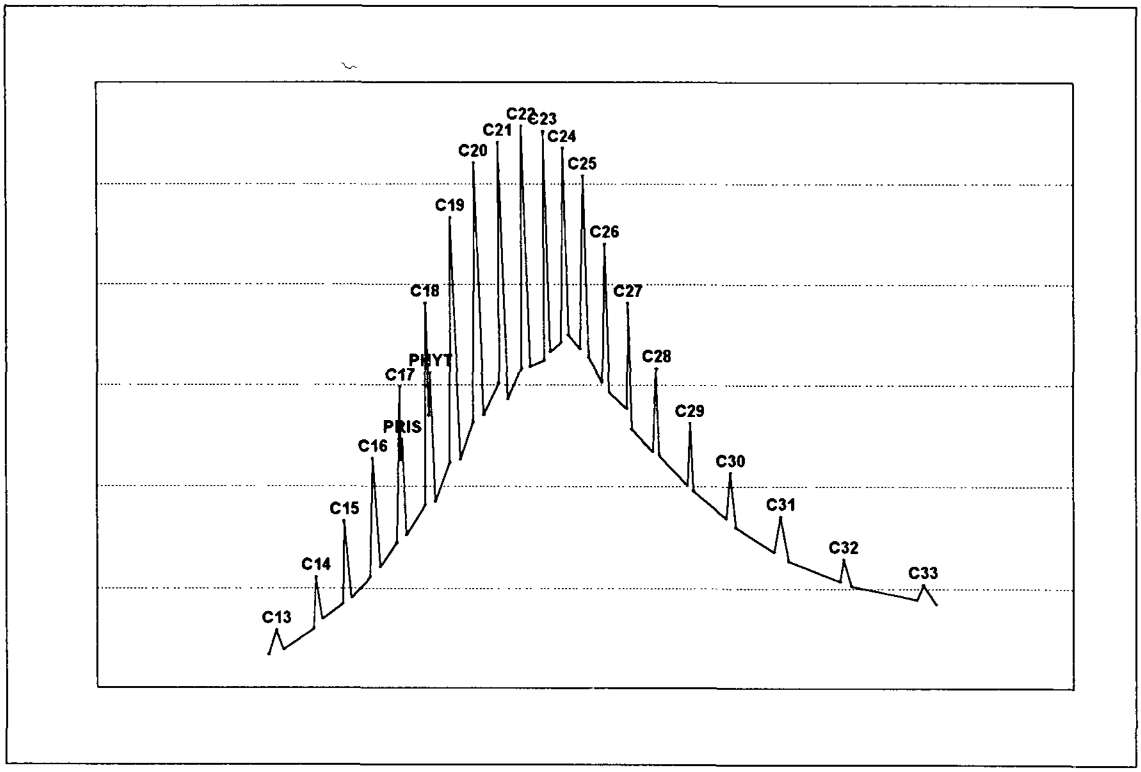

Figure 12 *Arrow* **Oil Trace, 1978 Analysis** (Keizer *et al.*, 1978)

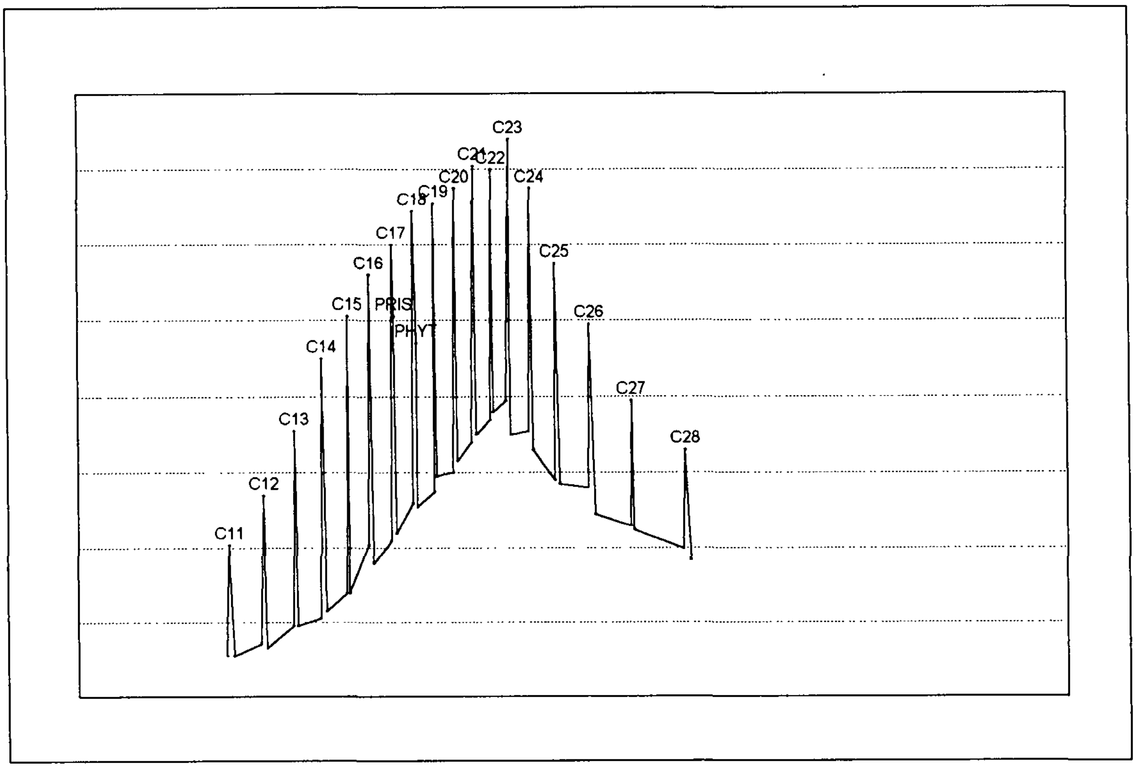

Figure 13 *Arrow* **Oil Trace, 1985 Analysis** (Humphrey and Vandermeulen, 1986)

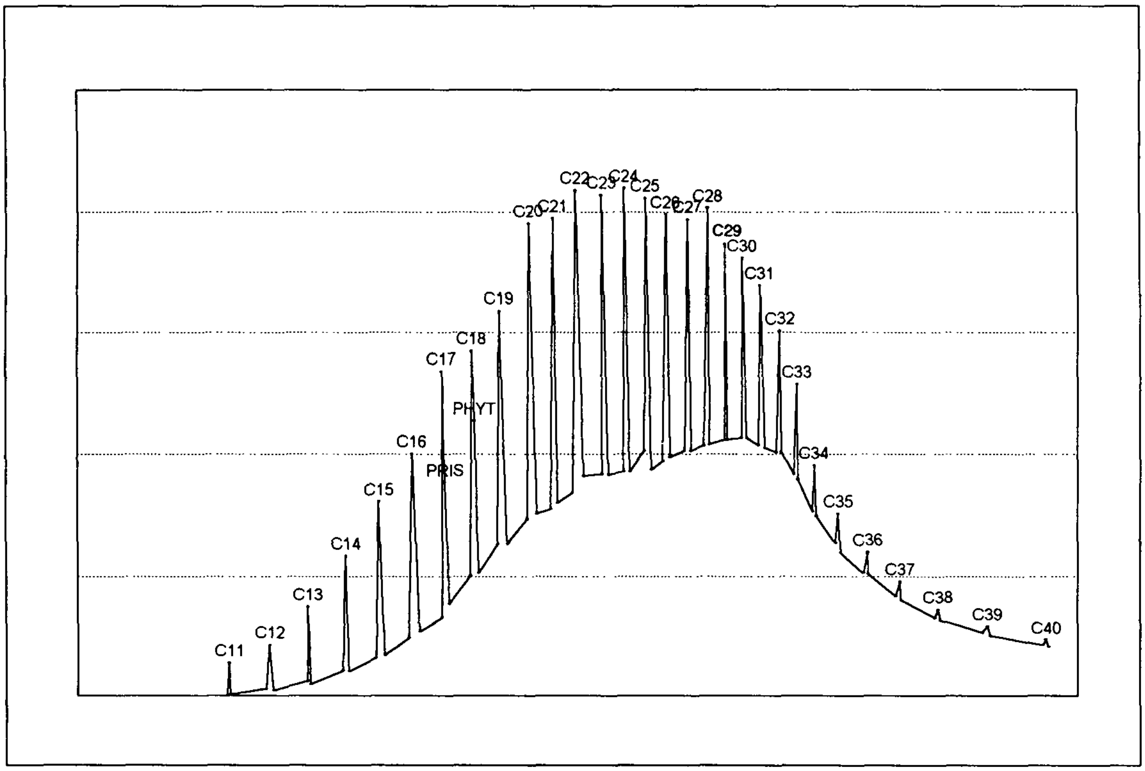

Figure 14 Sample 6 Trace (1992)

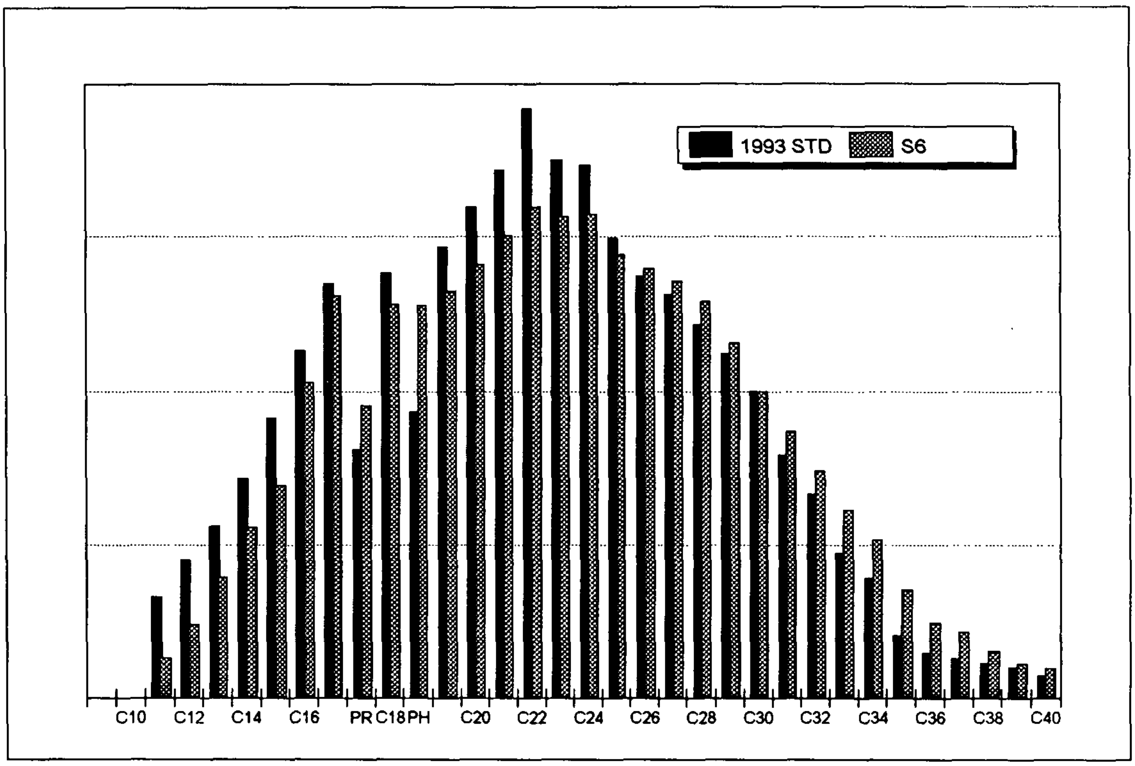

Figure 15 Relative Alkane Concentrations

based on the amount of alkane C30 (the straight-chain hydrocarbon with 30 carbon atoms). Alkane C30 was selected because it is at this point in the series that the relative changes go from loss to gain.

It can be seen that sample 6 has lower concentrations of low-boiling components and higher concentrations of high-boiling components. It is very similar to the original oil, which has been weathered further.

The other fraction from the extraction and cleanup is the aromatic fraction, F2. This fraction can be analyzed by GC/MS analysis to quantify the individual polynuclear aromatic hydrocarbons (PAHs) in the mixture. Those compounds selected for quantification are listed in Table 4. The relative concentrations of each compound in the samples are shown in Figure 16. For this analysis, the individual concentrations are compared with benzo(b or k)fluoranthene (O) = 1.

A more specific comparison of the PAH distribution between the original *Arrow* oil sample and sample 6 is shown in Figure 17. The relative reduction of the low-boiling compounds (A-D) and relative increase of high-boiling PAHs is consistent with weathering of different PAH compounds.

Detailed sediment sample analysis data are presented in Appendix B.

Table 4 Polynuclear Aromatic Hydrocarbon Compounds

	Compound		Compound
A	Naphthalene	L	1-methylphenanthrene
B	2-methylnaphthalene	M	Fluoranthene
C	1-methylnaphthalene	N	Pyrene
D	Biphenyl	O	Benzo(b or k)fluoranthene
E	2,6-dimethylnaphthalene	P	Benzo(e)pyrene
F	Acenaphthalene	Q	Benzo(a)pyrene
G	Acenaphthene	R	Perylene
H	2,3,5-trimethylnaphthalene	S	Indeno(1,2,3-cd)pyrene
I	Fluorene	T	Dibenz(a,h)anthracene
J	Phenanthrene	U	Benzo(ghi)perylene
K	Anthracene		

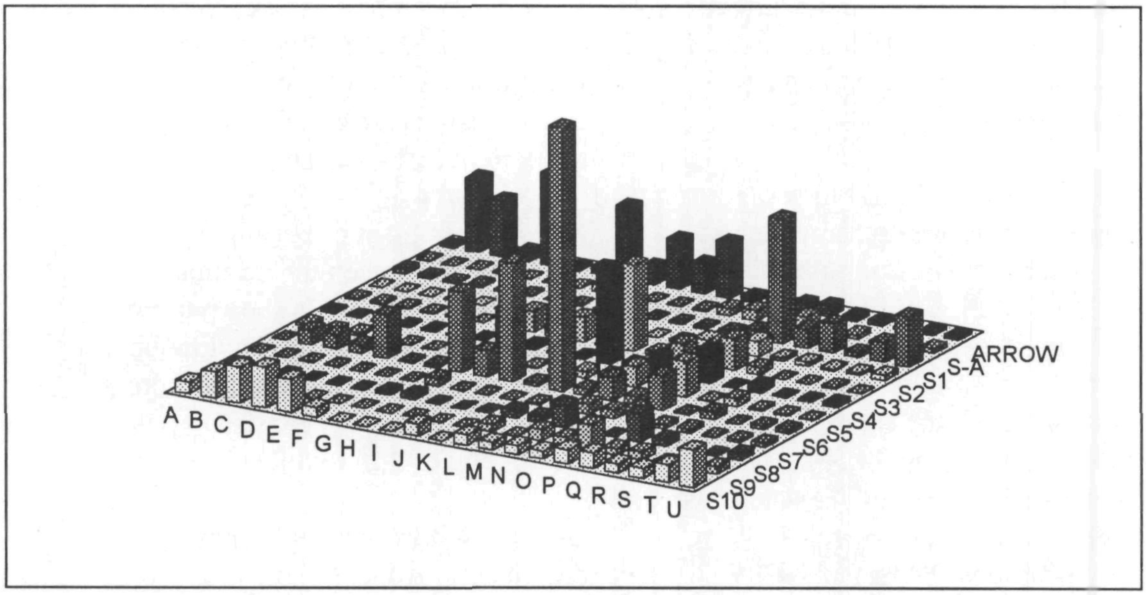

Figure 16 PAH Distribution

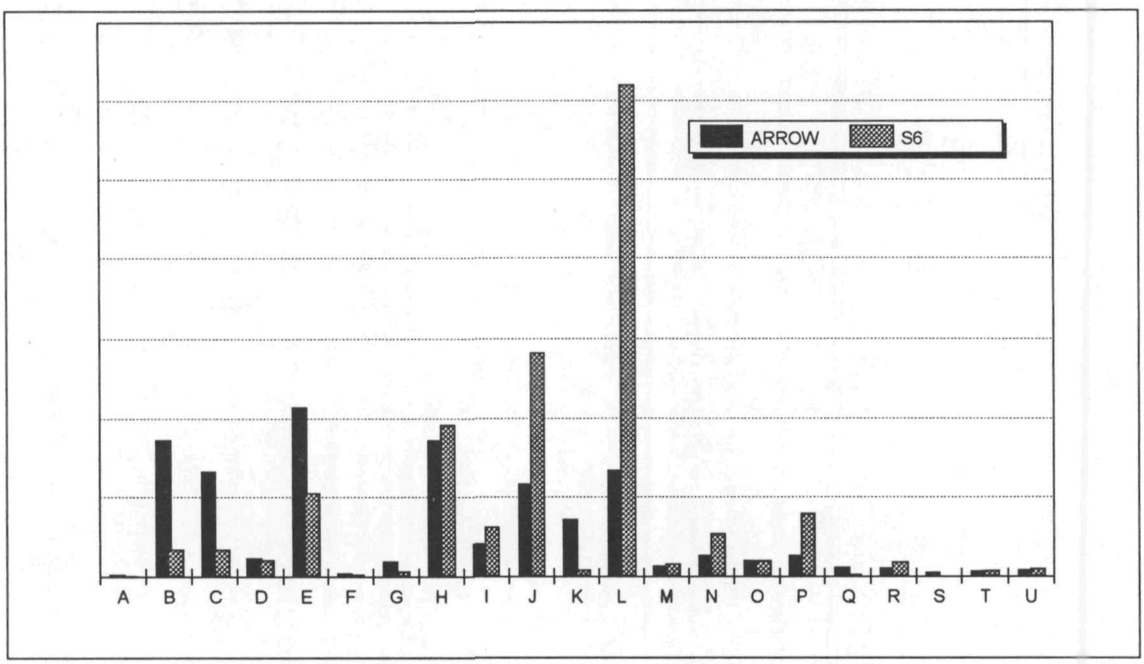

Figure 17 PAH Distribution, Original *Arrow* Oil vs. Sample 6 (1992)

Discussion

5.1 Distribution of Residual Shoreline Oil

5.1.1 Oiled Shoreline Lengths

The length of the coastline in the study area is estimated to be 305 km, of which 249 km were surveyed during the project. The total length of shoreline on which oil residues were observed, in one form or another, was 13.3 km. These residues were distributed in 129 of the 419 segments surveyed (Table 1), which represents a very scattered distribution throughout Chedabucto Bay. Although the percentage of oiled shoreline was relatively high (5.37% of the shoreline surveyed), more than 80% of the observed oil fell into the "light" and "very light" oil categories. Only 235 m of shoreline had "wide" (>6 m in width) oiled areas, and these were concentrated in four segments. This distinction between the 13.3 km of oiled shoreline and the length of shoreline with heavy oiling, based on either width/cover (0.87 km) of the oil band or width/cover plus oil thickness (1.3 km), illustrates the point developed by Sergy *et al.* (1991) that the "total length of oiled shoreline alone is a poor measure of the actual oiling conditions."

The segments from the 1992 survey that fell into the "heavy" and "moderate" oil categories were concentrated in the Black Duck Cove (BD) and Lennox Passage (LP) areas: 10 of the 24 segments that fell into the "heavy" oil category were located in these two areas (Table 5). In Black Duck Cove, four of the six segments fell into the "heavy" oil category. No "heavy" oil category observations were recorded in the Guysborough (GY) area, and neither "heavy" nor "moderate" oil categories were observed in the Petit de Grat Harbour (PT) or St. Peters Island (SI) areas.

The Haddock Harbour (HH) and Inhabitants Bay (IN) areas, which are adjacent to the *Arrow* spill site, are both sheltered, low wave-energy environments that were extensively oiled, probably on more than one occasion, in 1970 (Owens, 1970, 1971a). In 1992, only 7 of 36 and 11 of 75 segments surveyed, respectively, had documented oil (Table 5). In addition, Haddock Harbour had only two segments in the "heavy" oil category and Inhabitants Bay had one. Neither area had any segments in the "moderate" or "light" oil categories. The shoreline in these two areas, which totals approximately 70 km in length, was not cleaned during the 1970 response operations, indicating that natural recovery has been effective in the absence of high wave-energy levels.

Residual oil was found at only one location on an exposed, relatively high wave-energy beach: a very light stain on the south coast of Janvrin Island (JI-13).

The predominant features of the oil residues are a "narrow" band width (78% of the oiled shoreline length), "sporadic" or "patchy" distribution (87%), and "stain" thickness (73%).

Each of these features indicates a very light degree of oiling. Almost 60% of the coastline that has documented oil has an oil cover (width + distribution) that falls within

Table 5 Oil Cover and Category Summary

Segment Location*	Cover				Category				Total Oiled	Total No. of Segments
	Heavy	Moderate	Light	Very Light	Heavy	Moderate	Light	Very Light		
AR	-	2	4	4	2	2	4	2	10	30
BD	2	3	1	-	4	1	1	-	6	6
BR	-	1	-	5	1	-	-	5	6	20
CA	2	2	3	5	2	3	3	4	12	30
CI	-	2	3	2	1	2	3	1	7	14
GY	2	-	2	4	-	2	1	5	8	30
HH	1	1	1	4	2	-	-	5	7	36
IN	1	-	3	7	1	-	-	10	11	75
JI	2	-	1	5	2	-	1	5	8	26
LP	-	6	3	8	6	2	-	9	17	44
PD	-	2	2	1	1	2	2	-	5	18
PM	-	2	3	1	1	1	1	3	6	19
PT	-	-	1	9	-	-	-	10	10	26
SC	-	3	-	10	1	-	4	8	13	30
SI	-	-	2	1	-	-	-	3	3	15
Total	10	24	29	66	24	15	20	70	129	419

* Segment locations and an explanation of the abbreviations used are provided in Appendix A.

the "very light" category. Sixty-seven percent of the oiled shoreline falls within the "very light" oil category (width + distribution + thickness).

Heavy residual oiling conditions were observed on only 24 of the 419 segments surveyed. These heavy oil residues constitute only a small fraction of the total oiled shoreline, with a "wide" band width present on less than 2%, "continuous" oiling present on less than 1%, and "pooled" oil present on 2% of the oiled shoreline.

Only 6.5% of the coastline that has documented oil has an oil cover that falls within the "heavy" category and only 10% of the oiled shoreline falls within the "heavy" oil category.

5.1.2 Oil Distribution and Tidal Zone

All of the residual oil documented occurred in either the upper intertidal zone or the supratidal zone, with approximately half of the observations being made in each of the two zones.

5.1.3 Oil Distribution and Sediments

Virtually all of the oil residues were observed on coarse-sediment beaches. Only 20 of the 419 segments surveyed had no pebble, cobble, or boulder fraction present.

Oil on bedrock alone was observed in 11 of the 13 segments characterized by bedrock and no sediment, with seven of the observations falling within the "light" or "very light" oil categories.

Sand-sized sediment fractions were recorded in only 17 of the segments surveyed, but oil was observed on only 11 of these segments, with nine observations falling within the "heavy" oil category and 10 with an "asphalt pavement" oil character.

5.2 Amount and Character of Residual Shoreline Oil

No attempt has been made to estimate the volume of oil remaining on the shoreline of Chedabucto Bay based on the 1992 study, but from the survey data and field observations it is evident that the majority of the oil remaining is concentrated in a few localized areas; in particular, the Black Duck Cove and Lennox Passage areas.

Black Duck Cove contains by far the largest single concentration of oil, and historical, circumstantial, and now chemical evidence supports the contention that this oil came from the tanker *Arrow*. The oil was stranded over a short period of time by a slick that wandered from the spill site to the east and that affected a relatively small section of the coastline just outside, and to the south, of Chedabucto Bay. The oil was at sea possibly for several weeks, in which case it was weathered to some degree, before becoming stranded. Black Duck Cove is situated within an open-coast environment with predominantly bedrock shorelines and no nearby glacial till cliffs or rivers to supply fine-grained sediments to the shore zone. The oil that was stranded on the shore of Black Duck Lagoon, therefore, was not subject to the processes associated with clay-oil flocculation weathering. The formation of a weathered crust has prevented surface biological degradation and oxidation. Subsequent to the first series of site visits in 1970, mobile oil was removed by tidal pumping and flushing so that by the time of the 1973 survey, the oiled area and volume of residual oil had been reduced. A comparison of observations made and photographs taken during the 1973 survey and another survey carried out in 1982 indicates that the oiled area and volume of residual oil continued to decrease over this period, but at a slower rate. A similar comparison between the 1982 and 1992 surveys indicates that little additional change has occurred over this period.

The character of the oil residues in Black Duck Cove can be grouped broadly into two categories: oil that fills large voids between immobile, coarse-sediment particles, and an oil-sediment aggregate, usually referred to as an "asphalt pavement."

Oil remains as an asphalt pavement at the Rabbit Island site on the upper intertidal zone. This oil has a very weathered surface, which has protected the oil beneath from weathering and degradation processes. Patches of asphalt pavement found elsewhere in the study area are similar in character to that mapped on Rabbit Island. In each case, sediment and oil became mixed to form a pavement and the weathering and degradation normally associated with clay-oil flocculation and biological action did not occur for a number of possible reasons:

- Location on the beach: Oil was stranded on the beach during spring tides and a surface crust formed before the next period of inundation, thus precluding the flocculation process before a weathered crust formed.

- Absence of fines: In this region, fines are supplied to the shore zone through the erosion of glacial till deposits by river or coastal processes. In the Black Duck Cove area, however, there are no local glacial till deposits to supply the fines.

- Unavailability of fines: On open coasts, such as Lennox Passage, where oil was stranded but not removed by low-energy wave action, water exchange rates can be relatively high due to the tidal range and circulation pattern. Therefore, the concentration of fine sediments at the shore zone may be low.

Oil also remains on the beach in Arichat Harbour, where "asphalt balls" have been formed by the physical (bulldozer) mixing of oil and sediments (sand and granules). This occurred despite the presence of fine (clay) sediments, probably as a result of weathering induced by the mixing activity.

The formation of asphalt pavement has been described by Owens *et al.* (1986), who attribute this type of oil residue to a number of factors:

- the location of the oil between the mean high-water mark and spring high-water mark, or on the low-tide terrace;

- well-drained substrates, not finer than medium-grained sand;

- a low-angle slope;

- protection from strong physical forces;

- a groundwater table that is deeper than the depth of the stranded oil; and

- time for penetration and weathering.

This concept can be modified in light of data obtained following the *Exxon Valdez* spill in 1989 and during the present study. Probably the most important aspect that has been learned relates to understanding why asphalt pavements do not form when the conditions described above have been met. The concept of clay-oil flocculation has been developed as a result of studies associated with the *Exxon Valdez* spill and this biophysical process explains why asphalt pavements do not form in low wave-energy environments where one would otherwise expect them to form and persist.

The coarse-sediment and gravel beaches of Chedabucto Bay are similar in many respects to those of Prince William Sound, Alaska, the site of the *Exxon Valdez* spill, but no examples of the oiling conditions associated with beach armouring (Hayes *et al.*, 1991) were found during the present survey. Asphalt pavements were rarely formed in Prince William Sound due to flushing and manual removal of oil from the shoreline in 1989. In the few locations where they did occur, they were removed manually, for example, the 50 m long asphalt pavement found on Applegate Island.

Samples were collected from the detailed study sites to determine if the residual oil came from the *Arrow*. All of the samples, except one, were extensively chemically weathered. The gas chromatography traces showed an unresolvable complex mixture that contained little information of any value. Identification of the source of the oil, therefore, was not possible. The one sample that is probably *Arrow* oil has remained almost unweathered for 22 years. This oil was stranded on a cobble beach, filling the pore spaces between the cobbles. A weathered crust formed on the top and bottom of the pooled oil layer to seal it from biophysical weathering.

Although it is difficult to determine unequivocally if the samples collected contain oil from the *Arrow*, the following should be considered:

- The "original" *Arrow* oil sample used for comparative purposes is probably weathered relative to the oil that was spilled, given the storage method used and the length of time the oil has been stored.

- Sample 6 is probably from the *Arrow*. It is only slightly more weathered than the "original" oil that has been stored in a can for 22 years.

- It is not possible to attribute the hydrocarbon in the other samples to the *Arrow* spill.

The last point must be qualified. As oil weathers and degrades, the components used by analysts to identify the oil with respect to type and source disappear. An old asphalt may, in fact, have no identifiable components present, but may clearly be from a specific source as proven by its observed presence over time. The last remnants of an oil may be resins and asphaltenes, which are not extractable by the analytical solvent, and would not be recognizable even if they could be extracted.

The approach used in the interpretation of data in the present study was to prove that the oil observed in samples was not from the *Arrow*. This hypothesis was selected because to prove that the oil observed in samples was from the *Arrow* would have required examining a large number of Bunker C oils of varying ages to determine how *Arrow* oil differed from other Bunker C oils.

The final estimation of oil character for each sample is presented in Table 6.

We failed to prove that hypothesis in the case of sample 6 from the pooled oil on the lee side of Black Duck Spit. The existence after more than 22 years in pools on a beach of what is apparently original *Arrow* oil, with characteristics similar to the same oil stored in a sealed container, is astounding.

The results of the analyses of asphalt pavement residues derived from what we consider to be *Arrow* oil based on circumstantial evidence indicate that present

Table 6 Sample Character

	S-A	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Arrow ?	N ?	N	N	N ?	N ?	N ?	Y	N ?	N ?	N ?	N

techniques (gas chromatography) are rarely capable of characterizing very old oil or providing meaningful data on weathering.

5.3 *Natural Cleaning of Oiled Shorelines*

Observations made immediately following the *Arrow* spill provided a basic understanding of the behaviour of oil on coarse-sediment beaches (Drapeau, 1973; Owens, 1973). These ideas were refined on the basis of data gathered from other spills (particularly the *Urquiola* and *Metula* incidents) and from the Baffin Island Oil Spill (BIOS) experiment (Owens, 1977, 1978, 1985; Blount, 1978; Gundlach *et al.*, 1978; Owens *et al.*, 1986; Gundlach, 1987; Humphrey *et al.*, 1990, 1991, 1992). This initial work clearly defined the role of direct and indirect wave action in the physical removal of oil from shorelines by wave and/or tidal action. Observations on the character of stranded oil on coarse-sediment beaches and on rates of removal were improved as a result of detailed studies following the *Exxon Valdez* incident (Hayes *et al.*, 1991; Owens, 1991). These studies, combined with the earlier work, provide information on oil loading and rates of removal, but not on the range of biological, chemical, and physical processes involved in weathering and degradation.

No major advances in understanding the processes by which oil is cleaned or weathered naturally on coarse-sediment beaches emerged until laboratory studies on oiled coarse sediments collected from beaches affected by the *Exxon Valdez* spill provided insight into the relationship between clay (or mineral) particles and oil (Bragg and Yang, 1993). This work led to further understanding the interactive relationship between the clay-oil flocculation process and biodegradation (Bragg *et al.*, 1993) and to improved interpretations of the relationships between shoreline treatment and natural cleaning related to the *Exxon Valdez* spill (Jahns *et al.*, 1991; Neff *et al.*, 1993). The application of clay-oil flocculation is important to understanding the way in which oil was removed from the heavily oiled and sheltered, low wave-energy environments of Chedabucto Bay, where fine sediments are available to foster the process.

5.3.1 *Residual Oil and Natural Cleaning in Chedabucto Bay*

The majority of the segments that have documented oil residues occur in low wave-energy environments and the few sites with heavy oiling conditions probably account for over 90% of the residual oil by volume. However, a key finding of this study is that many of the originally heavily oiled shorelines in low wave-energy environments are now free of oil. It is significant that near the spill location, oil was found on only 18 of the 111 segments in the sheltered Inhabitants Bay and Haddock Harbour areas. These initially heavily oiled coastlines received little cleanup treatment in

1970. Natural cleaning on these low wave-energy shorelines cannot reasonably be attributed to physical abrasion. These waters have considerable amounts of fine sediments in suspension and the process of clay-oil flocculation is believed to have prevented the formation of a hard weathered surface on the stranded oil. This process allowed continuous surface weathering and removal to proceed through the biophysical combination of flocculation and biodegradation (oxidation).

The Haddock Harbour (HH) and Inhabitants Bay (IB) areas are both sheltered, low wave-energy environments that were extensively oiled in 1970 but were not cleaned so that natural recovery was effective in the absence of high wave-energy levels. Wave-energy levels are low in this sheltered location in the northern back bay of Chedabucto Bay and the fetch is generally less than 5 km; therefore, wave action would not be expected to contribute to physical abrasion of the oiled sediments. In the absence of wave energy, the natural removal of stranded oil is attributed to a combination of ice scour and/or abrasion, flocculation by suspended sediments, and biodegradation.

Ice action is a potential mechanism for oil weathering as this area experiences ice-foot formation and pack ice during most winters for periods up to several months. However, the role of ice is not considered to be significant because observations over the years have not found evidence of ice push or ice rafting on a large scale. Ice probably forms and melts *in situ*, with little or no physical effect, and protects the intertidal-zone sediments from the grounding of floating pack ice.

Processes associated with flocculation (Bragg and Yang, 1993; Neff *et al.*, 1993) are also a potential mechanism for oil weathering as there are large amounts of suspended clay material due to the continuing natural erosion of glacial till at the shoreline. In many locations in this area, the shorelines are characterized by a thin layer of beach sediment resting on a clay till platform produced by the erosion of glacial deposits. The erosion of the till by rain, waves, or currents provides a large local source of clay material directly to the littoral zone. These clays are frequently observed as suspended sediments that result in red discolouration of the nearshore waters. This flocculation process has not been effective in areas with more wave action and better circulation (e.g., Lennox Passage) and where fines are not present in the nearshore waters (Black Duck Cove area). Hence, the stranded oil has persisted in these areas.

Although biodegradation has been shown to be effective under certain circumstances (Hoff, 1992), it is not considered to be a primary mechanism for removing large quantities of stranded Bunker C oil by itself. However, in the presence of clay-oil flocculation processes, biodegradation can proceed as oil-eating bacteria oxidize the exposed unweathered surface of the residual oil (Bragg *et al.*, 1993). The potential rate of biodegradation of a bunker fuel is lower than that of lighter oils due to its higher content of resistant hydrocarbons.

The presence and absence of oil residues on the coastline of Chedabucto Bay, 22 years after the *Arrow* spill, can be explained by physical weathering and biological degradation processes. The direct effects of physical abrasion and hydraulic pressures resulting from wave action on exposed shorelines provide an effective and rapid mechanism for removing oil from exposed high and moderately high wave-energy environments. The relative importance of physical and biological processes varies, however, in areas where wave action is not the dominant removal process. Thus, oil has been removed from some sheltered, low wave-energy environments, but remains in substantial quantities in other sheltered locations.

5.3.2 Comparison of Black Duck Cove and Prince William Sound

Many similarities exist between the coastal environments of Prince William Sound, Alaska, and Chedabucto Bay, Nova Scotia. The shore-zone character is dominated by coarse-sediment beaches or bedrock outcrops and both areas have mixed sheltered and open, but not very high wave-energy, shorelines.

Rates of removal of oil from the shoreline of Prince William Sound were greater than reported rates from similar environments (Humphrey *et al.*, 1990). The 1989 cleanup, by low-pressure washing and flushing, of the pebble-cobble beaches of Prince William Sound that were oiled as a result of the *Exxon Valdez* spill removed virtually all of the free or mobile oil from within the pore spaces of the surface sediments (Owens, 1991). This allowed natural weathering (cleaning) processes to effectively remove the majority of the remaining oil (Jahns *et al.*, 1991). Subsequent cleanup activities in 1990 and 1991 in Prince William Sound focussed on the removal of predominantly residual subsurface oil that had not been flushed during the 1989 cleanup program or by subsequent natural weathering. Thus, by 1992 only 0.18 km of the original 487 km of heavily oiled shoreline had significant amounts of residual oil (Neff *et al.*, 1993).

The initial oiling conditions in Black Duck Cove in segments BD-1 and BD-6 were similar to those at some of the study sites in Prince William Sound (Owens, 1991). If the oil had not been washed and flushed from the sediments, it is conceivable that many low or medium wave-energy shorelines of Prince William Sound would continue to be oiled with the same amounts of oil and similar oiling characteristics as those persisting in Black Duck Cove. Similarly, if segments BD-1 and BD-6 had been washed and flushed in 1970, the oil that fills the pores between the cobble sediments and the residual asphalt pavements would probably not be present in Black Duck Cove today.

5.3.3 Long-term Effects

This study did not address the ecological implications of the presence of residual oil on the shores of Chedabucto Bay. However, the conclusion from a recent study of the 1969 West Falmouth oil spill (Massachusetts) by Teal *et al.* (1992) has direct relevance to the results of this study.

"The marsh is now visually no different from other healthy New England salt marshes as long as the oiled area is undisturbed. For the first 5-6 years after the spill, there was no doubt the oil was adversely affecting the marsh ecosystem. Twenty years later, the residual effects are extremely small. However, an animal burrowing into the still contaminated sediments would be exposed to oil concentrations that caused significant biological effects in the past."

This comment could equally apply to certain sections of Chedabucto Bay, such as the low-tide flats in Black Duck Cove and a few of the areas around Janvrin Island and Lennox Passage. Although oil residues remain in a number of locations and on biologically productive sections of the coast of Chedabucto Bay, the continuing ecological impacts are very limited in scale.

5.3.4 Chedabucto Bay as the Location of Long-term Study Sites

The Rabbit Island, Arichat Harbour, and Black Duck Cove sites provide valuable information on the fate and persistence of stranded oil in mid-latitude environments that helps in understanding natural recovery processes that follow shoreline oiling. This information and understanding can then be used to evaluate the likely fate and persistence of stranded oil resulting from future spills.

The sites in Chedabucto Bay are of considerable scientific value for continued long-term monitoring, constituting one of only a handful of locations in the world where:

- a reasonable data base exists from the original incident;
- the oil has persisted in observable quantities; and
- long-term fate, effects, and persistence studies can be carried out without threat from other human activities.

Only two similar locations exist in mid- or high-latitude environments: the BIOS experimental site on Baffin Island and the shores of the Strait of Magellan, which were oiled as a result of the *Metula* spill.

Section 6

Conclusions

6.1 Ground Survey

The ground survey showed the value of using a systematic approach and standard terms and definitions.

6.2 Site Surveys

The value of the videotape record as a means of documenting a phenomenon that is both complex and highly spatially variable cannot be overemphasized. The sketches drawn from the surveyed profile data present only a small fraction of the information that was gained by direct observation and the audiovisual commentary. Months, and even years, after a survey it is possible to view tapes and listen to a commentary that contain a much greater volume of information than can be obtained from a combination of mapping, sketching, notes, or photographs.

The distribution of surface oil at the three mapping sites is characterized by complex patterns. Owens and Teal (1990) pointed out that single-line transects are inadequate for describing/recording surface oil cover. Surveys that have one transect per unit or segment are adequate only for uniform oiling conditions on uniform substrates, but this is not common on mixed shorelines, such as those oiled as a result of the *Arrow* and *Exxon Valdez* spills.

6.3 Summary

1) Oil is present on 13.3 km of shoreline in Chedabucto Bay. Heavy oiling is restricted to 1.3 km, concentrated primarily in the Black Duck Cove and Lennox Passage areas. Some of this residual oil has been identified as coming from the *Arrow* based on circumstantial evidence; however, chemical analysis identifies one sample from Black Duck Cove as probably being *Arrow* oil.

2) Relatively little cleanup was carried out in 1970; only about 50 km of the more than 300 km that were oiled were treated. Natural weathering accounts for the removal of the majority of the oil from Chedabucto Bay. Where oil remains, it occurs as a thin stain on bedrock or coarse sediments (pebbles, cobbles, and boulders) or as a resistant oil-sediment asphalt-like mixture.

3) Areas in the low wave-energy environments of Haddock Harbour and Inhabitants Bay that were observed to be heavily oiled in the spring of 1970, and were not cleaned, are now virtually free of oil. These areas have a plentiful supply of fine-grained suspended sediments that may have contributed to clay-oil flocculation weathering as described recently for Prince William Sound, Alaska.

4) The most heavily oiled area is in Black Duck Lagoon, where asphalt pavement and pooled interstitial oil remain in three distinct areas of predominantly coarse sediments (cobbles and pebbles).

5) Resistant "asphalt balls" remain on the beaches of Arichat Harbour, where

oiled sediments were reworked by the action of a bulldozer.

6) The presence or absence of oil residues in Chedabucto Bay following the *Arrow* spill can be explained in terms of the physical, biophysical, and biological processes that act upon stranded oil. Oil remains on the shore when it is:

- outside the zone of physical wave action (including sheltered lagoons) required to move sediments and/or abrade the oil;
- in areas of nearshore mixing where fine sediments are not present to weather the oil through biophysical processes (clay-oil flocculation and biodegradation); and
- weathered on the surface, forming a crust that retards change and protects the oil beneath from those same weathering and oceanographic processes.

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Appendix A

Shoreline Oiling Description Terminology and Ground Survey Data

This appendix describes the terminology used on the Shoreline Oiling Summary (SOS) forms and accompanying sketches that were completed in the field (see Figures 2 and 3 in the text). The terms and definitions used are from Environment Canada (1992). Also included in this appendix is a summary, in tabular form, of the ground survey data collected.

Area

The survey region was subdivided into the following 15 areas (Figure A.1), each of which was assigned a prefix:

AR	Arichat
BD	Black Duck
BR	Bay of Rocks
CA	Canso
CI	Crichton Island
GY	Guysborough
HH	Haddock Harbour
IN	Inhabitants Bay
JI	Janvrin Island
LP	Lennox Passage
PD	Petit-de-Grat Island
PM	Point Michaud
PT	Petit-de-Grat Harbour/Inlet
SC	Strait of Canso
SI	St. Peters Island

Segment/Location

Within each area, segments were numbered sequentially. A total of 505 segments were defined. If oil was observed at more than one location within a segment, each location was identified by a number following the decimal point of the segment number, e.g., within segment BD-1, two separate oiled locations were identified as BD-1.0 and BD-1.1 (Table A.1, see p. 56). (On the field sketch shown in Figure 3 of the text, and on the corresponding Shoreline Oiling Summary form, these locations were identified as "A" and "B," respectively, in segment BD-1.)

Length

The approximate length (in metres) of a segment was obtained from topographic maps.

Length Surveyed

The actual length (in metres) of the segment surveyed.

Oiled Length

The length (in metres) of the oiled section(s) within a segment. In the example provided in Figure 2 of the text, the oiled length is 50 m.

Oiled Width

The width (in metres) of the oiled section(s) within a segment. In the example provided in Figure 2 of the text, the oiled width is 10 m. Oiled width represents the average width of the oiled area or band in the shoreline segment. If multiple bands or areas occur across the shore, the width represents the sum of the individual widths. For summary purposes, width data were grouped as follows:

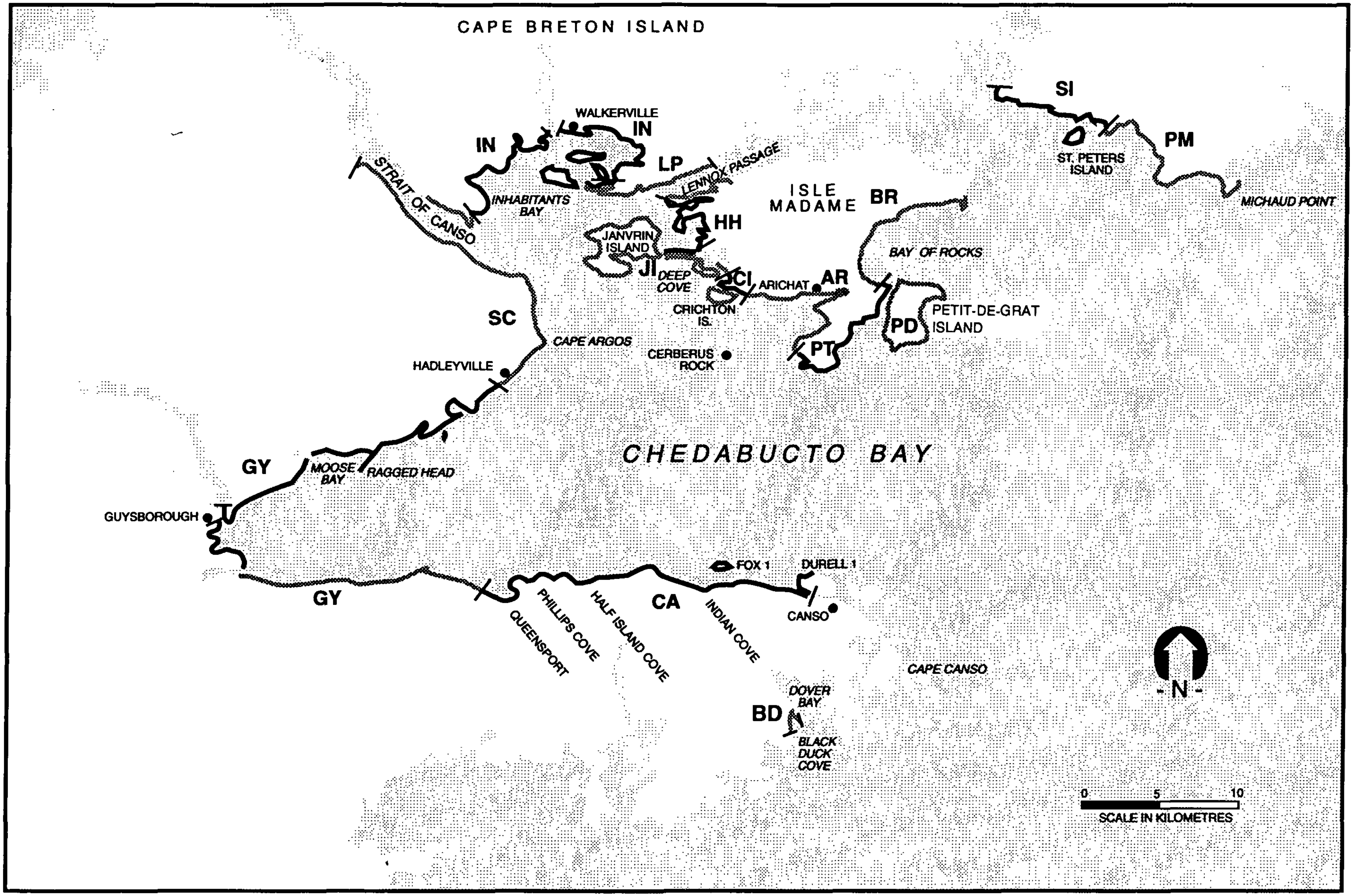


Figure A.1 Location of Segment Areas Within the Study Region

Wide (W)	>6 m
Medium (M)	>3 m and ≤6 m
Narrow (N)	>0.5 m and ≤3 m
Very Narrow (V)	≤0.5 m

Distribution

The observed surface distribution of oil expressed as the percentage of the total oiled area or band covered by oil. In the event of multiple bands, distribution refers to the term that best represents the oil conditions for the segment. An illustration used in the field to assist in estimating the oil distribution is presented in Figure A.2. For summary purposes, distribution data were grouped as follows:

Trace (T)	<1%
Sporadic (S)	1-10%
Patchy (P)	11-50%
Broken (B)	51-90%
Continuous (C)	91-100%

In the example provided in Figure 2 of the text, the distribution (DIST) is given as broken (B). On the accompanying sketch map presented in Figure 3 of the text, the distribution for segment BD-6 is given as 70%.

Thickness

The average or dominant oil thickness within an oiled band or area.

Pooled/thick oil (PO)	>1.0 cm
Cover (CV)	>0.1 cm and ≤1.0 cm
Coat (CT)	>0.01 cm and ≤0.1 cm. Can be scratched off coarse sediments or rock with fingernail
Stain (ST)	≤0.01 cm. Cannot easily be scratched off coarse sediments or rock
Film (FL)	Transparent or translucent film or sheen

In the example provided in Figure 2 of the text, the thickness is given as PO.

Character

The physical appearance of the observed oil that best describes the oil residue.

Fresh (FR): Unweathered, low-viscosity oil

Mousse (MS): Emulsified oil (oil and water mixture) existing as patches or accumulations, or within interstitial spaces

Tar balls or mousse patties (TB): Discrete balls or patties on a beach or adhered to rock or coarse sediment on the shoreline. Diameters of tar balls and mousse patties are generally <0.1 m and ≥0.1 m and ≤1.0 m respectively

Tar (TC): Weathered coat or cover (see "Thickness") of tarry, almost solid consistency

Surface oil residue (SR): Noncohesive, oiled surface sediments as continuous patches or in coarse-sediment interstices

Asphalt pavement (AP): Cohesive mixture of oil and sediments

No oil observed (NO)

Debris (DB): Logs (/LG), vegetation (/VG), rubbish (/RB), or general debris. Includes spill-response items (sorbents, boom, snares, etc.)

In the example provided in Figure 2 of the text, the character is given as AP.

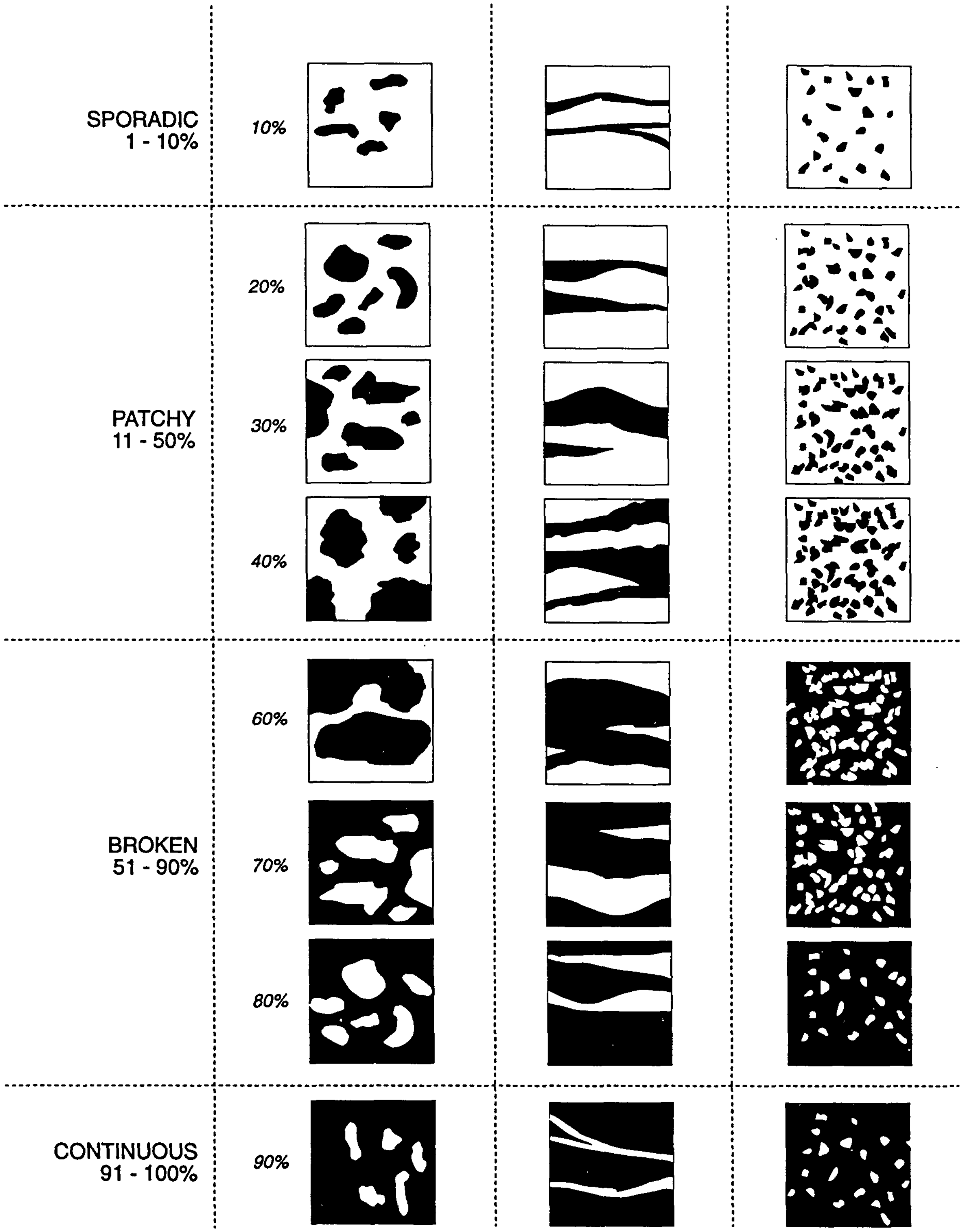


Figure A.2 Guide for Estimating Oil Distribution

Oil Cover

A four-term rating system has been developed to describe surface oil conditions: heavy (H), moderate (M), light (L), and very light (VL). At this first level of detail, oil width and oil distribution are combined in the Surface Oil Cover Matrix to provide a summary index of the degree of oiling.

	Width of Oiled Areas			
Oil Distribution	Wide >6 m	Medium >3 - 6 m	Narrow >0.5 - 3 m	Very Narrow ≤0.5 m
Trace <1%	Very light	Very light	Very light	Very light
Sporadic 1-10%	Light	Light	Very light	Very light
Patchy 11-50%	Moderate	Moderate	Light	Very light
Broken 51-90%	Heavy	Heavy	Moderate	Light
Continuous 91-100%	Heavy	Heavy	Moderate	Light

Oil Category

Oil thickness is combined with the Surface Oil Cover Matrix in the Surface Oil Categorization Matrix to provide a second level of detail to summarize the degree of oiling.

	Initial Categorization of Surface Oil			
Average Thickness	Heavy	Moderate	Light	Very Light
Thick or pooled >1 cm	Heavy	Heavy	Moderate	Light
Cover >0.1 - 1.0 cm	Heavy	Heavy	Moderate	Light
Coat >0.01 - 0.1 cm	Moderate	Moderate	Light	Very light
Stain/film ≤0.01 cm	Light	Light	Very light	Very light

Wave Exposure

Wave exposure is estimated as a function of the fetch window and distance within a segment, derived from the Wave Exposure Matrix.

Fetch	Fetch Window (degrees)			
Distance (km)	<45	45-120	121-180	>180
<5	Low	Low	Low	Low
5-10	Low	Medium	Medium	Medium
10-50	Medium	Medium	High	High
>50	High	High	High	High

Slope

The shore slope that generally characterizes the segment or location.

Low (L)	A shore with a slope of 30° or less
Medium (M)	A shore with a slope between 31° and 60°
High (H)	A shore with a slope between 61° and 90°
Vertical (V)	A vertical or near-vertical shoreline (>90°)

Zone

The tidal zone within which the oil residue is located.

Supratidal zone (S) The area above the mean high tide that occasionally experiences wave activity. Also known as the splash zone

Upper intertidal zone (U): Upper one-third of the intertidal zone

Mid-intertidal zone (M): Middle one-third of the intertidal zone

Lower intertidal zone (L): Lower one-third of the intertidal zone

Sediments

The predominant type(s) of substrate in a segment or location.

Bedrock outcrops (R)	
Boulder (B)	>256 mm diameter
Cobble (C)	64-256 mm diameter
Pebble (P)	4-64 mm diameter
Granule (G)	2-4 mm diameter
Sand (S)	0.06-2 mm diameter
Mud (M)	<0.06 mm diameter

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
AR	1.0	300	300	0	0	0	-	NO	-	-				
AR	2.0	200	200	0	0	0	-	NO	-	-				
AR	3.0	300	300	0	0	0	-	NO	-	-				
AR	4.0	250	250	0	0	0	-	NO	-	-				
AR	5.0	350	350	0	0	0	-	NO	-	-				
AR	6.0	400	400	0	0	0	-	NO	-	-				
AR	7.0	300	300	0	0	0	-	NO	-	-				
AR	8.0	800	800	50	1	20	ST	SR	L	VL	Low	M	U	R,B
AR	8.1	-	-	10	1.5	15	CV	AP	L	M	Low	L	S	B,C
AR	9.0	1200	1200	20	1	15	ST	SR	L	VL	Low	L	S	B,C,P
AR	9.1	-	-	20	1	5	ST	SR	VL	VL	Low	L	S	B,C,P
AR	9.2	-	-	15	2	5	CV	AP	VL	L	Low	M	S	B,C,P
AR	10.0	400	400	25	1	20	ST	SR	L	VL	Low	L	S	B,C,P
AR	11.0	800	800	25	1	5	ST	SR	VL	VL	Low	L	S	B,C,P
AR	11.1	-	-	20	1	5	ST	SR	VL	VL	Low	L	S	B,C,P
AR	12.0	1400	1400	0	0	0	-	NO	-	-				
AR	13.0	800	800	50	2	60	CV	AP	M	H	Low	L	S	C,P
AR	14.0	600	600	0	0	0	-	NO	-	-				
AR	15.0	800	800	0	0	0	-	NO	-	-				
AR	16.0	700	700	0	0	0	-	NO	-	-				
AR	17.0	300	300	0	0	0	-	NO	-	-				
AR	18.0	700	700	0	0	0	-	NO	-	-	Low	L	S	B,C,P
AR	19.0	300	300	75	1.5	30	CV	AP	L	M	Low	M	S	R,C,P
AR	19.1	-	-	0	0	0	-	NO	-	-	Low	M	S	C,P
AR	20.0	500	500	30	1	5	CV	AP	VL	L	Low	L	S	R,C,P
AR	21.0	600	0											
AR	22.0	800	0											
AR	23.0	1100	1100	30	1	15	CV	AP	L	M	Low	L	S	C,P
AR	23.1	-	-	2	0.75	80	CV	AP	M	H	Low	L	S	C,P
AR	23.2	-	-	30	1.5	20	ST	SR	L	VL	Low	M	S	B,C
AR	23.3	-	-	25	1	5	CV	AP	VL	L	Low	M	S	B,C

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
AR	24.0	700	700	0	0	0	-	NO	-	-				
AR	25.0	600	600	10	1	5	CV	AP	VL	L	Low	L	S	B,C,P
AR	26.0	700	700	20	2	5	ST	SR	VL	VL	Low	L	S	B,C,P
AR	26.1	-	-	10	1.5	5	CV	AP	VL	L	Low	L	S	B,C,P
AR	27.0	500	500	0	0	0	-	NO	-	-				
AR	28.0	250	0											
AR	29.0	400	0											
AR	30.0	800	0											
BD	1.0	400	400	150	2	80	PO	AP	M	H	Low	L	S,U	B,C
BD	1.1	-	-	100	2	25	CT	SR	L	L	Low	L	S	B,C
BD	2.0	500	500	75	2	70	PO	AP	M	H	Low	L	U	S,M
BD	3.0	200	200	150	10	40	CT	SR	M	M	Low	L	U	B,C
BD	4.0	600	600	100	1	25	CT	SR	L	L	Low	L	S	B,C
BD	5.0	500	500	20	5	60	CV	SR	H	H	Low	-	-	G,S
BD	6.0	400	400	50	10	70	PO	AP	H	H	Low	L	S,U	B,C,P
BR	1.0	300	0											
BR	2.0	1100	1100	0	0	0	-	NO	-	-				
BR	3.0	300	300	0	0	0	-	NO	-	-				
BR	4.0	800	800	30	1.5	5	ST	SR	VL	VL	Med	L	U	B,C,P
BR	5.0	600	600	25	1	5	ST	SR	VL	VL	Med	L	U	B,C,P
BR	6.0	400	400	15	1	5	ST	SR	VL	VL	Med	L	S	B,C,P
BR	7.0	1600	1000	0	0	0	-	NO	-	-				
BR	8.0	600	0											
BR	9.0	1000	0											
BR	10.0	400	0											
BR	11.0	1000	1000	0	0	0	-	NO	-	-				
BR	12.0	250	250	80	2	5	ST	SR	VL	VL	Med	M	S	R,B,C
BR	13.0	600	600	0	0	0	-	NO	-	-				
BR	13.11	150	150	40	2	70	CV	AP	M	H	Low	L	U	S,M
BR	13.12	-	-	0	0	0	-	NO	-	-				
BR	14.0	700	700	75	1	5	ST	SR	VL	VL	Med	L	U	R,B

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
BR	15.0	800	800	0	0	0	-	NO	-	-				
BR	16.0	1100	1100	0	0	0	-	NO	-	-				
BR	17.0	500	500	0	0	0	-	NO	-	-				
BR	18.0	700	700	0	0	0	-	NO	-	-				
BR	19.0	400	400	0	0	0	-	NO	-	-				
BR	20.0	300	0											
CA	1.0	1000	800	2	1	10	CV	SR	VL	L	Low	L	S	R
CA	2.0	500	0											
CA	3.0	600	0											
CA	4.0	500	0											
CA	5.0	1000	900	10	2	60	CV	AP	M	H	Low	L	S	R,B
CA	5.1	-	-	150	1	30	CT	SR	L	L	Low	L	S	R,B
CA	6.0	4000	2500	0	0	0	-	NO	-	-				
CA	7.0	900	900	0	0	0	-	NO	-	-				
CA	8.0	500	0											
CA	9.0	800	0											
CA	10.0	200	0											
CA	11.0	350	350	2.5	2	100	CV	AP	M	H	Med	M	S	R
CA	11.1	-	-	3	4	80	CV	AP	H	H	Med	M	S	R
CA	11.2	-	-	5	2	40	CT	SR	L	L	Med	M	S	R,B
CA	12.0	250	250	0	0	0	-	NO	-	-				
CA	13.0	1000	1000	5	7	60	CT	SR	H	M	Med	M	S	R
CA	14.0	600	600	0	0	0	-	NO	-	-				
CA	15.0	1300	1300	0	0	0	-	NO	-	-				
CA	16.0	1600	1600	300	0.5	15	CT	AP	VL	VL	Med	M	S	R
CA	17.0	500	500	0	0	0	-	NO	-	-				
CA	17.1	400	400	10	3	30	CT	AP	L	L	Med	-	-	R
CA	18.0	800	400	20	2	5	CT	SR	VL	VL	Med	H	S	R
CA	19.0	700	700	15	2	20	CT	AP	L	L	Med	M	U	R,B,C
CA	19.1	-	-	10	2	30	CT	AP	L	L	Med	M	U	R,B,C
CA	20.0	1100	1100	0	0	0	-	NO	-	-				

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
CA	21.0	1200	900	50	2	5	ST	SR	VL	VL	Med	L	S,U	R,B
CA	22.0	600	0											
CA	23.0	500	0											
CA	24.0	800	800	70	1	5	ST	SR	VL	VL	Low	L	S	B,C,P
CA	24.1	-	-	100	2	5	ST	SR	VL	VL	Low	L	U	R,B,C
CA	25.0	1000	1000	0	0	0	-	NO	-	-				
CA	26.0	500	500	0	0	0	-	NO	-	-				
CA	27.0	800	800	4	3	60	CT	AP	M	M	Low	?	?	?
CA	28.0	900	900	0	0	0	-	NO	-	-				
CA	29.0	1400	0	5	1	20	CT	SR	L	L	Med	L	S	B,C
CA	29.1	-	-	2	1	20	CV	TB	L	M	Med	L	S	B,C
CA	29.2	-	-	20	1	30	CT	SR	L	L	Med	L	S	B,C
CA	30.0	400	0											
CI	1.0	400	400	0	0	0	-	NO	-	-				
CI	2.0	300	300	0	0	0	-	NO	-	-				
CI	3.0	350	350	0	0	0	-	NO	-	-				
CI	3.1	350	350	10	2	5	ST	SR	VL	VL	Med	L	U	B,C,P
CI	4.0	600	600	25	5	15	ST	SR	M	L	Med	L	U	R,B,C
CI	4.1	-	-	35	4	15	ST	SR	M	L	Med	L	U	R,B,C
CI	4.2	-	-	20	0.3	20	CV	AP	VL	L	Med	M	S	R
CI	5.0	250	250	0	0	0	-	NO	-	-				
CI	6.0	600	600	75	2	5	ST	SR	VL	VL	Med	M	S	R,B
CI	6.1	-	-	50	1	5	CV	AP	VL	L	Med	M	S	R,B
CI	6.2	-	-	30	2	5	ST	SR	·VL	VL	Med	M	S	R,B
CI	7.0	500	500	15	1.5	15	CV	AP	L	M	Med	M	S	R,B
CI	7.1	-	-	30	1	5	ST	SR	VL	VL	Med	M	S	R,B
CI	8.0	700	700	3	1	15	CV	AP	L	M	Med	L	S	R,B
CI	9.0	400	400	0	0	0	-	NO	-	-				
CI	10.0	600	600	0	0	0	-	NO	-	-	Low	M	S	C,P
CI	11.0	250	250	0	0	0	-	NO	-	-	Low	L	S	C,P
CI	12.0	700	700	20	2	20	ST	SR	L	VL	Low	L	S	C,P

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
CI	12.1	-	-	2	0.5	15	CV	AP	VL	L	Low	L	S	C,P
CI	13.0	500	500	6	1.5	60	CV	AP	M	H	Low	L	S	C,P
CI	13.1	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
CI	14.0	350	350	0	0	0	-	NO	-	-	Low	L	S	C,P
GY	1.0	1500	0											
GY	2.0	1700	1700	0	0	0	-	NO	-	-				
GY	3.0	3000	0											
GY	4.0	500	500	0	0	0	-	NO	-	-				
GY	5.0	4400	2000	0	0	0	-	NO	-	-				
GY	6.0	400	400	0	0	0	-	NO	-	-				
GY	7.0	1100	1100	0	0	0	-	NO	-	-				
GY	8.0	500	500	300	5	60	CT	SR	H	M	Med	M	U	B,C
GY	9.0	350	350	100	5	60	CT	SR	H	M	Med	M	U	B,C
GY	10.0	600	600	1	2	10	CT	SR	VL	VL	Med	L	U	G,P
GY	11.0	1200	0											
GY	12.0	700	700	0	0	0	-	NO	-	-	Low	L	U	C,P
GY	12.1	-	-	100	1	5	ST	SR	VL	VL	Low	L	U	C,P
GY	13.0	1200	1200	5	0.5	5	CV	AP	VL	L	Low	L	S	G,S
GY	13.1	-	-	0	0	0	-	NO	-	-	Low	L	U	?
GY	14.0	1000	800	400	2	20	ST	SR	L	VL	Low	?	?	?
GY	15.0	1200	1200	0	0	0								
GY	16.0	1500	1500	0	0	0								
GY	17.0	300	300	0	0	0								
GY	18.0	2000	1500	30	2	5	ST	SR	VL	VL	Low	?	U	?
GY	19.0	2000	2000	0	0	0	-	NO	-	-	Low	L	S	C,P,S
GY	19.1	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
GY	19.2	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
GY	20.0	3000	3000	0	0	0	-	NO	-	-		L	S	C,P,S
GY	20.1	-	-	0	0	0	-	NO	-	-		L	S	C,P,S
GY	20.2	-	-	0	0	0	-	NO	-	-		L	S	C,P
GY	21.10	800	800	0	0	0	-	NO	-	-	Low	M	S	B,C,P

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
GY	21.11	-	-	3	2	30	ST	SR	L	VL	Low	M	U	R,C,P
GY	21.12	-	-	2.5	2	30	ST	SR	L	VL	Low	M	U	R,C,P
GY	21.20	1200	1200	0	0	0	-	NO	-	-	Low	L	S	C,P,S
GY	21.21	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
GY	22.0	2000	2000	0	0	0	-	NO	-	-	Low	L	S	C,P
GY	22.1	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
GY	23.0	800	800	0	0	0	-	NO	-	-				
GY	24.0	500	500	0	0	0	-	NO	-	-				
GY	25.0	500	500	0	0	0	-	NO	-	-	Low	L	S	C,P
GY	26.0	1100	1100	0	0	0	-	NO	-	-				
GY	27.0	700	700	0	0	0	-	NO	-	-				
GY	28.0	500	500	0	0	0	-	NO	-	-				
GY	29.0	400	400	0	0	0	-	NO	-	-				
GY	30.0	700	700	0	0	0	-	NO	-	-	Low	L	U	B,C
HH	1.0	1000	1000	0	0	0	-	NO	-	-				
HH	2.0	400	400	0	0	0	-	NO	-	-				
HH	3.0	600	600	0	0	0	-	NO	-	-				
HH	4.0	800	800	30	0.5	5	ST	SR	VL	VL	Low	L	U	C,P
HH	5.0	800	800	0	0	0	-	NO	-	-				
HH	6.0	400	400	25	1	5	ST	SR	VL	VL	Low	L	U	C,P
HH	7.0	1100	1100	150	1	5	ST	SR	VL	VL	Low	L	U	C,P
HH	8.0	900	900	0	0	0	-	NO	-	-				
HH	9.0	500	500	0	0	0	-	NO	-	-				
HH	10.0	600	600	100	1	15	ST	SR	L	VL	Low	L	U	C,P
HH	11.0	300	300	0	0	0	-	NO	-	-				
HH	12.0	200	200	0	0	0	-	NO	-	-				
HH	13.0	400	400	0	0	0	-	NO	-	-				
HH	13.1	300	300	0	0	0	-	NO	-	-				
HH	14.0	700	700	0	0	0	-	NO	-	-				
HH	15.0	500	500	0	0	0	-	NO	-	-				
HH	16.0	300	300	0	0	0	-	NO	-	-				

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
HH	17.0	300	0											
HH	18.0	500	0											
HH	19.0	500	0											
HH	20.0	500	500	0	0	0	-	NO	-	-				
HH	21.0	500	500	0	0	0	-	NO	-	-				
HH	22.0	600	600	0	0	0	-	NO	-	-				
HH	23.0	600	600	0	0	0	-	NO	-	-				
HH	24.0	300	300	0	0	0	-	NO	-	-				
HH	25.0	300	300	0	0	0	-	NO	-	-				
HH	26.0	400	400	0	0	0	-	NO	-	-				
HH	27.0	500	500	0	0	0	-	NO	-	-				
HH	28.0	500	500	0	0	0	-	NO	-	-				
HH	29.0	900	900	75	0.5	5	ST	SR	VL	VL	Low	L	U	C,P
HH	30.0	500	500	0	0	0	-	NO	-	-				
HH	31.0	500	500	0	0	0	-	NO	-	-				
HH	31.1	400	400	0	0	0	-	NO	-	-				
HH	32.0	1000	1000	3	0.75	15	CV	AP	L	M	Low	L	U	P,S
HH	32.1	-	-	150	3.5	85	CV	AP	H	H	Low	L	U	S,M
HH	33.0	1200	1200	100	2	70	CV	AP	M	H	Low	L	U	G,S
HH	34.0	600	600	0	0	0	-	NO	-	-				
HH	35.0	600	600	0	0	0	-	NO	-	-				
HH	36.0	700	700	0	0	0	-	NO	-	-				
IN	1.0	400	400	0	0	0	-	NO	-	-				
IN	2.0	500	500	50	2	15	ST	SR	L	VL	Low	L	U	B,C,P
IN	2.1	-	-	40	2	25	ST	SR	L	VL	Low	L	U	B,C
IN	2.2	-	-	0	0	0	-	NO	-	-	Low	M	S	R,B
IN	3.0	1200	1200	10	1	4	ST	SR	VL	VL	Low	L	U	B,C,P
IN	3.1	-	-	20	2	15	ST	SR	L	VL	Low	L	U	B,C
IN	4.0	2000	1500	100	0.3	2	ST	SR	VL	VL	Med	L	U	B,C
IN	5.0	1300	1300	0	0	0	-	NO	-	-	Low	L	S	B,C,P
IN	6.0	1600	1600	0	0	0	-	NO	-	-				

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
IN	7.0	600	600	0	0	0	-	NO	-	-	Low	L	S	B,C,P
IN	8.0	800	800	0	0	0	-	NO	-	-	Low	M	S	B,C,P
IN	9.0	500	500	0	0	0	-	NO	-	-				
IN	10.0	1000	1000	0	0	0	-	NO	-	-	Low	L	S	C,P
IN	10.1	-	-	0	0	0	-	NO	-	-	Low	L	U	C,P
IN	11.0	1100	1100	30	2	5	ST	SR	VL	VL	Low	L	U	B,C
IN	12.0	300	0											
IN	13.0	250	0											
IN	14.0	400	0											
IN	15.0	600	600	0	0	0	-	NO	-	-				
IN	16.0	800	800	0	0	0	-	NO	-	-				
IN	17.0	300	300	0	0	0	-	NO	-	-				
IN	18.0	800	0											
IN	19.0	300	0											
IN	20.0	400	0											
IN	21.0	600	0											
IN	22.0	500	0											
IN	23.0	500	0											
IN	24.0	400	0											
IN	25.0	900	900	0	0	0	-	NO	-	-				
IN	26.0	700	700	0	0	0	-	NO	-	-				
IN	27.0	250	0											
IN	28.0	150	0											
IN	29.0	800	800	0	0	0	-	NO	-	-				
IN	30.0	1100	1100	125	2	5	ST	SR	VL	VL	Low	L	S	C,P
IN	31.0	600	600	0	0	0	-	NO	-	-	Low	L	U	P,S
IN	31.1	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
IN	31.2	-	-	0	0	0	-	NO	-	-	Low	L	U	P,S
IN	32.0	900	900	0	0	0	-	NO	-	-	Low	L	U	C,P
IN	33.0	700	700	0	0	0	-	NO	-	-	Low	L	U	P,S,M
IN	33.1	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
IN	34.0	1000	1000	0	0	0	-	NO	-	-	Low	L	U	C,P,S
IN	35.0	500	0											
IN	36.0	300	0											
IN	37.0	400	400	0	0	0	-	NO	-	-				
IN	38.0	300	300	0	0	0	-	NO	-	-				
IN	39.0	300	300	0	0	0	-	NO	-	-				
IN	40.0	700	700	0	0	0	-	NO	-	-				
IN	41.0	1500	1500	0	0	0	-	NO	-	-				
IN	42.0	500	500	0	0	0	-	NO	-	-				
IN	43.0	600	600	0	0	0	-	NO	-	-				
IN	44.0	600	600	0	0	0	-	NO	-	-				
IN	45.0	300	300	0	0	0	-	NO	-	-				
IN	46.0	700	700	75	2	20	ST	SR	L	VL	Low	L	U	B,C,P
IN	47.0	800	800	0	0	0	-	NO	-	-				
IN	48.0	500	500	0	0	0	-	NO	-	-				
IN	49.0	400	400	0	0	0	-	NO	-	-				
IN	50.0	400	400	0	0	0	-	NO	-	-				
IN	51.0	500	500	0	0	0	-	NO	-	-				
IN	52.0	300	300	0	0	0	-	NO	-	-				
IN	53.0	800	800	0	0	0	-	NO	-	-				
IN	54.0	600	600	200	1	5	ST	SR	VL	VL	Low	L	U	B,C,P
IN	55.0	300	300	0	0	0	-	NO	-	-				
IN	56.0	700	700	0	0	0	-	NO	-	-				
IN	56.1	300	300	0	0	0	-	NO	-	-				
IN	57.0	300	300	0	0	0	-	NO	-	-				
IN	58.0	300	300	0	0	0	-	NO	-	-				
IN	59.0	1100	1100	0	0	0	-	NO	-	-				
IN	60.0	300	300	0	0	0	-	NO	-	-				
IN	61.0	600	600	150	1	5	ST	SR	VL	VL	Low	L	U	B,C,P
IN	62.0	400	400	0	0	0	-	NO	-	-				
IN	62.1	400	400	0	0	0	-	NO	-	-				

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
IN	63.0	300	300	0	0	0	-	NO	-	-				
IN	64.0	350	350	0	0	0	-	NO	-	-				
IN	65.0	500	500	0	0	0	-	NO	-	-				
IN	66.0	600	600	0	0	0	-	NO	-	-				
IN	67.0	900	900	300	1	4	ST	SR	VL	VL	Low	L	S	C,P
IN	68.0	500	500	0	0	0	-	NO	-	-				
IN	69.0	300	300	0	0	0	-	NO	-	-				
IN	69.1	600	600	150	3.5	60	CV	AP	H	H	Low	L	U	P,S
IN	70.0	400	400	0	0	0	-	NO	-	-				
IN	71.0	700	700	0	0	0	-	NO	-	-				
IN	72.0	900	900	75	1	5	ST	SR	VL	VL	Low	L	U	C,P
IN	73.0	250	250	0	0	0	-	NO	-	-				
IN	74.0	900	900	0	0	0	-	NO	-	-				
IN	75.0	500	500	0	0	0	-	NO	-	-				
JI	1.0	700	700	30	8	80	CV	AP	H	H	Low	?	?	G,S
JI	1.1	500	500	0	0	0	-	NO	-	-				
JI	2.0	900	900	0	0	0	-	NO	-	-				
JI	3.0	800	800	0	0	0	-	NO	-	-				
JI	4.0	900	900	0	0	0	-	NO	-	-				
JI	5.0	800	800	120	1.5	15	ST	SR	L	VL	Low	L	S,U	C,P
JI	5.1	-	-	20	1	5	CV	AP	VL	L	Low	L	S	C,P
JI	6.0	500	500	0	0	0	-	NO	-	-				
JI	7.0	600	600	0	0	0	-	NO	-	-				
JI	8.0	1000	1000	0	0	0	-	NO	-	-				
JI	9.0	600	600	0	0	0	-	NO	-	-				
JI	10.0	500	500	0	0	0	-	NO	-	-				
JI	11.0	400	400	0	0	0	-	NO	-	-				
JI	12.0	1200	1200	25	2	5	ST	SR	VL	VL	Med	L	U	B,C
JI	12.1	-	-	10	1	5	ST	SR	VL	VL	Med	L	U	B,C
JI	13.0	300	300	20	2	5	ST	SR	VL	VL	High	L	U	R,B
JI	13.1	800	800	0	0	0	-	NO	-	-	Med			C,P

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
JI	14.0	800	800	50	2	5	ST	SR	VL	VL	Med	L	U	B,C
JI	15.0	800	800	30	1	5	ST	SR	VL	VL	Low	L	U	B,C
JI	16.0	600	600	0	0	0	-	NO	-	-				
JI	17.0	500	500	0	0	0	-	NO	-	-				
JI	18.0	750	750	0	0	0	-	NO	-	-				
JI	19.0	500	0											
JI	20.0	600	0											
JI	21.0	900	900	0	0	0	-	NO	-	-				
JI	22.0	800	800	0	0	0	-	NO	-	-				
JI	23.0	600	600	0	0	0	-	NO	-	-				
JI	24.0	150	150	30	2	4	ST	SR	VL	VL	Med	M	U	B,C,P
JI	24.1	75	75	60	5	80	CV	AP	H	H	Low	L	U	S,M
JI	25.0	1000	1000	0	0	0	-	NO	-	-				
JI	26.0	1600	1600	50	1.5	5	ST	SR	VL	VL	Med	L	U	B,C
LP	1.0	1000	1000	50	2	30	ST	SR	L	VL	Low	L	S	C,P
LP	1.1	-	-	60	1.5	60	CV	AP	M	H	Low	L	S	C,P
LP	2.0	200	200	70	1.5	60	CV	AP	M	H	Low	L	S,U	C,P
LP	3.0	300	300	50	1	60	CV	AP	M	H	Low	?	?	C,P
LP	4.0	500	500	50	2	40	CV	AP	L	M	Low	L	U	R,C,P
LP	4.1	-	-	60	1	20	ST	SR	L	VL	Low	L	S	R,C,P
LP	5.0	400	400	50	1	40	CV	AP	L	M	Low	L	U	C,P
LP	6.0	900	900	60	2	60	CV	AP	M	H	Low	L	S	S,M
LP	6.1	-	-	40	1	40	CV	AP	L	M	Low	L	S	C,P
LP	6.2	-	-	100	2	60	CV	AP	M	H	Low	L	S	C,P
LP	6.3	-	-	20	1	15	CV	AP	L	M	Low	L	S	C,P
LP	7.0	400	400	0	0	0	-	NO	-	-				
LP	8.0	500	500	0	0	0	-	NO	-	-				
LP	9.0	400	400	0	0	0	-	NO	-	-				
LP	10.0	800	800	0	0	0	-	NO	-	-				
LP	11.0	600	600	0	0	0	-	NO	-	-				
LP	12.0	900	900	30	2	75	CV	AP	M	H	Low	L	U	R,C,P

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
LP	12.1	-	-	40	2	40	CV	AP	L	M	Low	L	S	R,C,P
LP	13.0	300	300	20	4	15	CV	AP	M	H	Low	L	S	C,P
LP	13.1	-	-	30	1.5	30	CV	AP	L	M	Low	L	U	C,P
LP	14.0	1200	1200	0	0	0	-	NO	-	-				
LP	15.0	1500	1500	0	0	0	-	NO	-	-				
LP	16.0	1100	1100	100	1	5	ST	SR	VL	VL	Low	L	U	R,B,C
LP	17.0	600	600	0	0	0	-	NO	-	-				
LP	18.0	800	800	150	1	5	ST	SR	VL	VL	Low	L	S	R,B,C
LP	19.0	900	900	0	0	0	-	NO	-	-				
LP	20.0	400	400	0	0	0	-	NO	-	-				
LP	21.0	700	700	0	0	0	-	NO	-	-				
LP	22.0	800	800	30	1	5	ST	SR	VL	VL	Low	L	U	R
LP	23.0	600	600	150	1	5	ST	SR	VL	VL	Low	L	S	R
LP	24.0	300	300	0	0	0	-	NO	-	-				
LP	25.0	350	350	0	0	0	-	NO	-	-				
LP	26.0	700	700	0	0	0	-	NO	-	-				
LP	27.0	800	800	80	2	20	ST	SR	L	VL	Low	L	U	C,P
LP	28.0	500	500	0	0	0	-	NO	-	-				
LP	29.0	500	500	0	0	0	-	NO	-	-				
LP	30.0	550	550	0	0	0	-	NO	-	-				
LP	31.0	400	400	0	0	0	-	NO	-	-				
LP	32.0	700	700	0	0	0	-	NO	-	-				
LP	33.0	600	600	0	0	0	-	NO	-	-				
LP	34.0	500	500	0	0	0	-	NO	-	-				
LP	35.0	250	250	0	0	0	-	NO	-	-				
LP	36.0	300	300	0	0	0	-	NO	-	-				
LP	37.0	400	400	0	0	0	-	NO	-	-				
LP	38.0	300	300	0	0	0	-	NO	-	-				
LP	39.0	900	900	0	0	0	-	NO	-	-				
LP	40.0	600	600	100	1	5	ST	SR	VL	VL	Low	L	S	B,C,P
LP	41.0	500	500	120	1	5	ST	SR	VL	VL	Low	L	U	C,P

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
LP	42.0	400	400	0	0	0	-	NO	-	-				
LP	43.0	800	800	150	1	5	ST	SR	VL	VL	Low	L	U	C,P
LP	44.0	400	400	50	1	4	ST	SR	VL	VL	Low	L	U	C,P
PD	1.0	500	500	30	2	15	ST	SR	L	VL	Med	M	S	R
PD	1.1	-	-	10	1	15	CV	AP	L	M	Med	M	S	R
PD	2.0	750	0											
PD	3.0	800	0											
PD	4.0	500	0											
PD	5.0	500	0											
PD	6.0	400	0											
PD	7.0	400	400	0	0	0	-	NO	-	-				
PD	8.0	500	500	15	1	5	ST	SR	VL	VL	Med	M	S	B,C,P
PD	8.1	-	-	10	2	15	CV	AP	L	M	Med	M	S	B,C,P
PD	9.0	300	300	150	4	30	ST	SR	M	L	Med	M	S	R,B,C
PD	10.0	600	600	0	0	0	-	NO	-	-	Med	L	S	C,P
PD	10.1	-	-	10	4	40	CV	AP	M	H	Med	L	S	C,P
PD	10.2	-	-	150	2.5	15	ST	SR	L	VL	Med	L	S	R,C,P
PD	11.0	750	750	0	0	0	-	NO	-	-				
PD	12.0	700	700	0	0	0	-	NO	-	-				
PD	13.0	500	500	50	1	5	CV	AP	VL	L	Low	L	S	R,B,C
PD	13.1	-	-	50	1.5	5	CV	AP	VL	L	Low	L	S	R,B,C
PD	14.0	700	0											
PD	15.0	1300	0											
PD	16.0	800	0											
PD	17.0	2000	0											
PD	18.0	500	0											
PM	1.0	500	500	20	2	5	ST	SR	VL	VL	Med	L	U	B,C,P
PM	2.0	900	900	0	0	0	-	NO	-	-				
PM	3.0	600	600	0	0	0	-	NO	-	-				
PM	4.0	800	800	0	0	0	-	NO	-	-				
PM	5.0	700	700	0	0	0	-	NO	-	-				

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
PM	6.0	1100	0											
PM	7.0	900	900	20	2	20	ST	SR	L	VL	Med	L	S	B,C,P
PM	8.0	400	400	15	2	20	ST	SR	L	VL	Med	L	S	B,C,P
PM	9.0	600	600	0	0	0	-	NO	-	-				
PM	10.0	600	0											
PM	11.0	900	0											
PM	12.0	750	0											
PM	13.0	300	300	30	5	30	ST	SR	M	L	Med	L	U	R
PM	14.0	800	800	20	0.75	5	CV	AP	VL	L	Med	L	S	R,C,P
PM	14.1	-	-	15	1	5	ST	SR	VL	VL	Med	L	S	R,C,P
PM	14.2	-	-	30	4	30	CV	AP	M	H	Med	L	S	R,C,P
PM	14.3	-	-	25	2	5	ST	SR	VL	VL	Med	L	S	R,C,P
PM	15.0	600	600	30	2.5	15	CV	AP	L	M	Med	M	S	R,C,P
PM	15.1	-	-	25	1.5	5	CV	AP	VL	L	Med	M	S	R,C,P
PM	15.2	-	-	40	1.5	5	CV	AP	VL	L	Med	M	S	R,B
PM	15.3	-	-	40	1.5	5	ST	SR	VL	VL	Med	M	S	R,B
PM	16.0	2000	2000	0	0	0	-	NO	-	-				
PM	17.0	600	600	0	0	0	-	NO	-	-				
PM	18.0	400	0											
PM	19.0	600	0											
PT	1.0	500	0											
PT	2.0	600	0											
PT	3.0	1500	0											
PT	4.0	500	0											
PT	5.0	600	0											
PT	6.0	700	0											
PT	7.0	800	0											
PT	8.0	500	0											
PT	9.0	600	0											
PT	10.0	400	400	25	1	5	ST	SR	VL	VL	Low	L	U	B,C,P
PT	11.0	300	300	20	1	5	ST	SR	VL	VL	Low	M	U	R,C,P

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
PT	12.0	350	350	0	0	0	-	NO	-	-				
PT	13.0	600	600	0	0	0	-	NO	-	-				
PT	14.0	250	250	20	1	5	ST	SR	VL	VL	Low	L	U	C,P
PT	15.0	500	500	15	1	5	ST	SR	VL	VL	Low	L	U	C,P
PT	16.0	300	300	50	1	5	ST	SR	VL	VL	Low	L	U	C,P
PT	17.0	750	750	30	1	5	ST	SR	VL	VL	Low	L	U	C,P
PT	18.0	400	400	0	0	0	-	NO	-	-				
PT	19.0	500	0											
PT	20.0	500	500	75	1	20	ST	SR	L	VL	Low	L	U	C,P
PT	21.0	700	700	20	1	5	ST	SR	VL	VL	Low	L	U	C,P
PT	22.0	400	400	20	1	5	ST	SR	VL	VL	Low	L	U	C,P
PT	23.0	300	300	25	1.5	5	ST	SR	VL	VL	Low	L	U	C,P
PT	24.0	500	500	0	0	0	-	NO	-	-				
PT	25.0	600	600	0	0	0	-	NO	-	-				
PT	26.0	750	750	0	0	0	-	NO	-	-				
SC	1.0	1200	1200	0	0	0	-	NO	-	-	Med	L	S	C,P
SC	1.1	-	-	0	0	0	-	NO	-	-	Med	L	S	C,P
SC	1.2	-	-	8	1.5	60	CV	AP	M	H	Med	L	S	C,P
SC	2.0	500	500	0	0	0	-	NO	-	-	Med	L	S	C,P
SC	3.0	300	300	0	0	0	-	NO	-	-				
SC	4.0	600	600	0	0	0	-	NO	-	-				
SC	5.0	1000	1000	0	0	0	-	NO	-	-	Low	L	S	C,P,S
SC	5.1	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
SC	5.2	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
SC	5.3	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
SC	6.0	1000	1000	0	0	0	-	NO	-	-	Low	L	S	C,P
SC	7.0	300	300	1	0.5	5	CT	AP	VL	VL	Med	L	U	B
SC	7.1	-	-	0	0	0	-	NO	-	-	Med	L	S	B,C,P
SC	8.0	1200	1200	200	2	5	ST	SR	VL	VL	Med	L	U	B,C
SC	9.0	500	500	60	5	15	ST	SR	M	L	Med	L	U	B,C,P
SC	10.0	900	900	0	0	0	-	NO	-	-	Med	L	S	C,P

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
SC	11.0	1500	1500	900	5	15	ST	SR	M	L	Low	L	U	B,C
SC	12.0	2000	2000	0	0	0	-	NO	-	-				
SC	13.0	500	500	0	0	0	-	NO	-	-				
SC	14.0	300	300	0	0	0	-	NO	-	-				
SC	15.0	1000	1000	200	2	5	ST	SR	VL	VL	Low	L	U	C,P
SC	16.0	400	400	100	2	5	ST	SR	VL	VL	Low	L	U	C,P
SC	17.0	2500	2500	600	2	5	ST	SR	VL	VL	Low	L	S	B,C,P
SC	17.1	-	-	100	3	5	CV	AP	VL	L	Low	L	U	C,P,G
SC	17.2	-	-	1	0.5	30	CV	AP	VL	L	Low	L	S	B,C,P
SC	18.0	500	500	0	0	0	-	NO	-	-				
SC	19.0	900	800	0	0	0	-	NO	-	-	Low	L	U	C,P
SC	20.0	400	400	0	0	0	-	NO	-	-	Low	L	U	C,P,G
SC	20.1	-	-	0	0	0	-	NO	-	-	Low	L	S	C,P
SC	21.0	750	750	400	2	5	ST	SR	VL	VL	Low	L	U	B,C,P
SC	22.0	300	300	150	2	5	ST	SR	VL	VL	Low	L	U	C,P
SC	23.0	500	500	150	2	5	ST	SR	VL	VL	Low	L	U	B,C,P
SC	23.1	-	-	1	0.5	5	CV	AP	VL	L	Low	L	U	B,C,P
SC	24.0	650	650	200	2	5	ST	SR	VL	VL	Low	L	U	C,P
SC	25.0	2500	2500	1500	2	5	ST	SR	VL	VL	Low	L	U	B,C,P
SC	26.0	1500	1500	0	0	0	-	NO	-	-				
SC	27.0	1200	1200	0	0	0	-	NO	-	-				
SC	28.0	1000	0											
SC	29.0	3000	3000	0	0	0	-	NO	-	-				
SC	30.0	600	600	0	0	0	-	NO	-	-				
SI	1.0	600	600	10	2.5	20	ST	SR	L	VL	Med	M	S	R,C,P
SI	2.0	1000	1000	0	0	0	-	NO	-	-				
SI	3.0	700	700	0	0	0	-	NO	-	-				
SI	4.0	600	600	0	0	0	-	NO	-	-				
SI	5.0	600	600	0	0	0	-	NO	-	-				
SI	6.0	1400	0											
SI	7.0	1100	1100	50	1.5	5	ST	SR	VL	VL	Med	L	S	B,C,P

"Arrow" Survey Data Summary - 1992

AREA	SEGMENT LOC.	LENGTH (m)	LENGTH SURVEYED	OILED LENGTH	OILED WIDTH	DISTRIBUTION %	THICKNESS	CHARACTER	OIL COVER	OIL CATEGORY	WAVE EXPOSURE	SLOPE	ZONE	SEDIMENTS
SI	8.0	500	500	0	0	0	-	NO	-	-				
SI	9.0	750	0											
SI	10.0	1800	0											
SI	11.0	800	0											
SI	12.0	1200	1200	0	0	0	-	NO	-	-				
SI	13.0	500	500	0	0	0	-	NO	-	-				
SI	14.0	1200	1200	0	0	0	-	NO	-	-				
SI	15.0	500	500	100	4	5	ST	SR	L	VL	Med	L	U	B,C,P

Appendix B

Sediment Sample Analysis Data

This appendix describes the parameters measured during the sediment sample analyses. The data presented in the tables were provided directly from the Environmental Technology Centre. The sample numbers are identical to those used in the text of this report, except the prefix "S" was deleted in the text. Sample 10 (S-10) should be ignored as it was not collected for this project, but was included in the sample batch sent for analysis.

The following were determined during the sediment sample analyses:

TSEM (total extractable material): Using a solvent mixture, such as hexane/CH_2Cl_2, a wide range of materials can be extracted. These include petroleum components, such as the hydrocarbons, as well as some polar components, resins, and asphaltenes. In addition, many natural products will be extracted.

PHC (petroleum hydrocarbon): After column cleanup and extraction, a portion of each of the two fractions is combined to determine the amount of petroleum hydrocarbons. These include the aliphatics (straight and branched chained hydrocarbons, the smaller of which are volatile and most of which are biodegradable) and the aromatics (compounds containing the benzene ring structure, the smaller of which are volatile; these compounds may have a relatively high solubility in water and are not very biodegradable; they are also the more toxic compounds of the two classes), but not the polars, resins, or asphaltenes.

PHC/TSEM: This ratio provides an indication of the origin of the extractable material or of the degree of degradation of an oil. Fresh oils will have a high PHC/TSEM ratio, whereas degraded oils will not, nor will natural materials. A bunker oil will appear as a very degraded oil, having had most of the PHC removed during processing.

PAHs (polynuclear aromatic hydrocarbons): These are identifiable compounds in the F2 or aromatic fraction of the extract.

Ts(18a(H),21b(H)-22,29,30-trisnorneohopane), Tm(17a(H),21b(H)-22,29,30-trisnorhopane), C29 Hopane, C30 Hopane, C23 Triterpane, C24 Triterpane: These terpanes are relatively nondegradable, nonvolatile, and insoluble. They can act as long-term markers for petroleum products. The composition pattern is useful for determining if one oil is the same as another oil.

Another useful indicator of the presence of oil is the compositional trace resulting from GC/FID (gas chromatography/flame ionization detector) analysis. Fresh oils have a very distinctive pattern of aliphatic hydrocarbon distribution and natural materials have an equally distinctive but different pattern. As oils weather, the pattern becomes more like that of natural material. Bunker C oil (the oil spilled from the *Arrow*) resembles a very weathered oil in that the trace has lower amounts of identifiable alkanes compared with unidentifiable material than fresh oils. As Bunker C oil degrades further in the environment, the remaining alkanes biodegrade, leaving an unresolvable complex mixture that closely resembles natural material. To permit comparisons, therefore, gas chromatography traces were digitized and the scales were adjusted for visual comparison.

Table 1 Analysis of Results of Suspected *Arrow* Oil Samples by Gravimetric and GC/FID Methods

Sample	Total Solvent-Extractable Materials (TSEM, mg/g Sample)	Total Petroleum Hydrocarbons (PHC, mg/g Sample)	Aliphatics in PHC (%)	Aromatics in PHC (%)	PHC/TSEM
Aged Source Arrow Oil	825	424	56	44	0.51
S-A	100	33.3	72	28	0.33
S-2	194	51.0	74	26	0.26
S-3	124	50.6	72	28	0.41
S-4	73.0	33.1	60	40	0.45
S-5	5.20	2.21	51	49	0.43
S-6	500	229	64	36	0.46
S-7	76.0	31.6	62	38	0.42
S-8	295	12.8	64	36	0.43
S-9	34.6	9.00	42	38	0.26
S-1	3.02	0.452	73	27	0.15
S-10	1.00	0.177	50	50	0.18

Table 2 Analysis Results for Polycyclic Aromatic Hydrocarbons (PAHs)

Environment Canada Conservation & Protection							
Emergencies Science Division							
RRETC Ottawa Ontario							
Arrow oil PAH Analysis							
Compound	Sourse Oil	S-A	S-1	S-2	S-3	S-4	S-5
	(ug/g TSEM)	(ug/g TSEM)	(ug/g TSEM)	(ug/g TSEM)	(ug/g TSEM)	(ug/g TSEM)	(ug/g TSEM)
Naphthalene	1.350	1.119	0.963	0.006	1.610	1.157	1.872
2-Methylnaphthalene	123.650	0.522	0.448	0.312	1.435	0.843	1.067
1-Methylnaphthalene	92.050	0.371	0.274	0.190	1.855	1.091	2.536
Biphenyl	15.950	2.071	0.528	0.294	1.160	0.554	0.778
2,6 -Dimethylnaphthalene	145.900	0.619	0.153	0.106	5.050	1.400	0.441
Acenaphthalene	2.550	0.138	0.361	0.012	0.155	0.243	0.142
Acenaphthene	13.300	1.280	ND	0.044	0.665	1.157	0.244
2,3,5-Trimethylnaphthalene	116.000	14.175	0.110	0.156	18.950	29.716	6.724
Flourene	29.250	3.946	0.085	0.082	5.055	4.437	0.320
Phenanthrene	81.100	1.033	0.346	0.222	22.375	1.451	0.760
Anthracene	50.000	1.590	0.108	0.058	1.200	2.183	1.433
1-Methylphenanthrene	93.450	2.171	0.270	0.304	78.000	79.282	5.052
Flouranthene	9.300	14.075	0.304	0.702	3.300	4.146	5.196
Pyrene	18.350	18.564	0.460	5.926	14.630	13.685	15.784
Benzo(b) & Benzo(k)flouranthrene	14.200	15.575	1.692	6.674	7.630	7.282	6.648
Benzo(e)pyrene	18.150	25.171	24.913	12.350	28.135	27.713	27.312
Benzo(a)pyrene	8.000	8.554	3.669	2.532	6.345	0.500	0.786
Perylene	7.450	8.373	5.831	3.036	0.075	6.243	6.036
Indeno(1,2,3-cd)pyrene	3.050	1.885	0.927	1.078	0.075	0.211	1.172
Dibenz(a,h)anthracene	4.600	5.074	3.976	1.760	1.600	1.320	0.965
Benzo(ghi)perylene	5.800	8.854	10.110	3.756	0.265	3.140	0.400
Total PAH'S	809.050	135.170	55.318	39.600	199.540	187.753	85.666
Surogate Recovery							
d10-Acenapthene	NA	39.70%	42.68%	58.90%	57.90%	59.80%	43.65%
d-10-Phenanthrene	NA	51.00%	54.05%	69.78%	73.18%	62.24%	39.93%
d12-Benz(a)anthracene	NA	140.00%	98.45%	134.48%	135.00%	118.57%	77.75%
d-12Perylene	NA	121.70%	119.80%	103.00%	125.13%	106.00%	62.63%

ND: Nondetectable
NA: Nonapplicable

Table 2 (Cont'd)

Environment Canada Conservation & Protection					
Emergencies Science Division					
RRETC Ottawa Ontario					
Arrow oil PAH Analysis					
Compound	S-6	S-7	S-8	S-9	S-10
	(ug/g TSEM)	(ug/g TSEM)	(ug/g TSEM)	(ug/g TSEM)	(ug/g TSEM)
Naphthalene	0.120	0.500	0.122	0.395	4.555
2-Methylnaphthalene	12.440	0.377	0.085	0.308	10.800
1-Methylnaphthalene	12.040	0.234	0.047	0.186	15.465
Biphenyl	7.440	0.690	0.051	0.643	16.715
2,6 -Dimethylnaphthalene	37.400	0.330	0.015	0.130	14.210
Acenaphthalene	0.680	0.060	0.003	0.018	4.012
Acenaphthene	2.320	0.263	0.257	0.095	ND
2,3,5-Trimethylnaphthalene	67.880	8.779	0.433	0.088	ND
Flourene	22.480	0.487	0.025	0.071	ND
Phenanthrene	99.520	0.550	0.008	0.129	5.130
Anthracene	2.920	0.333	0.062	0.079	ND
1-Methylphenanthrene	217.680	1.110	0.649	5.961	4.368
Flouranthene	5.520	5.606	0.544	0.319	3.122
Pyrene	18.760	11.959	1.870	9.396	3.777
Benzo(b) & Benzo(k)flouranthrene	7.120	10.329	0.763	6.951	3.632
Benzo(e)pyrene	28.120	16.892	0.049	21.428	6.015
Benzo(a)pyrene	0.840	4.460	2.548	5.325	6.725
Perylene	6,200	4.746	0.648	6.558	3.973
Indeno(1,2,3-cd)pyrene	0.360	1.320	0.065	1.598	3.959
Dibenz(a,h)anthracene	2.640	2.743	0.063	3.945	7.670
Benzo(ghi)perylene	3.480	4.666	0.570	5.929	15.670
Total PAH'S	555.960	78.539	8.877	69.549	129.797
Surogate Recovery					
d10-Acenapthene	43.54%	59.52%	49.06%	66.88%	73.60%
d10-Phenanthrene	51.14%	57.55%	59.40%	60.89%	67.85%
d12-Benz(a)anthrcene	104.80%	114.28%	122%	92.56%	84.75%
d12-Perylene	89.42%	95.38%	108.55%	82.81%	82.25%

ND: Nondetectable
NA: Nonapplicable

Table 3 Triterpanes and Steranes Identified in Suspected *Arrow* Oil-spill Samples

TRITERPANES	STERANES
1. Tricyclic Triterpanes	C20H34
C20H36	C21H36
C21H38	C22H38
C22H40	
C23H42	C27H48 (20S-aaa)
C24H44	C27H48 (20R-abb)
C25H46	C27H48 (20S-abb)
C26H48	C27H48 (20R-aaa)
2. Tetracyclic Triterpanes	C28H50 (20S-aaa)
C27H48 (I)	C28H50 (20R-abb)
C27H48 (II)	C28H50 (20S-abb)
C28H50 (I)	C28H50 (20R-aaa)
C28H50 (II)	
	C29H52 (20S-aaa)
3. Pentacyclic Triterpanes	C29H52 (20R-abb)
C27H46 (Ts)	C29H52 (20S-abb)
C27H46 (Tm)	C29H52 (20R-aaa)
C27H46 (25-Trisnorhopane)	
C28H48 (aab-28,30-Bisnorhopane)	
C28H48 (baa-28,30-Bisnorhopane)	
C28H48 (25-Bisnorhopane)	
C29H50 (ab-30-Norhopane)	
C29H50 (ba-30-Norhopane)	
C30H52 (ab-Hopane)	
C30H52 (ba-Hopane)	
C31H54 (22S-ab-30-Homohopane)	
C31H54 (22R-ab-30-Homohopane)	
C32H56 (22S-ab-30,31-Bishomohopane)	
C32H56 (22R-ab-30,31-Bishomohopane)	
C33H58 (22S-ab-30,31,32-Trishomohopane)	
C33H58 (22R-ab-30,31,32-Trishomohopane)	
C34H60 (22S-ab-30,31,32,33-Tetrakishomohopane)	
C34H60 (22R-ab-30,31,32,33-Tetrakishomohopane)	
C35H62 (22S-ab-30,31,32,33,34-Pentakishomohopane)	
C35H62 (22R-ab-30,31,32,33,34-Pentakishomohopane)	

Table 4 Analysis Results of Some Representative Biomarker Compounds in Suspected *Arrow* Oil Samples by GC/MSD

Sample	Ts/Tm*	C29-ab-Hopane		C30-ab-Hopane		C29/C30	C23H42 Triterpane		C24H44 Triterpane		C23/C24
		(ug/g sample)	(ug/g TSEM)	(ug/g sample)	(ug/g TSEM)		(ug/g sample)	(ug/g TSEM)	(ug/g sample)	(ug/g TSEM)	
Aged Source Arrow oil	0.42	86.5	104.8	90.5	109.7	0.96	225	272.7	105	127.5	2.13
S-A	0.40	17.1	171.4	20.8	207.8	0.87	27.3	273.0	13.0	129.8	2.09
S-2	0.40	23.6	121.6	26.4	135.1	0.90	58.6	302.0	28.8	148.5	2.04
S-3	0.41	18.5	149.2	20.6	165.7	0.90	38.0	306.0	18.1	143.6	2.10
S-4	0.40	10.7	148.4	11.8	164.3	0.90	24.5	340.0	12.0	166.7	2.04
S-5	0.39	0.666	128.2	0.75	144.2	0.89	1.79	344.0	0.866	166.7	2.07
S-6	0.39	75.0	150.0	78.4	156.8	0.96	193	386.2	92.7	185.3	2.08
S-7	0.42	13.2	173.6	15.6	204.8	0.85	37.5	493.0	18.2	239.0	2.06
S-8	0.41	4.98	168.8	5.57	188.8	0.89	13.0	440.7	6.15	208.5	2.12
S-9	0.44	3.54	101.9	4.13	119.2	0.85	13.5	390.8	6.63	191.4	2.04
S-1	0.45**	0.0568	18.8	0.0696	23.1	0.82	0.0151	5.00	0.0244	8.08	0.62
S-10	***	0.0250	25.0	0.0350	35.0	0.71	0.0506	50.6	0.0456	45.6	1.11

*Ts: 18a(H), 21b(H)-22,29,30-trisnorneohopane; Tm: 17a(H),21b(H)-22,29,30-trisnorhopane

**0.45: Estimated value from the measurement of peak heights because of the low ratio of signal to noise

***: Due to the low contents of Ts and Tm in S-10, their concentrations and ratio can not be accurately quantified

Table 5 Comparison of *n*-Alkane Distribution of the Aged Source *Arrow* Oil and Sample 6

n-Alkane	Aged source arrow oil		Sample 6		n-Alkane Ratios
	(ug/g oil)	(ug/g TSEM)	ug/g sample	(ug/g TSEM)	of Two Samples
n-C8	not detected	not detected	not detected	not detected	
n-C9	48.8	59.2	4.62	9.24	0.156
n-C10	122	148	13.6	27.1	0.183
n-C11	206	249	28.3	56.6	0.227
n-C12	281	341	51.4	103	0.302
n-C13	352	426	84.5	169	0.397
n-C14	449	544	120	240	0.441
n-C15	573	694	149	299	0.431
n-C16	705	854	219	440	0.515
n-C17	842	1020	280	560	0.549
Pristane	507	615	205	409	0.665
n-C18	861	1044	273	547	0.524
Phytane	584	708	273	546	0.771
n-C19	913	1107	284	567	0.512
n-C20	992	1202	301	603	0.502
n-C21	1068	1295	322	643	0.587
n-C22	1197	1451	341	682	0.470
n-C23	1089	1320	334	669	0.507
n-C24	1078	1307	336	672	0.514
n-C25	930	1127	309	617	0.547
n-C26	855	1036	299	598	0.577
n-C27	818	991	290	581	0.586
n-C28	756	917	276	552	0.602
n-C29	698	846	248	495	0.585
n-C30	623	755	214	428	0.567
n-C31	497	602	187	374	0.621
n-C32	418	506	160	320	0.630
n-C33	295	358	132	265	0.740
n-C34	244	296	111	222	0.750
n-C35	128	155	75.9	152	0.980
n-C36	93.0	113	53.2	106	0.938
n-C37	81.8	99.2	45.8	91.5	0.922
n-C38	71.4	86.5	32.9	65.9	0.762
n-C39	62.6	75.9	24.0	48.1	0.634
n-C40	45.5	55.1	21.1	42.1	0.764
Total	18484	22403	6098	12200	
Pristane/Phytane		0.87		0.75	
(C10+C12+C14)/(C22+C24+C26)		0.2723		0.1896	
(C10+C12+C14+C16)/(C22+C24+C26+C28)		0.4007		0.3227	

Appendix C - Photographs

1

Plate 1 **Eastern Rabbit Island. Remnant asphalt pavement in the upper intertidal zone near the location from which sample 9 (Figure 6) was collected (11 September 1992).**

2

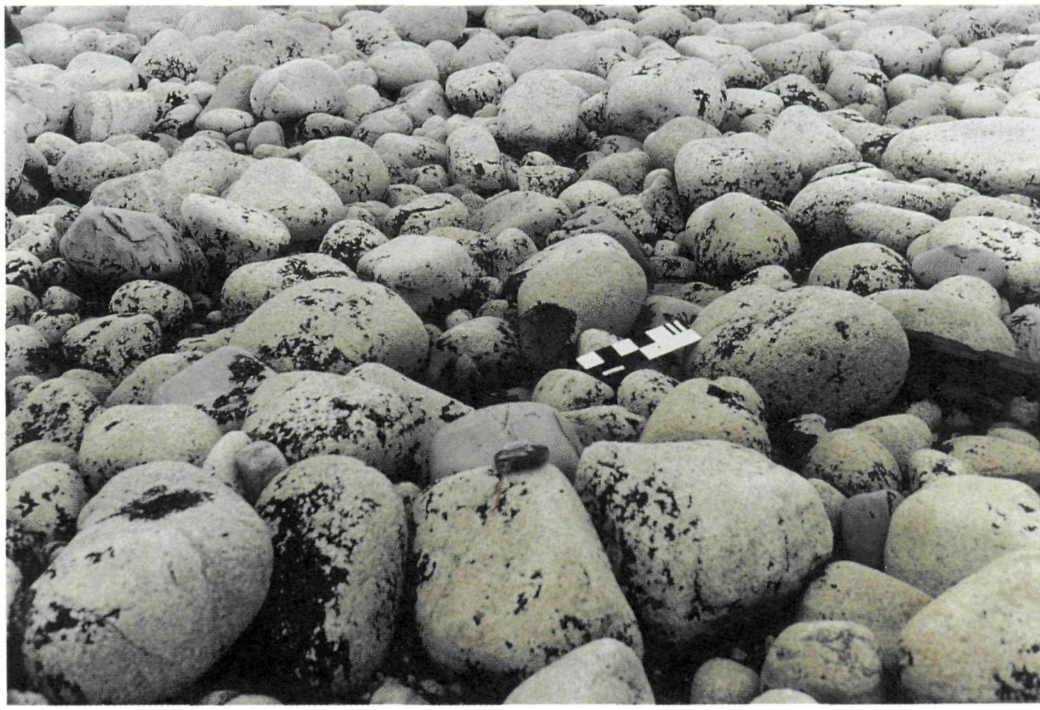
Plate 2 **Eastern Rabbit Island. Remnant asphalt pavement in the lower part of the upper intertidal zone near the location from which sample 8 (Figure 6) was collected (11 September 1992). The surface oil appears fresh, but sample analysis showed that the oil was composed of a heavily weathered, unresolvable complex mixture.**

3

Plate 3 **Black Duck spit. Pit location of the top section of the beach-face slope from which sample 1 was collected (Figure 7) (9 September 1992). Residual oil was found below a clean surface layer. The photo scale has 5 cm squares.**

4

Plate 4 **Black Duck spit. Residual asphalt pavement in the upper intertidal zone on the lagoon side of the spit from which sample 4 was collected (Figure 8) (9 September 1992).**



5

Plate 5 **Black Duck spit. Low-angle view alongshore. Sample 6 (Figure 8) was collected from the pit to the left of the photo scale, which has 5 cm squares (9 September 1992).**

6

Plate 6 **Black Duck spit. Close-up of the pit from which sample 6 was collected (Figure 8) (9 September 1992). The photo scale has 5 cm squares.**

7

Plate 7 **Black Duck Lagoon. View to the northeast towards the study area in the upper intertidal zone (Figure 9) (9 September 1992).**

8

Plate 8 **Black Duck Lagoon. View to the southwest at profile 7 (Figure 9) in the upper intertidal zone (9 September 1992).**

9

Plate 9 **Arichat Harbour. Close-up of beach sediments in the upper intertidal zone. Two "asphalt balls" are indicated by the arrows (13 September 1992).**

10

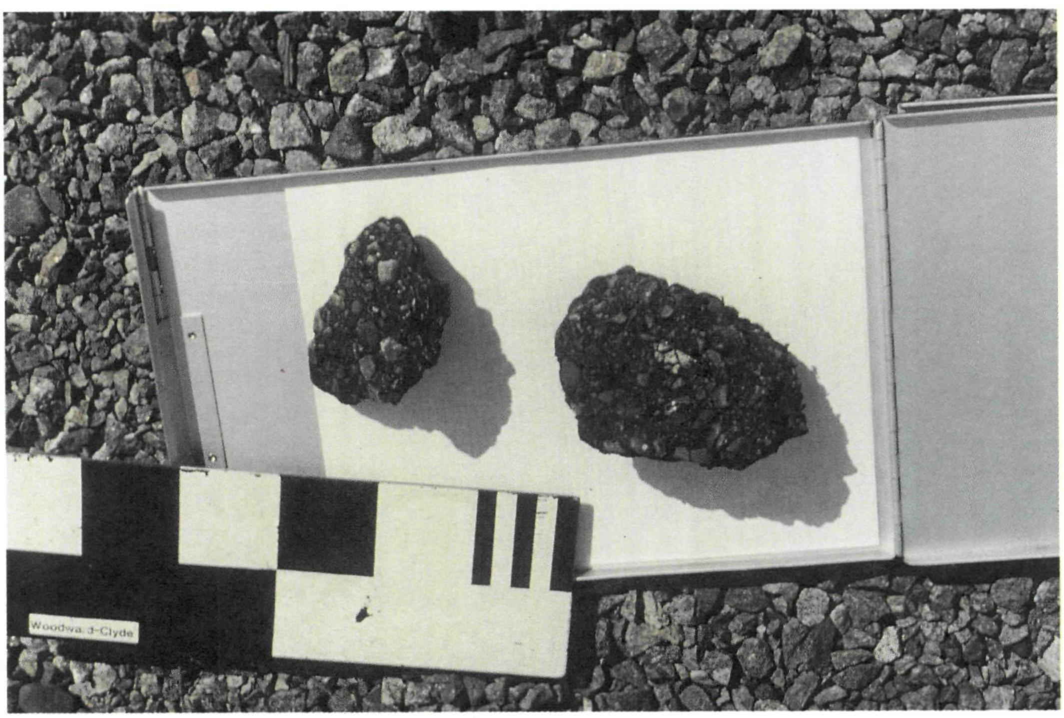


Plate 10 **Arichat Harbour. Close-up of two "asphalt balls." The photo scale has a total length of 30 cm (13 September 1992).**