MARINE DEBRIS AS AN INDICATOR OF OIL SPILL VULNERABILITY ALONG SELECTED BEACHES OF NORTHERN PLACENTIA BAY, NEWFOUNDLAND AND LABRADOR

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Marine Debris as an Indicator of Oil Spill Vulnerability Along Selected Beaches of Northern Placentia Bay, Newfoundland and Labrador

by

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Abstract

This study investigated the morphological, sedimentological, energy regime, and marine debris characteristics of 4 beaches at the head of Placentia Bay, Newfoundland and Labrador. Differing morphological, sedimentological and energy regime conditions alter the sensitivity of each system to oil spill contamination. Differences in the type and amount of marine debris between each system alter the potential risk of exposure to oil spill contamination. Based on differences in sensitivity and exposure, a vulnerability assessment was created for each system. This system was applied to an additional 5 beaches to demonstrate the applicability of the method and to highlight the actual vulnerability of each study beach relative to the spectrum of beaches actually present throughout Placentia Bay.

Typical of the majority of beaches throughout Placentia Bay, the 4 study beaches are characterized by gravel dominated, reflective, moderate to high energy systems. Observations of sediment re-working and accretionary features along the beaches of Arnold's Cove and Come by Chance indicate that self-cleaning would not be an effective agent of oil removal in the case of a spill. The absence of sediment re-working and protected nature of Goose Cove beach suggest that oil would persist in this environment for an extended period of time. Evidence of high wave energies at Hollett's Cove indicates that this beach would self-clean effectively.

Differing types and quantities of marine debris indicate that each beach, with the exception of Goose Cove, would likely be exposed to oil originating from a Placentia Bay spill. The heaviest quantities would be expected at Hollett's Cove and Arnold's Cove. Based on these factors, Arnold's Cove and Come by Chance are considered the most

vulnerable beaches to oil contamination. Hollett's Cove and Goose Cove are considered the least vulnerable respectively. Applying the vulnerability assessment to additional 5 beaches revealed that the 4 study beaches rank moderately to highly vulnerable to oil spill contamination.

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1.0 Setting

1.1 Introduction

Placentia Bay is located on the southern shoreline of the Island of Newfoundland. Nestled between the Burin Peninsula to the west and Avalon Peninsula to the east, the Bay has been the attention of increased industrial development, particularly in the northern regions. The increase in shipping associated with these and other offshore developments has increased the probability of an oil spill in Placentia Bay, which was identified nearly 2 decades ago as the most likely spot in Canada for a major oil spill (Brander-Smith *et al.*, 1990).

Understanding the behaviour of spilled oil on shorelines is reliant on an understanding of the geomorphologic and sedimentologic character as well as the dominant energy processes shaping a beach. Similar to most beaches throughout Atlantic Canada, the beaches of Placentia Bay are dominated by glacially derived gravel sediment, although muds, silts, sands, and boulders are also present. Some beaches are open to the ocean while others are much more sheltered. By studying similar beaches where oil spills have occurred in the past, it becomes possible to assess the likely behaviour of potential oil pollution on beaches in Placentia Bay

Another important component to consider when understanding the behaviour of spilled oil is the likelihood that a particular beach or section of shoreline will receive oil in the event of a spill. In general terms, the likelihood of a major spill in Placentia Bay is higher than in other bays around Newfoundland where industrial developments and shipping activities are less. However, some beaches may be more prone to contamination based on their orientation, proximity to potential sources, and physical characteristics such as the presence or absence of headlands, offshore islands, and local current patterns.

Using these concepts, the similarities and differences between each of the 4 beaches considered in this study will highlight the uniqueness of the behaviour of spilled oil over a relatively small geographical area.

1.2 Objective

This study was designed to assess the vulnerability of 4 beach systems at the head of Placentia Bay to oil spill contamination (Figure 1.1). Vulnerability was determined through an analysis of each beach's sensitivity and potential exposure to oil pollution. As in similar studies, geomorphological and sedimentological data were collected to determine the likely behaviour of spilled oil and the sensitivity of each site to oil spill contamination. Marine debris was used as the main indicator of exposure to oil spill pollution. Proximity to shipping lanes, oil handling facilities, and other potential sources were also considered. The method used to assess vulnerability was applied to several other Avalon Peninsula beaches where previous oil pollution sensitivity studies have been conducted.

Figure 1.1. Study area location in relation to provincial capital of St. John's (Source: Environment Canada, 2005)

1.3 Physical setting

The study area is located at the head of Placentia Bay, Newfoundland and Labrador. Situated approximately 140 kilometres west of the capital of St. John's, the beaches targeted for study fall along a 40 km stretch of shoreline and include, (1) Arnold's Cove, (2) Come by Chance, (3) Hollett's Cove, and (4) Goose Cove (Figure 1.2). Several rural communities fall within or near this area and are associated with the beaches of Arnold's Cove, Come by Chance, and Goose Cove.

. Due to its coastal nature, industry around Placentia Bay is largely tied to the ocean. Between 2001 and 2004, fish harvesting and processing accounted for approximately 23% of total employment in the Placentia Bay region (Fisheries and Oceans Canada, 2005). In 2004, the fish processing plant of Arnold's Cove employed nearly 400 people; approximately 40% of the population (Taylor, 2004). Despite the growth of the petroleum sector, the fishery still plays a very important economic role in many of the communities of Placentia Bay.

Figure 1.2. Location of study beaches at head of Placentia Bay (Source: Environment Canada, 2005)

Several industrial developments exist within the study area, including two land-based oil handling facilities (North Atlantic Refining Limited Refinery near Come by Chance and the International-Matex Tank Terminal Transshipment Terminal near Arnold's Cove). An additional refinery has been proposed for the area near Hollett's Cove and a liquid natural gas plant near Arnold's Cove (Figure 1.3).

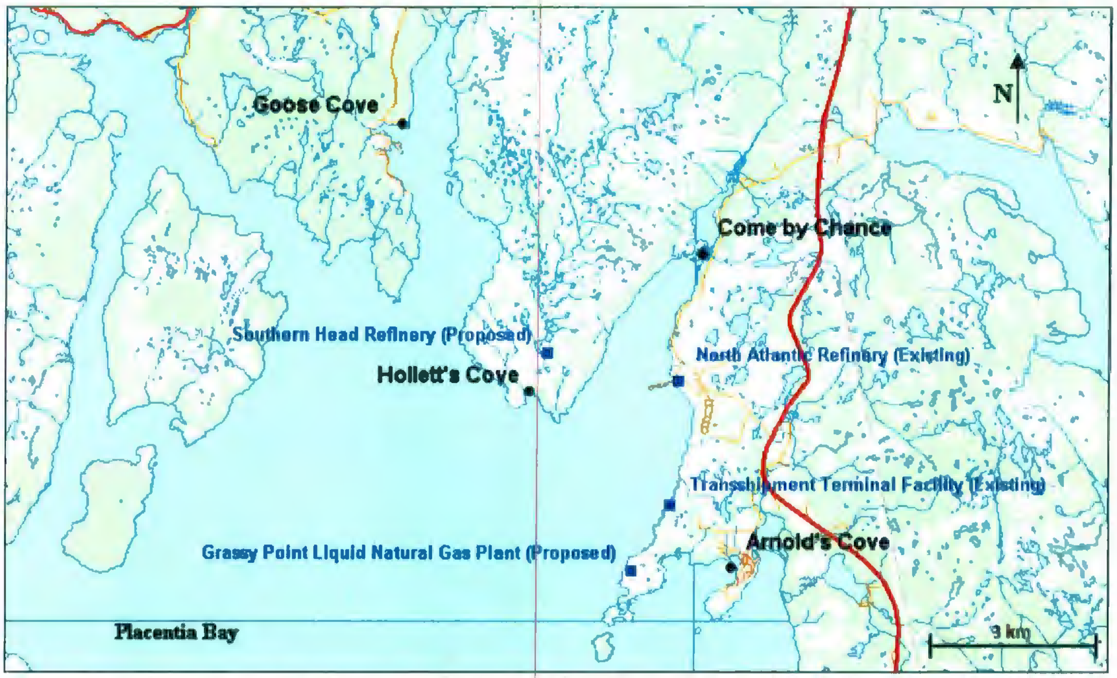


Figure 1.3. Location of existing and proposed industrial sites in relation to study beaches (Source: Environment Canada, 2005)

1.3.1 Physiography and bedrock geology

The study area falls within the Atlantic Uplands physiographic region of Canada (Bostock, 1970). Generally, inland areas of this region may be described as low, rolling uplands with maximum relief not exceeding 300 m (Catto *et al.*, 2003). Coastal cliffs exceeding 70 m in height are present in several areas including the southern Cape Shore (Catto *et al.*, 2003). However, coastal cliffs within the study area are significantly less than this, with maximum heights approximately 15 m.

The island portion of Newfoundland is a northeast continuation of the Appalachian geological region (Bird, 1972). The orogenic events that led to the formation of the Appalachians imposed a dominant northeast-southwest orientation on many of the major features of the island, including Placentia Bay (Bird, 1972).

Tectonically, Placentia Bay falls within the Avalon Zone (Colman-Sadd *et al.*, 1990). The Avalon Zone is characterized by late Proterozoic submarine and non-marine volcanic rocks and turbiditic, deltaic, and fluviatile sedimentary rocks. These are overlain, unconformably, by a late Proterozoic and early Paleozoic shallow marine succession (Colman-Sadd *et al.*, 1990).

Geological groups found at the head of Placentia Bay include the Connecting Point Group, Conception Group, Musgravetown Group, Love Cove Group, and the Adeyton Group (O'Driscoll and Hussey, 1978; Colman-Sadd *et al.*, 1990). A variety of lithological expressions may be found within each group.

Along the coast north from Arnold's Cove to Long Beach, Late Proterozoic Connecting Point Group rocks are present (O'Driscoll and Hussey, 1978). The exposed units contain green, grey, and black shale, siliceous siltstone, and resistant sandstone and conglomerate strata (O'Driscoll and Hussey, 1978; King, 1988; Hodych and King, 1989; Colman-Sadd *et al.*, 1990).

North of Long Beach and underlying much of the Southern Head area are rock units of varying resistance belonging to the Late Proterozoic Musgravetown Group, including cross-bedded sandstone, pebble conglomerates, and interbedded black shales (O'Driscoll and Hussey, 1978; King, 1988; Colman-Sadd *et al.*, 1990). Coastal exposures of slate, limestone, orthoquartzite siltstone, and sandy shale of the Lower Cambrian Bonavista and Random formations are also present along the eastern and western shores of Come by Chance Gut (O'Driscoll and Hussey, 1978). Two 500 m (approximate) exposures of Ackley Batholith granite are present within the western Come by Chance Gut (O'Driscoll and Hussey, 1978). At the head of Come by Chance Gut are Late Proterozoic to Early Ordovician siliciclastic sedimentary rocks (Colman-Sadd *et al.*, 1990).

Bonavista Formation sedimentary rocks are also exposed along the northeastern and southwestern shores of North Harbour (O'Driscoll and Hussey, 1978; Colman-Sadd *et al.*, 1990; Hodych and King, 1989). Several exposures of Sail-the-Maid Granites are present within the slates and limestone of the northeastern Bonavista Formation (O'Driscoll and Hussey, 1978). These resistant granites extend approximately 1 km south from the northwestern portion of the North Harbour shoreline. Directly to the south are less resistant sandstones and shales of the Baker Cove Formation and North Harbour Formation (O'Driscoll and Hussey, 1978; Colman-Sadd *el al.*, 1990). These rocks belong to the Proterozoic Love Cove Group and extend along the shoreline to contact the slates and limestones of the Bonavista Formation at southwestern North Harbour. Late Proterozoic to Cambrian Swift Current granitoid intrusions belonging to the Musgravetown Group are present along an 800 m section of shoreline at the head of Goose Cove (O'Driscoll and Hussey, 1978; Colman-Sadd *el al.*, 1990).

1.3.2 Quaternary geomorphology

Sediments of the Avalon Peninsula are primarily comprised of glacial diamictons with particles ranging in size from clay to boulders (Catto *et al.*, 2003). The majority (30-55%) of sediments are coarse-textured (equal to or greater than 2mm diameter) with silt concentrations of <2-30% (Henderson, 1972; Catto and Thistle, 1993; Catto and St. Croix, 1997; Sommerville, 1997).

Sediments of glacial and marine origin are present along much of the shoreline of the study area. Surficial sediments within Arnold's Cove are primarily glacial in origin with marine deposited clays, silt, and gravel diamictons within the more sheltered areas (Catto and Taylor, 1998a). The relatively exposed eastern shoreline of Come by Chance

Gut is comprised primarily of glacial diamicton veneers of less than 1.5 m thickness overlying bedrock (Catto and Taylor, 1998b). Fluvial deposits of silt, clay, and gravel are also present at the mouth of the stream present near Barachois Head. These sediments have locally been reworked by marine processes and then re-deposited.

Organic veneers of poorly drained peat, peat moss, and other organic matter overlying marine derived clasts are present at the head of Come By Chance Gut (Catto and Taylor, 1998b). The northern portion of the western Come by Chance Gut shoreline is characterized largely by glacial and marine deposited sediments with areas of concealed bedrock. Exposed and concealed bedrock makes up much of the remainder of the western shoreline, including Southern Head and the eastern North Harbour shoreline north to Winging Head. Minor colluvial deposits are present at the base of the cliffs east of Hollet's Cove (Catto and Taylor, 1998b). Similar surficial arrangements are present along the shoreline between North Harbour Point and the southerly extent of the town of North Harbour.

The remainder of the North Harbour shoreline is comprised primarily of glacially derived sediment (Catto and Taylor, 1998b). Eroded hummocky diamicton is present at the base of steep slopes in more northerly regions. Minor marine deposits are located in the relatively sheltered environments of Caplin Cove and the head of North Harbour and are also present within Goose Cove and near the southerly extent of the town of North Harbour (to the north of the bedrock assemblages). The marine deposits within Goose Cove overlie glacial diamicton (Catto and Taylor, 1998b).

1.3.3 Sea-level fluctuations

Deglaciation of the Placentia Bay shoreline occurred approximately 12,000 – 11,000 B.P (Catto *et al.*, 1997). Since deglaciation, Placentia Bay has experienced a series of changes in sea-level, the bay-head area exhibiting the greatest fluctuations of the Avalon Peninsula (Catto, 1994). Following initial deglaciation, sea-levels rose approximately 20 m above present levels, the result of glacioisostatic depression caused by the Laurentide ice-sheet to the northwest in Labrador (Catto, 1994; Catto *et al.*, 2003). Evidence is provided by erosional benches and deposited gravel terraces above current sea-level.

Following the postglacial maximum (approximately 11000 B.P), sea-levels declined to, and in some areas below present levels along the Placentia Bay shoreline (Catto *et al.*, 1999). Approximately 21 kilometres northwest of Arnold's Cove, submerged estuarine and deltaic sediments provide evidence of sea-levels 8 m below present (Shaw and Forbes 1995, Catto *et al.*, 2003). Offshore of Argentia are wave-cut terraces 19.6 metres below current sea-level (Shaw and Forbes 1995). The decline is attributed to glacioisostatic overcompensation (Catto *et al.*, 1999, 2003).

Since 6000 B.P, sea-levels have risen to current levels with some fluctuation as a result of on-going isostatic adjustment over the past 3000 years (Catto, 1994; Catto *et al.*, 2000, 2003). Catto *et al.*, (2000) investigated sea-level rise at three selected sites along the Avalon Peninsula shoreline. One of the sites, Ship Harbour (N47.36401 W53.83479), is located along the eastern shoreline of Placentia Bay. ^{14}C dating of submerged *Picea* tree stumps at this location suggest sea-level rise of between 1 mm/a and 2 mm/a over the past 2200 – 2300 years. Further ^{14}C analysis of exhumed spruce stumps near Mobile (approximately 40 km south of St. John's) suggest that sea level at this location has risen at a rate of approximately 6 mm/a over the past 300 years (Catto *et al.*, 2003). Further refinements to this approximation place the actual rate of sea-level rise on the order of 3-3.5 mm/year (Catto, 2006).

1.4 Climate

1.4.1 Early to mid-Holocene variations

In North America, the period following deglaciation (approximately 11.5 ka B.P) was characterized by climatic variability, with smaller scale regional variability. Throughout the Holocene, the climatic trend is generally characterized by warming, although periods of cooling have been recorded in proxy data. Hu *et al.*, (1999) describes evidence of a pronounced North American cooling event 8.9 ka B.P; likely caused by the final collapse of the Laurentide ice sheet. Alley *et al.*, (1997) reported another cooling event between ~8.4 to 8 ka B.P extending well beyond the boundaries of the North Atlantic Basin. Between 8 ka B.P and 3 ka B.P, such variability appears to have increased relative to the preceding and succeeding millennia (Sandweiss *et al.*, 1999). Although global CO_2 levels were increasing during this period, changes in thermohaline circulation and insolation may have caused a period of global cooling between 7 and 5 ka B.P (Steig, 1999). By 3000 years ago, the climate became relatively stable and continued its general warming trend.

1.4.2 Recent climatic variations

Between approximately 900-1300 AD, a period of climatic history characterized by warm temperatures in Europe and neighbouring regions of the North Atlantic comparable to temperatures of the late 20th century occurred (Mann, 2002; Catto et al., 2003). Referred to as the *Little Climatic Optimum* or *Medieval Warm Period*, the period was marked by the expansion of the range of plants such as grapes, figs, and olive trees beyond their current northerly range (Mann, 2002). Glacial retreat of mountain glaciers in Europe also likely occurred, as evidenced in the geological record of these areas (Grove and Switsur, 1994).

Following this period, a colder and in some areas, wetter period referred to as the Neo-glacial occurred along the margins of the northern North Atlantic (Catto *et al.*, 2003; Mann, 2002). Colder mean temperatures and increased precipitation helped contribute to a reduced growing season in many areas. Catto *et al.*, 2003 states that some communities in Newfoundland were temporarily abandoned due to crop failures during this time. By the mid-19th century, the Neo-glacial had generally ended in North America, although regional variations persist.

1.4.3 Modern climate

The current climate of the Atlantic Provinces is greatly influenced by the ocean and predominately westerly winds (Environment Canada, 1994). Much of the island portion of Newfoundland falls within the Köppen-Geiger Dfb category (Banfield, 1981). Local weather patterns for the study area are predominantly influenced by Placentia Bay to the south and Trinity Bay to the north. Proximity to these two water bodies moderates the climate of the study area, in particular temperatures.

On the Avalon Peninsula summers are generally short, cool, and wet, winters mild and wet, springs long, and autumns short (Catto et al. 2003). At Come by Chance, mean daily temperatures are approximately -4.6° C in January and 14.1° C in July. Mean annual precipitation is approximately 1250 mm, 15% of which falls as snow (Environment Canada, 2004).

Newfoundland is noted for its considerable seasonality and unpredictable weather patterns. Fog is common to many coastal regions. The island portion of the province, generally, receives 1400-1550 hours of sunshine annually (Banfield, 1981). This is amongst the lowest recorded levels in Canada.

Wind patterns vary both spatially and seasonally. Generally, coastal areas experience higher wind speeds than inland areas. In Placentia Bay, easterly and southwesterly winds alternate during the summer months and southwesterlies dominate during the winter (Catto *et al.*, 2003). Along the western portion of the isthmus connecting the Avalon Peninsula to the Newfoundland mainland, southwesterly winds are prevalent throughout much of the year (Catto, 1994; Newfoundland and Labrador Refining Corporation, 2006). Strong southwesterly winds are associated with many of the major summer and autumn storms in Placentia Bay and the southwest – northeast orientation of the bay allows these winds to be effective agents of shoreline modification (Banfield, 1993; Catto *et al.*, 2003). Northeasterly winds are not generally effective at modifying the shoreline in Placentia Bay (Catto, 1994; Catto *et al.*, 2003).

Annually, 28% of winds at Arnold's Cove between 1971 and 1993 were from the southwest while 13 – 15% were from the northeast, northwest, and south (Newfoundland and Labrador Refining Corporation, 2006). Using data obtained from the Meteorological Service of Canada, Newfoundland and Labrador Refining Corporation (2006) calculated monthly mean hourly wind directions based on a 32 year sample for Arnold's Cove (Table 1.1).

	NE	E	SE	S	SW	W	NW	N
January	13.6	4.3	6.7	7.1	24.9	14.8	21.2	7.1
February	16.8	3.5	6.4	7.5	22.3	12.7	23.4	6.5
March	19.2	4.4	6.4	10.5	26.9	12.0	14.2	5.9
April	20.8	6.0	10.8	13.3	26.0	5.7	10.8	6.1
May	19.6	5.3	15.2	16.8	25.0	4.3	8.3	4.5
June	15.5	4.2	18.9	18.3	29.1	3.3	6.0	3.6
July	9.3	3.3	13.2	27.2	37.4	3.0	3.3	2.3
August	12.4	3.5	13.7	18.9	34.1	5.4	7.0	4.0
September	14.4	3.5	5.5	14.4	32.7	10.0	13.0	5.9
October	13.8	2.9	5.6	10.8	30.1	11.7	17.0	7.3
November	14.3	3.8	6.5	8.6	24.4	12.2	22.8	7.1
December	14.7	3.9	5.3	6.8	24.2	11.2	23.6	9.7

Table 1.1. Wind direction percentage totals for Arnold's Cove 1971 to 1993 (Source: Environment Canada, 2003)

1.5 Oceanography

1.5.1 Wave climate

Modal significant deep water wave heights off the open Atlantic shoreline are 7-8 m throughout the year (Neu, 1982). However, this represents modal conditions and individual waves are known to exceed these heights. Modal wave periods generally fall between 6 and 8 seconds off much of the eastern Newfoundland coastline (Catto *et al.*, 2003).

Due to the northeast – southwest orientation, Placentia Bay is exposed to waves originating in the Atlantic Ocean (Chevron *et al.*, 1996). The eastern channel of Placentia Bay reaches depths of 200 metres and extends from the mouth to near the head (Chevron *et al.*, 1996). This allows deep water waves originating offshore to propagate a considerable distance into the bay before being influenced by shallow-water bathymetry. Total wave energy off the southern Newfoundland coast may be 5 to 6 times greater during the winter than during the summer (Farmer, 1981).

The largest measured fetches within the study area coincide with the dominant southwesterly wind direction. The head of the bay is, however, somewhat protected as a result of the presence of Merasheen Island and Long Island. This may help to dampen the wave energy experienced in the study area.

A study conducted in 2004 for the IMTT transshipment terminal at Whiffen Head estimated that waves in that area would exceed 1 metre in height only 10% of the time (Seacom, 2004). During the summer months, waves were not expected to exceed 0.5 metres in height more than 25% of the time.

1.5.2 Tides and currents

Tides of the study area may be classified as semi-diurnal, with two daily high and low tides propagating southwestward along the eastern Newfoundland shoreline (Catto *et al.*, 2003). Tides along the eastern Newfoundland shoreline are considered microtidal although low-mesotidal conditions do exist at the heads of some shallow embayment such as Come By Chance (Catto *et* al., 2003). The mean tidal range for Placentia Bay is approximately 1.6 metres with the largest spring tides near 2.4 metres (Canadian Hydrographic Service, 2003). Compared to changes induced by wave action, tides may be considered ineffective agents of shoreline modification in Placentia Bay (Catto *et al.*, 2003).

Surface water circulation in Placentia Bay is generally counter-clockwise, although local variations do exist (Catto *et al.*, 1997). Currents generally travel north along the western side of the Avalon Peninsula and south along the eastern portion of the Burin Peninsula. Diverse circulation patterns have been measured at the head of the bay (Chevron *et al.*, 1996).

1.5.3 Sea-ice

Several classifications of ice type are described by the Canadian Ice Service. New Ice refers to ice that first develops when the sea freezes (Environment Canada, 2003). Over the progression of the winter months, ice grows in extent and thickness and is referred to as grey ice. During the 30 year period prior to 1998, new ice occurred throughout the majority of Placentia Bay less than 25% of the time by late February (Environment Canada, 2001). Grey ice occurred less than 25% of the time along the eastern shoreline north of Placentia by late February but did not extend into the study area (Environment Canada, 2001). Pack-ice rarely extends north of Argentia, although by late February local brash ice forms in most of the sheltered embayments of northeastern Placentia Bay (Catto *et al.,* 1999). During severe years sea-ice in Newfoundland waters may extend south of latitude 45°N (Farmer, 1981). However, relative to many other coastal areas of Newfoundland, Placentia Bay is not substantially affected by sea-ice.

The occurrence of icebergs is sporadic. Generally, they are concentrated near the mouth of the bay. Icebergs have been sighted as far north as Argentia and Red Island but are unlikely to drift as far north as the study area (Newfoundland and Labrador Refining Corporation, 2006).

According to Catto (1994), ice-foot development in the 50 years prior to 1994 was not as consistent on the Placentia Bay coastline relative to the coastlines of Conception Bay and Trinity Bay. However, between 1989 and 1994 ice-foot development was more extensive than in the previous 45 years. During the mild winters of 1995 and 1996, and during the early 1980s, ice-foot development did not occur in Placentia Bay (Catto *et al.*, 2003). Similarly, ice-foot development did not occur along the eastern shore of Placentia

Bay from Cape St. Mary's to the northern tip of the Argentia Peninsula during the El Nino winter of 1997-1998 (Catto *et al.*, 2003).

1.6 Coastal vegetation

Much of the Placentia Bay shoreline, including all of the study area, falls within the Maritime Barrens ecoregion (South, 1983). Some northerly and southerly areas of the Placentia Bay shoreline are also classified within the Central Newfoundland and Long Range Barrens ecoregions respectively The Maritime Barrens ecoregion is characterized by extensive barren areas consisting mainly of ericaceous dwarf shrub vegetation, blanket bogs and shallow, oligotrophic bogs and fens (South, 1983; Damman, 1981). Boreal forest may be found in valleys, and some hilltops and slopes (South, 1983). However, much of this has been replaced by dwarf shrub heath as a result of anthropogenic fire and logging (Catto *et al.*, 2003).

Dwarf shrubs are dominated primarily by *Kalmia angustifolia* although other species such as *Rhododendron canadense* and *Vaccinium angustifolium* are abundant (South, 1983; Damman, 1981). Kalmia may be replaced by *Empetrum nigrum* and *Vaccinium vitis-idaea* on exposed sites (Meades, 1973; Damman, 1981). On exposed sites overlooking the shore, additional species may be present including *Arctostaphylos, Vaccinium boreale, Ledum groenlandicum*, and *Rubus chamaemorus* (Ryan, 1978; Thannheiser, 1984). Site-specific factors including slope, drainage, aspect, temperature, precipitation, and frequency of fog may affect vegetation distribution throughout the study area.

2.0 Previous Work

2.1 Shoreline processes and oil spill contamination

Understanding the properties of oil is important when determining how it will react and persist in the environment. The physical characteristics of the shoreline and the processes operating during the time of a spill also influence the behaviour and persistence of spilled oil. Figure 2.1 illustrates the effect of some of the major factors affecting oil persistence on shorelines.

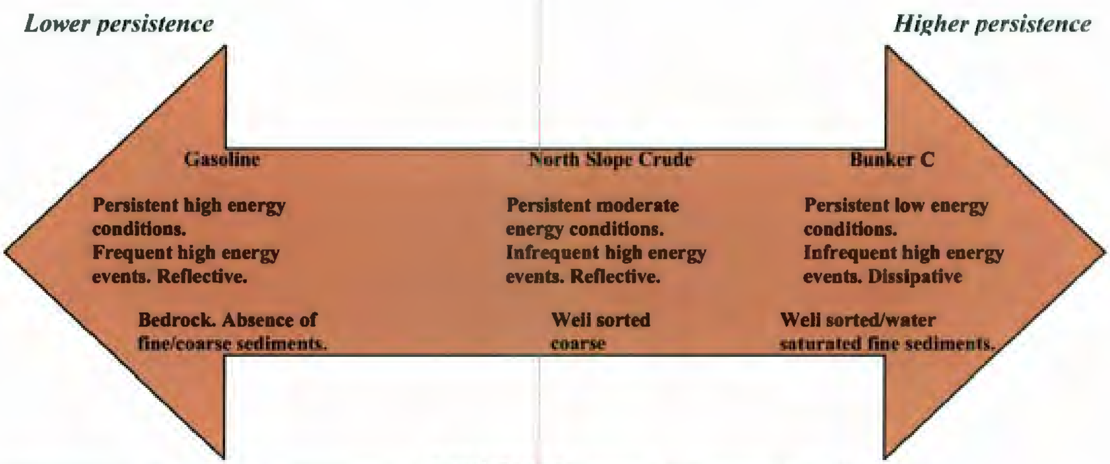


Figure 2.1. Summary of the major persistence factors for stranded oil

Oil properties which are of particular interest to the study of persistence are specific gravity, pour point, and viscosity (International Tanker Owners Pollution Federation Limited (ITOPF), 2007). Specific gravity is a measure of density and determines whether oil will float or sink. The specific gravity of most oils is below 1.0 which means the oil will float on the waters surface. Heavier oils such as Bunker C have a specific gravity measure of very near 1.0. Weathering of such oil may cause the specific gravity to increase above 1.0, causing it to sink. Lighter oils which have been substantially weathered may also have a specific gravity above 1.0.

The pour point of oil refers to the lowest temperature at which oil will flow as a liquid. Below the pour point, oil begins to act as a semi-solid. Light oils such as gasoline have a lower pour point than heavier oils, such as Bunker C. Viscosity is inversely related to temperature. Light oils, such as gasoline, have low viscosity values of approximately 0.05, at 38°C. Heavy oils, such as Bunker C, have high viscosity values of approximately 30, at 38°C. With the exception of very light oils, most oils will have a higher viscosity than saltwater (approximately 0.4 at 38°C). However, light oils may behave as high viscosity oils at low temperatures. High viscosity oils are more resistant to dispersion by wave action than are low viscosity oils (Maderich and Brovchenko, 2005). Both the pour point and viscosity of spilled oil are important when determining the degree of beach sediment penetration.

Generally, the natural degradation and dispersion of spilled oil is directly related to the level of wave energy (Owens, 1994). In Atlantic Canada, high energy beaches are generally reflective. Under these circumstances, the natural breakdown of spilled oil is generally higher, and persistence less relative to dissipative systems. However, this broad relationship can be affected if oil is protected from wave action through burial or sediment penetration (Owens, 1994). Sediment reworking as result of normal shoreline accretion can bury oil as deep as 1 metre within 1 year (Fingas, 2001). Similarly, continued reworking may bring buried oil to the surface. An indicator of the energy of a beach system may be determined through an analysis of grain shape and roundness (Masselink and Hughes, 2003). For instance, well-rounded, low-sphericity sediments may indicate a high energy environment where there is constant mechanical abrasion as a result of wave activity.

Transport dynamics should also be considered. In addition to determining which sections of shoreline will most likely receive oil, the distribution of sediments and debris provide insight into how spilled oil will be transported and distributed. Shore-normal transport will distribute oil largely over the intertidal or wave-influenced portion of the beachface. Shore-parallel transport will increase the likelihood of oil distribution laterally along entire beachface. Longshore currents influence both coastal erosion and accretion (Masselink and Hughes, 2003) and may provide additional insight into sediment burial potential.

Sediment penetration is related to sediment texture and oil viscosity (Owens *et al.*, 2007). Coarse textured sediments such as cobble and boulders offer more pore space than finer sediments such as granules and sands. Bladed and oblate shaped sediments (c.f. Zingg, 1935) can be packed more closely, and thus can offer less pore space than would an assemblage dominated by equant or prolate clasts. Higher porosity allows for deeper oil penetration. Generally speaking, oil penetration will be less on shorelines dominated by poorly sorted, water saturated, fine textured sediments (Baker, 1999). Less viscous oils more readily penetrate sediment matrices than viscous oils.

Oil penetration of fine sediments such as clay and silt may increase the natural breakdown of stranded oil through oil-mineral fines interaction. An example of such a process is provided by clay-oil flocculation, which allows oil to degrade despite the absence of high wave energies (Bragg and Yang, 1993; Owens, 1994). In some instances, oil may persist on the surface in the form of asphalt pavements. Asphalt pavements may be produced as a result of stranded oil mixing with shoreline sediments, typically in the upper-intertidal zone (Owens *et al.*, 2007). Asphalt pavements are highly resistant to erosion.

The presence of snow and ice may also influence the persistence of oil. Oil may be restricted from reaching the shoreline while the movement of ice may aid physical degradation. Alternatively, ice movement may protect oil from incident way energy, bury oil, or move oil above the zone of maximum wave activity (Owens, 1994).

2.1.1 Arrow

The tanker *Arrow* ran aground in Chedabucto Bay along the coast of Nova Scotia in early February, 1970. Approximately 80,000 barrels of heavy Bunker C fuel oil were released. The spilled oil had a pour point of -1.1°C (Owens, 1994), which was greater than the temperature of the water. This caused the oil to behave as a semi-solid. An estimated 300 km of shore were eventually oiled. The majority of the spilled oil was removed by natural processes such as physical abrasion and hydraulic pressures resulting from moderate to high wave incident wave energies (Vandermeulen, 1982; Owens *et al.*, 1994; Owens, 1994). Between 1970 and 1975, Thomas (1977) reported a logarithmic reduction of surface oil cover on the north shore of Chedabucto Bay. However, despite the low pour point and high viscosity, oil in sheltered environments had degraded relatively slowly over the same time period due to deep penetration of coarse textured shoreline sediments (Thomas, 1978). More sophisticated studies conducted by Rashid (1974) indicated the residual oils in low energy environments may remain unaltered for years. Further studies by Vandermeulen and Gordon (1976) suggested that oil residues persisting by 1975 in Chedabucto Bay had the potential to remain for at least 170 years.

As of 2006, the majority of oil remaining from the Arrow spill exists at Black Duck Cove at both exposed and sheltered locations (Owens *et al.*, 2007). Highly weathered asphalt pavements persist within the upper-intertidal zone. Oil persists subsurface within the mid and upper-intertidal zones due to infiltration. This has restricted penetration by seawater and reduced the ability of wave action to rework and redistribute beach sediments by increasing the entrainment threshold (Owens *et al.*, 2007). Lack of sediment fines which contribute to biophysical weathering such as clay-oil flocculation and biodegradation helped oil to persist in some areas (Owens, 1994). However, in sheltered locations which were heavily oiled initially following the spill but are now virtually oil free, the presence of fine sediments may have contributed to clay-oil flocculation weathering (Owens, 1994). A surface cover of boulder armour has also protected oil veneers on bedrock and coarse-grained clasts persisting below the normal zone of sediment redistribution (Hayes *et al.*, 1991; Isla, 1993). Weathering processes were still evident as of 2006 (Owens *et al.*, 2007).

2.1.2 Baffin Island Oil Spill (BIOS) Experiment

The BIOS experiment took place in mid-August, 1981. Approximately 30 barrels of slightly weathered (8% weight loss), Lago Medio crude were released near a sheltered beach on northern Baffin Island, Canada (Prince *et al.*, 2002). The beach was characterized by mixed coarse-sediments, low wave-energy levels, and an ice-foot 10 months of the year. No attempts at remediation were made.

The amount of oil initially released exceeded the absorption capacity of the beach sediments and the majority of the oil was refloated and removed by natural processes within 24 hours (Owens *et al.*, 1994). Despite cold temperatures, by 1983 much of the remaining oil persisted largely within the sediments of the beachface and on the gravel-cobble low tide ridge (Owens, 1994). Oil-mineral fines interaction may have also played a role in the removal of BIOS oil (Prince *et al.*, 2002). Within 4 open water months of the experiment, a resistant asphalt pavement had developed in the upper-intertidal zone which persisted for an additional 13 open-water months (Owens *et al.*, 1994; 2002; Owens 1994; Owens and Humphrey, 1988). By 2001 the resistant asphalt pavement had disintegrated while unaltered and highly biodegraded oil still persisted interstitially amongst some of the coarser beach sediments (Owens *et al.*, 2002; Prince *et al.*, 2002).

2.1.3 Exxon Valdez

In March of 1989, the tanker *Exxon Valdez* ran aground in Prince William Sound, Alaska. Over a period of a few days, over 250,000 barrels of North Slope Crude oil were lost resulting in the contamination of over 700 kilometres of shoreline within the Sound (Owens, 1994). A further 9500 km of coastline were oiled to varying degrees when the oil was carried by currents into the Gulf of Alaska (Jahns *et al.*, 1991; Owens, 1991a). Due to a combination of spring tides and winds during the time of the spill, oil deposited along the Prince William Sound shoreline (72% bedrock; 24% mixed coarse-sediment) was primarily within the upper-intertidal and supra-tidal zones (Owens, 1991b).

An intensive cleanup response was initiated in the spring of 1989. The artificial removal of oily debris and flushing of heavily oiled sections of shoreline allowed natural cleaning processes to be more effective during the following winter (Owens, 1994). Flushing also reduced the formation of resistant asphalt pavements (Owens, 1994) in an environment that would have otherwise been very conducive to their formation (Owens, *et al.*, 1986).

Residual oil has persisted in both surface and subsurface environments within Prince William Sound. Ground surveys completed in 2002, 2004, and 2005 found isolated occurrences of surface oil primarily in the form of asphalt pavements. The pavements were primarily found in areas protected from the effects of normal wave energy, including the supra-tidal zone and behind coastal boulders and bedrock formations (Owens *et al.*, 2007). Subsurface oil has persisted mainly on three north facing coarse sediment beaches on Smith Island, Northwest Bay, and Latouche Island (Michel and Hayes, 1999; Short *et al.*, 2004; Taylor and Reimer, 2005). The majority of subsurface oil exists as a discontinuous 3 cm thick band buried beneath a 5-10 cm thick armouring layer of sediment within the upper portion of the shoreface (Taylor and Reimer, 2005).

2.1.4 Braer

In early January of 1993, the oil tanker Braer ran aground on the southern shore of the Shetland Islands. Approximately 640,000 barrels of light, Gullfaks Norwegian Crude oil was spilled. A smaller quantity of Bunker C and diesel was also lost. The pour point of the Gullfaks oil was approximately -15°C (StatoilHydro, 2007), considerably less than the temperature of the surrounding surface waters. The nearby coastline is characterized largely by steep cliffs and wave exposed rocky sections of shore (Newey and Seed, 1995). Despite these factors, the light nature of the spilled crude and very high wave-energy conditions at the time of the spill helped to disperse much of the oil before it reached shore (Edgell, 1994; Newey and Seed, 1995). A week after the spill ground surveys identified only a few contaminated sections of shore (Ritchie, 1993).

2.1.5 Placentia Bay

Prior to the early 1980s, many of the studies of the eastern Newfoundland shoreline focused on general descriptions of the Quaternary history of the area. Since 1980, the Geological Survey of Canada has conducted research more focused on the factors that affect oil spill behaviour such as geomorphology and coastal processes and dynamics (Forbes, 1984; Forbes and Syvitski, 1995; Forbes and Taylor, 1994; Shaw and Edwardson, 1994; Shaw and Forbes, 1987; 1990; 1995; Shaw and Frobel, 1992; Shaw *et al.*, 1989; 1990; 1992a; 1992b; 1998; 1999; Syvitski and Shaw, 1995). Throughout the 1990s, a cooperative program between the Geological Survey of Canada and the Geological Survey of Newfoundland and Labrador monitored coastal geomorphic and textural changes and shoreline erosion (Catto *et al.*, 2003). The program was not intended to assess oil spill dynamics, but the data collected can be used in oil spill studies. Recent research focusing on several eastern Newfoundland coastal sites has also been conducted by researchers based at Memorial University of Newfoundland and Labrador (Pittman, 2005; Taylor, 1994; Connors and Tuck, 1999; Prentice, 1993; Jones, 1995; White, 1999; Griffiths, 1999; Boger, 1994, Catto *et al.*, 1997; 1999; 2003; Etheridge, 2005, Catto and Etheridge 2006).

Classifying a shoreline with respect to oil spill sensitivity was a concept originally developed in 1976 for the Lower Cook Inlet (Hayes *et al.*, 1976; Michel *et al.*, 1978). Since then the idea has been further refined. Systems for classifying the sensitivity of the Placentia Bay shoreline to an oil spill have been based on ideas proposed by John R. Harper for the Pacific Coast of Canada and concepts expressed in Howes *et al.* (1993) and Owens (1994).

In 1980, Ed Owens, under the auspices of Mobil Oil Canada, conducted reconnaissance flights of the Placentia Bay shoreline, including the study area. The purpose of these flights was to establish an oil spill response baseline in preparation for future petroleum exploration/production activities (Jim Dempsey, Environmental and Emergency Response Advisor, Husky Energy, personal communication). Poor resolution, and inconsistent camera angles and perspective, as well as a lack of temporal variation (only single flights were conducted) negatively affected the utility of these videos for determining oil spill sensitivity in certain areas, particularly the southern portion of the Cape Shore. However, the data captured was useful for the development of a broad based oil spill sensitivity classification scheme for the Placentia Bay shoreline. This data continues to provide an important shoreline information resource for emergency oil spill response in the region. Specifically, the data acts as the baseline for the Atlantic Sensitivity Mapping Program, which is used by Eastern Canada Response Corporation, the registered Response Organization for Placentia Bay as well as Environment Canada's Environmental Emergencies Branch.

Catto *et al.* (1997, 2003) utilized the abovementioned videos as well as aerial photos and site visits to geomorphically and sedimentologically classify the Placentia Bay shoreline. Specifically, the classification system focused on shoreline substrate, slope, and sediment texture (Catto *et al.*, 1997, 2003). It also incorporated spatial transitions along the shoreline and provided a method for expressing the temporal variability of specific sections of shoreline. This is important as it exemplifies the seasonality and overall variability of oil spill sensitivity in specific areas, which in-turn provides an opportunity for more effective oil spill response.

Additional work completed by Catto *et al.* (1999) added a preliminary, biological component to the previously-noted classification. Furthermore, the study also examined the degree to which the biological components were related to and affected by the geomorphological components (Catto *et al.*, 1999). A lack of such detailed, regional environmental sensitivity data was one of the findings from the Public Review Panel on Tanker Safety Spills Response Capability (Brander-Smith *et al.,* 1990), which identified Placentia Bay as an area having a high potential for an oil-related environmental accident. This study helped to fill that gap. Additionally, as the occurrence of shoreline species is largely a product of substrate type and wave exposure, the absence or presence of specific intertidal species provides a means for determining wave exposure at specific sites (Harper and Morris, 2004).

2.2 Marine debris

Marine debris may be generally described as discarded anthropogenic solid wastes that are present in the marine environment (Leous and Parry, 2005). Concern for marine debris has been expressed from a variety of biologic, environmental, and economic perspectives. In areas especially reliant on fishing and tourism, marine debris can have serious negative economic impacts (Otley and Ingham, 2003). Predicting where marine debris may be distributed can be difficult, as mobile litter can travel long distances from their source. However, nearshore current patterns and wave activity offer a potential guide (Catto *et* al., 2003, Pink 2004). Subsequently, the presence of marine debris may provide a better understanding of transport dynamics, which is important for understanding the behaviour of spilled oil. For this reason, the study of marine debris should be of particular importance to Placentia Bay.

The majority of marine debris around the world is comprised of plastics (Ross *et al*,. 1991; Lucas 1992; Coe and Rogers 1997; Frost and Cullen 1997; Walker *et al*,. 1997; Willoughby *et al*,. 1997; Bowman *et al*,. 1998; Leous and Parry, 2005). Approximately 80% of marine debris originates on land (Leous and Parry, 2005), although the fishing industry has been shown to be a major source, particularly at sites near fishing areas which are relatively isolated from major cities (Otley and Ingham, 2003; Piatt and Nettleship, 1987; Pruter, 1987; Lucas, 1992; Wace, 1994; Walker *et al*,. 1997). Lines, nets, and other plastic fishery related debris on shorelines was less in areas where fishing activity had declined or ceased (Merrell 1984; Velander and Mocogni 1998). Similarly, areas near major shipping lanes have a tendency to accumulate plastic jetsam (Horsman, 1982; Vauk and Schrey, 1987).

Anthropogenic wood is generally considered to be the second most abundant type of marine debris (Catto *et al*., 2003). Marine debris found in areas near large cities or major fishing areas tend to have a relatively high proportion of wood (Lucas, 1992). Glass, metal, and rope debris are also commonly observed on shorelines. Depending on wind, tide, and current patterns, debris can originate from a variety of nearshore and offshore sources including recreation and tourism, fishing, and shipping related activities. An area need not be in close proximity to a source to collect debris. Uninhabitated, isolated shorelines are capable of accumulating as much debris as populated ones (Benton, 1995; Gregory and Ryan, 1997; Haynes, 1997; Ribic *et al*., 1997; Convey *et al*., 2002). Some beaches act as litter sinks, collecting debris temporarily or permanently (Somerville *et al*., 2003). It is the quantity and type of such debris that will be considered in this study.

2.2.1 Placentia Bay

The issue of marine debris in Newfoundland, including the eastern shoreline, has not received a lot of attention from researchers (Catto *et al.*, 2003; Pink, 2004). However, some preliminary work has been completed. In 2004, the Canadian Department of Fisheries and Oceans conducted beach surveys along much of the Placentia Bay shoreline and qualitatively expressed the severity of debris accumulation at each site. Between 1995 and 2002, PITCH-IN CANADA, in cooperation with Environment Canada's Marine Environment Division, conducted a national marine surveillance program. Data on marine debris were collected from both the Pacific and Atlantic coasts, sourced, and compared to debris collected in other countries. Since 1997, Ocean Net® has made efforts to increase public awareness of the issue of marine debris and has organized numerous beach cleanups. Unfortunately, the previously noted works do not provide specific information on the composition, volume, or source of litter along the Placentia Bay shoreline. However, they are still helpful for the purposes of assessing potential oil spill exposure.

Casual observations described in Catto *et al.*, (2003) provide valuable insight into the type and location of marine debris along the eastern Newfoundland coastline, including Placentia Bay. Along the northeastern coast of Newfoundland, the proportion of fishery related debris has decreased since 1992 (Catto *et al.*, 2003). This is likely related to the decrease in fishing activity associated with the 1992 cod moratorium. However, along the Placentia Bay shoreline where active fisheries are still based, fishery related debris is still a major component (Catto *et al.*, 2003). Such debris is seasonal. Increases are often associated with the opening and closing of specific fishing seasons. During the summer months, the proportion of domestic debris increases. General increases in the volumes of marine debris tend to occur during the breakup of winter ice as well as during high energy storm events such as hurricanes along the Placentia Bay shore. In contrast to the global trend of plastic dominated marine debris, debris found along the eastern Newfoundland shoreline typically contains lower proportions of plastics and higher proportions of anthropogenic wood (Catto *et al.*, 2003).

Pink (2004) described the litter assemblages of 4 east coast Newfoundland beaches based on quantitative surveys conducted between November of 2003 and May of 2004. Arnold's Cove, which is within the study area, recorded the highest quantity of litter. This was attributed to the predominant southwest wind direction, funneling effects of the wind around several major islands, north flowing tides, a sheltered coast, and weak shore-parallel currents (Pink, 2004). As in other studies, the majority of debris was composed of plastics (with the exception of the Ferryland site). At the Arnold's Cove site, fishery related debris dominated. Increases in the abundance of marine debris were also noted at Arnold's Cove following the winter months (Pink, 2004). This is similar to observations noted in Catto *et al.*, (2003). Casual littering and unregulated waste disposal were found to be the primary sources of marine debris at the other 3 sites. Observing the concentrations of marine debris at other sites and the physical features that contributed to those concentrations may provide some indication of the behaviour of spilled oil at the head of Placentia Bay.

2.3 Exposure, sensitivity, and vulnerability

Catto *et al.*, (2003) provided additional discussion of the geomorphologic, sedimentologic, and coastal energy level conditions of the eastern Newfoundland shoreline, including Placentia Bay. Shoreline classification was based on the same system employed in Catto *et al.*, (1997). The report also ranked sensitivity to petroleum contamination for each shoreline class.

Additional data on the geomorphologic and sedimentologic character of the eastern Newfoundland shoreline are discussed in Etheridge (2005). Specifically, that report analyzed the sensitivity to petroleum contamination of 5 beach systems on the southeastern Avalon Peninsula shoreline. Etheridge focused on the temporal variability of beach slope, beach sediments, and energy levels present at each system.

Additional work by Catto and Etheridge (2005) built upon this previous research in an attempt to classify the vulnerability of each of these beach systems. The potential exposure to oil pollution was assessed for each system based on a variety of criteria including population dynamics, type and intensity of economic activity, location relative to major shipping lanes and petroleum development, as well as transport dynamics and local energy regimes (Catto and Etheridge, 2005). Sensitivity was analyzed using the considerations previously-listed for Etheridge (2005). Finally, a vulnerability assessment was undertaken by combining the results of the exposure and sensitivity evaluations. A similar approach will be utilized to assess the vulnerability of the 4 beach systems presented in this paper.

3.0 Methods

3.1 Site selection

The head of Placentia Bay was chosen for study due to the growing number of tanker vessel movements in the area. The 4 study beaches selected for intensive study were chosen on the basis of accessibility, variability of wave climate, dynamics, and sedimentology, and proximity to existing and proposed shore-based oil handling facilities. Site visits were attempted at approximately 3 month intervals, although visits to some sites did not adhere to this timetable. The 4 beaches provide a general representation of the dominant types of shoreline found in the bay head area.

3.1.1 Arnolds Cove beach

Arnold's Cove is a pebble-cobble beach located at the easternmost extremity of the study area (Figure 3.1). It is located in the northeastern region of Placentia Bay within the community of Arnold's Cove. Arnold's Cove beach is approximately 334 m in length. It is oriented along a northwest-southeast trend and has a maximum fetch of approximately 15 kilometres to the southwest. A lagoon backs the beach which occasionally drains to the ocean via a surface outlet near the eastern portion of the beach. Cusps, berms, and antecedent overwash fans are present throughout the beach but are concentrated at the western end where energy levels appear to be higher. Following the classification scheme proposed by Catto *et al.*, (2003), Arnold's Cove may be categorized as a wide gravel flat (Class 13).

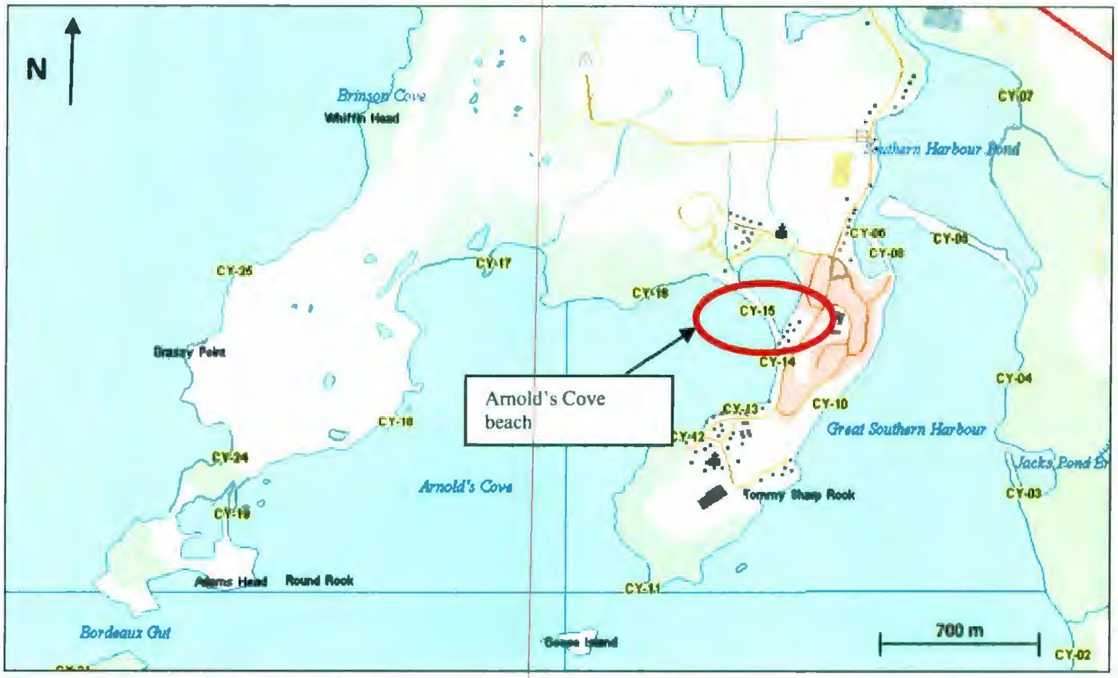


Figure 3.1. Arnold's Cove beach

3.1.2 Come by Chance beach

Come by Chance beach is a pebble-cobble beach located at the head of Come by Chance Gut (Figure 3.2). The study section of shoreline measures approximately 205 m in length. It is oriented along a northwest-southeast trend and has a maximum fetch of approximately 20 km to the southwest. Come by Chance River runs directly west of the beach. The estuary provides important spring and fall staging habitat for waterfowl and is a recreational area. The cobble dominated barachoix periodically extends westward, closing the eastern outlet of Come by Chance Gut. The easternmost area of the beach is marked by an anthropogenic breakwater. Following the classification scheme proposed by Catto *et al.*, (2003), Come by Chance may be categorized as a bouldery tidal flat (Class 24).

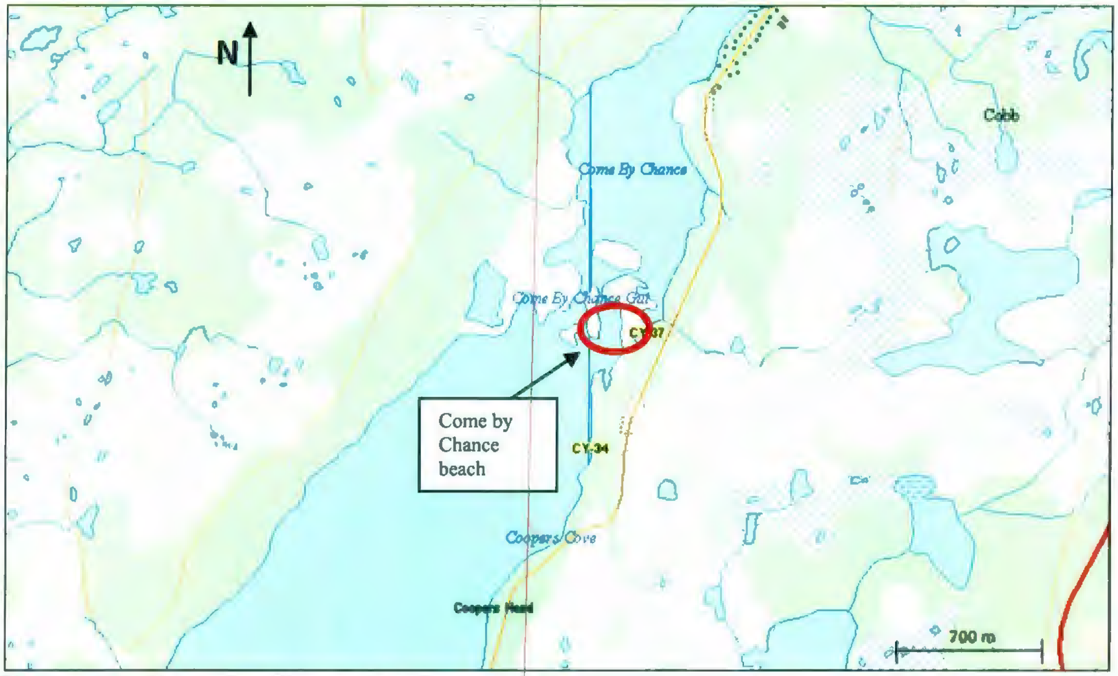


Figure 3.2. Come by Chance beach

3.1.3 Hollett's Cove beach

Hollett's Cove beach is a pebble-cobble beach located along the southern shore of Southern Head (Figure 3.3). The area surveyed is approximately 55 m in length. Hollett's Cove is oriented southwest-northeast and has a maximum fetch of approximately 60 km to the southeast. A small lagoon backs the western portion of the beach and flows to the ocean via a small stream. Following the classification scheme proposed by Catto *et al.*, (2003), the beach at Hollett's Cove may be categorized as a steep gravel beach (Class 15).

Figure 3.3. Hollett's Cove beach

3.1.4 Goose Cove beach

Goose Cove beach is a pebble-cobble beach located along the western shore of North Harbour (Figure 3.4). The area surveyed is approximately 184 m in length. Goose Cove beach is oriented along an east-west trend and has a relatively short maximum fetch to the southeast of approximately 1.7 km. The beach lies within the community of Goose Cove and is backed by a road and several houses. An anthropogenic wooden wall separates the upper-shoreface from the backshore. Located several metres offshore from the central region of the beach is an area of bedrock which protrudes slightly above the waters surface. Following the classification scheme proposed by Catto *et al.*, (2003), Goose Cove beach may be categorized as a sand and gravel beach on a wide rock platform (Class 7).

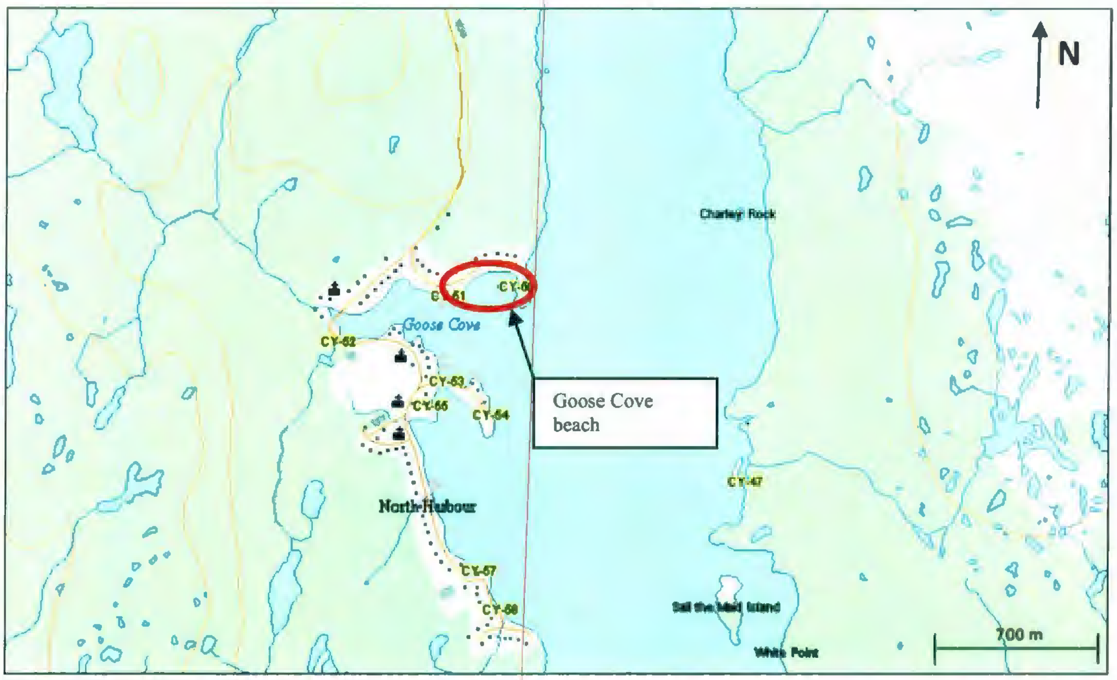


Figure 3.4. Goose Cove beach

3.2 Energy regime

Energy conditions at each beach system were quantitatively assessed using several formulae (Table 3.1). Each of the 4 study beaches were classified as either reflective or dissipative based on their calculated surf scaling parameter. Surf scaling parameter is a useful parameter for determining the relative importance of wave reflection and dissipation (Masselink and Hughes, 2003). It is a function of wave height, period, and beach slope. Wave period was estimated by recording the number of waves breaking at the beach-water interface every 60 seconds. Beach slope was determined from beach profiles. Beach profiles were surveyed at approximately 50 metre intervals beginning at fixed locations approximately 50 metres from the easternmost boundary of each beach. Transects were oriented shore-normal and extended from the shoreface-backshore interface to the waters edge. This distance was measured during each visit and divided by 5 to provide an equal number of sample points each time. The calculated mean slope for each beach was used in the surf scaling parameter equation.

Formula	Calculation	Variables
Wave Energy Density	$E = \frac{1}{2}\rho g h_i^2$	p = density of salt water g = gravity h = wave height
Wave Power	$P = E\mu$	E = Wave Energy Density μ = wave velocity (shallow water) * $\mu = \sqrt{(gd)}$ g = gravity d = water depth
Longshore Current Velocity	$V_l = 1.17\sqrt{(gh_i)}\sin\alpha\cos\alpha$	g = gravity h = wave height α = angle of incidence
Longshore Wave Power	$P_l = E\mu\sin\alpha\cos\alpha$	E = Wave Energy Density $\mu = \sqrt{(gd)}$ g = gravity d = water depth α = angle of incidence
Surf Scaling Parameter	$\varepsilon = \frac{4\Pi^2 h_i}{gT^2\tan^2\beta}$	h = wave height g = gravity T = wave period β = slope

Table 3.1. Formulae used to assess beach energy conditions

3.2.1 Wave energy

Assuming linear wave theory, the total amount of energy contained in a wave may be expressed by its wave energy density (Masselink and Hughes, 2003). Wave energy density is a function of wave height, water density, and gravity. Wave height was visually estimated during each site visit. Density was assumed to be approximately 1027 kg/m^3; assuming a constant salinity value of 35 ppt and a mean annual ocean surface temperature for Placentia Bay of 5.4°C (Fisheries and Oceans Canada, 2007).

Wave power is a measure of the rate of energy carried along by moving waves (Masselink and Hughes, 2003). It is a function of wave energy density and wave velocity. Wave velocity is influenced by water depth. Wave velocity decreases as waves propagate from deep water to shallow water. Waves measured at the shoreline were assumed to be shallow water in nature. To calculate wave velocity, a water depth of 1.0 m was used and deemed appropriate given its usage by other researchers (Pethick, 1991; Tolvanen and Suominen, 2005; and Masselink and Hughes, 2003) and was used to calculate wave velocity.

Longshore current velocity is a function of wave height and wave angle of incidence. Angle of incidence was visually estimated using a compass aligned shorenormal at a fixed location at each beach site. Longshore wave power is an estimation of the longshore component of wave power. It is a function of wave energy density, wave angle of incidence, and water depth. A shallow-water approximation of 1.0 was also used in the calculation of longshore wave power.

3.3 Sediment characteristics

3.3.1 Clast texture

Clast texture was assessed following Environment Canada's Shoreline Cleanup Assessment Technique (SCAT). The SCAT technique characterizes clasts according to grain size following the Udden-Wentworth Scheme. Collecting sample sizes from coarse grain beaches for laboratory testing is impractical due to the large sample size required (Church *et al.*, 1987; Catto, 1989; Gomez, 1983; Gale and Hoare, 1992). For example, to correctly describe gravel deposits containing a maximum grain size of 100 mm, Church *et al.*, (1987) recommended a minimum sample size of 1000 kg. As a result, sediment texture was visually estimated during site visits.

3.3.2 Clast shape and roundness

Clasts were classified based on their shape following Zingg's (1935) classification scheme for grain shape. Roundness and sphericity classifications were assigned following Power's (1953) classification scheme of grain roundness for grains displaying low sphericity and high sphericity. Measurements were visually estimated in the field by randomly selecting 25 clasts at each transect sample point previously described. Each selected clast was compared to sketches and figures illustrating grain shape and roundness (c.f. Masselink and Hughes 2003).

3.4 Morphology

Lateral shore changes at each beach system were assessed. Beach profiling provided evidence of sediment accretion and erosion rates. Visual assessments of each system were also made during site visits. The spatial distribution and size of features including cusps, berms, and marine debris were recorded using digital photography and GPS measurements. Cusp measurements recorded include wavelength, depth, and height (Figure 3.5).

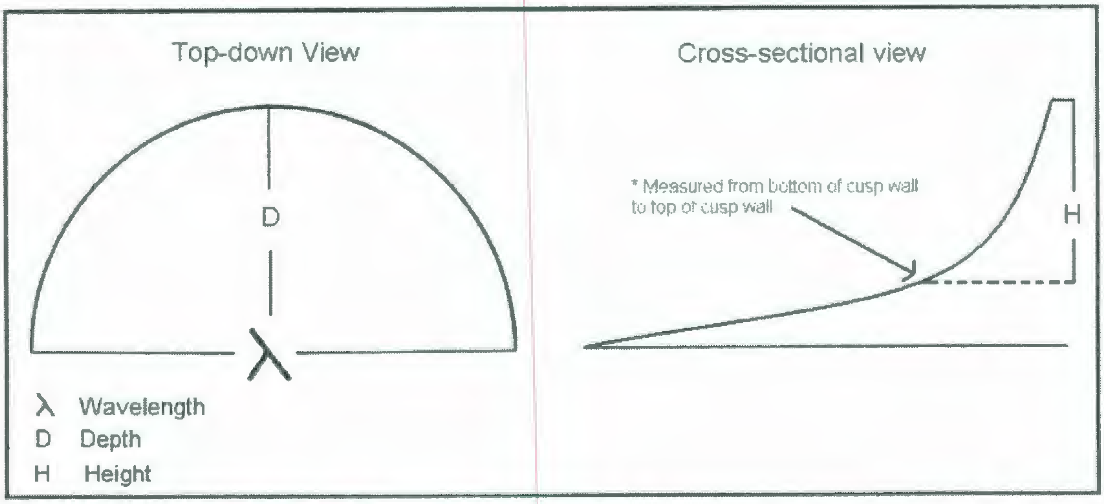


Figure 3.5. Diagram of cusp dimensions

3.5 Marine debris

3.5.1 Sampling strategies

There exist a large variety of methods for surveying beach litter. Currently however, no standard methodology exists (Williams and Tudor, 2001). The method utilized for this project most closely resembles the approaches taken by Williams and Tudor (2001) and Frost and Cullen (1997). Williams and Tudor (2001) divided a beach in

5 m wide orthogonal transects. Given the size of the beach, all beach litter was recorded. Frost and Cullen (1997) utilized 10 m-wide orthogonal transects spaced 10 m apart, sampling only a portion of the debris. This study utilized 5 m-wide orthogonal transects centered around the transects used to measure beach profiles. Transects ran from the waters edge to 6 m into the backshore (backshore beginning at vegetation line). All anthropogenic marine debris located within each transect was counted, categorized, and its location recorded. Marine debris was not collected.

3.5.2 Classification and sourcing

Classifying marine debris is important for determining source (Pink, 2004). Ribic (1998) classified debris as indicator and non-indicator items. Probable source could be assigned to indicator items (ocean-based or land-based). Indicator items described by Ribic (1998) mirrored those used in the US Marine Debris Monitoring Program (Table 3.2). Non-indicator items were categorized compositionally. The compositional categories include plastic, Styrofoam, glass, metal, paper, wood, rubber, and cloth. Probable source could not be assigned to non-indicator items. The classification and sourcing scheme for this study followed that utilized by Ribic (1998).

Probable Source	Item
Ocean-based	All gloves
	Plastic sheets > 1m
	Light bulbs/tubes
	Oil/gas containers >1quart
	Pipe-thread protectors
	Nets, traps/pots, fish baskets
	Fishing line
	Floats/buoys
	Rope >1m
	Salt bags
	Cruiseline logo items
Land-based	Syringes
	Condoms
	Metal beverage cans*
	1 quart motor oil containers*
	Mylar or rubber balloons
	Six-pack rings*
	Straws
	Tampon applicators
	Cottonswabs
General	Plastic bags with seams
	Straps
	Plastic bottles
* Indicates items sourced as land-based which may also be sourced as ocean-based	

Table 3.2. Indicator items used in the US Marine Debris Monitoring Program (from Escardo-Boomsma et al., 1995)

4.0 Results

4.1 Arnold's Cove

Arnold's Cove beach is located within the community of Arnold's Cove and at 334 m in length, is the largest of the 4 study beaches (Figure 4.1). For the purposes of this study, the easternmost boundary is located at N47.76102°, W53.98708° and the westernmost at N47.76355°, W53.98947°. The shoreline generally consists of pebble-cobble sediments, although finer grained sediments such as granules and coarse sand are also present in lesser amounts. The immediate backshore is vegetated. A lagoon backs this vegetated area and occasionally drains to the ocean via a surface outlet. Debris, cusps, berms, and antecedent overwash fans are present throughout the beach.

Figure 4.1. Arnold's Cove beach. Picture taken August 1, 2006 from eastern side of beach looking west

A total of 4 transects spaced approximately 50 m apart were used to study the beach at Arnold's Cove (Figure 4.2). Datum was determined from Canadian Hydrographic Tide Charts for Arnold's Cove. Profiles were plotted based on spring low-tide conditions. Thus, the datum level refers to spring low-tide. Transects were approximately 24 m in length measured from the low-tide water line. The shoreface (measured from the seaward side of the vegetated backshore to the low tide water line) was further sub-divided into three, approximately 6 m wide shore-parallel sections; upper, mid, and lower-shoreface (Figure 4.4). Surveys were undertaken on December 23rd, 2006, February 6th, 2007, April 13th, 2007, and September 7th, 2007. This section summarizes data collected during these surveys. Sediment characteristics, the type and distribution of marine debris, beach morphology, and energy characteristics recorded during each survey date are presented.

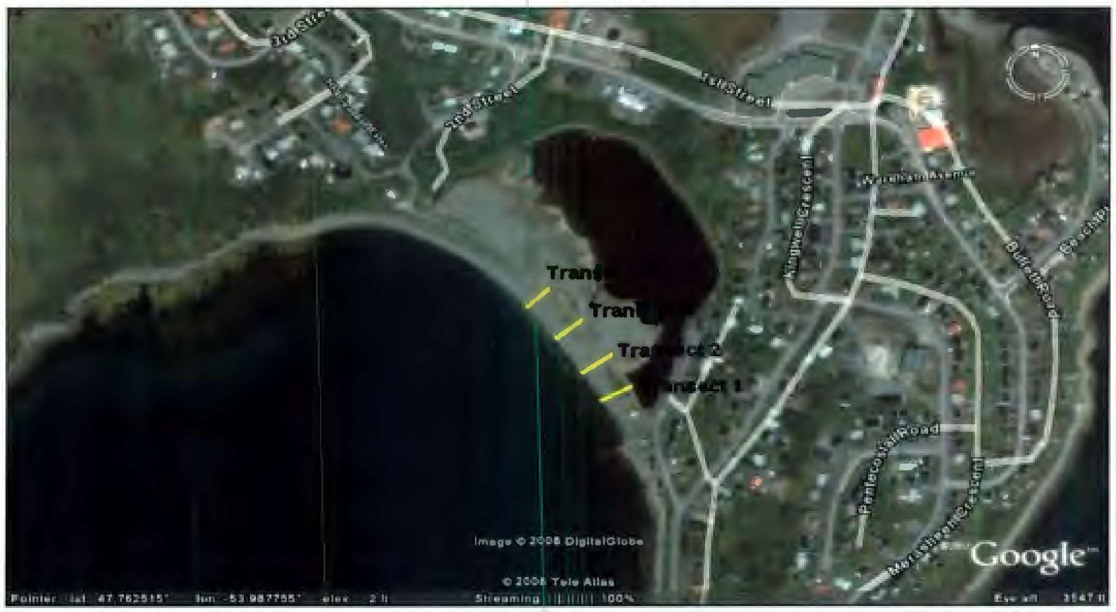


Figure 4.2. Arnold's Cove beach transect locations (Source: Google Earth, 2008)

4.1.1 Sediment Composition

Arnold's Cove beach was comprised primarily of pebble-cobble sediments. Coarse sand and granules were also present, particularly in the mid and upper-shoreface. Texture generally coarsened seaward with the largest cobbles found in the lower-shoreface. However, granules and pebbles could also be found extending into the lower-shoreface in lesser amounts. Laterally, the proportion of coarse grained sediments was generally higher along the eastern portion of the beach. This distribution may be explained by the prevalence of southwest winds and waves which impact the eastern side of the beach first. As a result of these relatively higher wave energies, finer grained sediments such as granules and sand remain entrained within the wave and are transported further west before being deposited amid lower energy conditions.

Clast shape was dominated by prolate and equant shaped clasts (Figure 4.3). Prolate clasts were more commonly found nearer the ocean than in the mid or upper-shoreface while bladed clasts were most prevalent in the upper-shoreface. Because of their shape, bladed and oblate clasts settle out of the water column at a slower rate than equant or prolate shaped sediments. As a result, the proportion of bladed and oblate shaped clasts is generally higher in the mid- and upper-shoreface relative to the lower-shoreface. The proportions of high-sphericity to low-sphericity grains were generally equal. Clast roundness ranged from sub-angular to well-rounded.

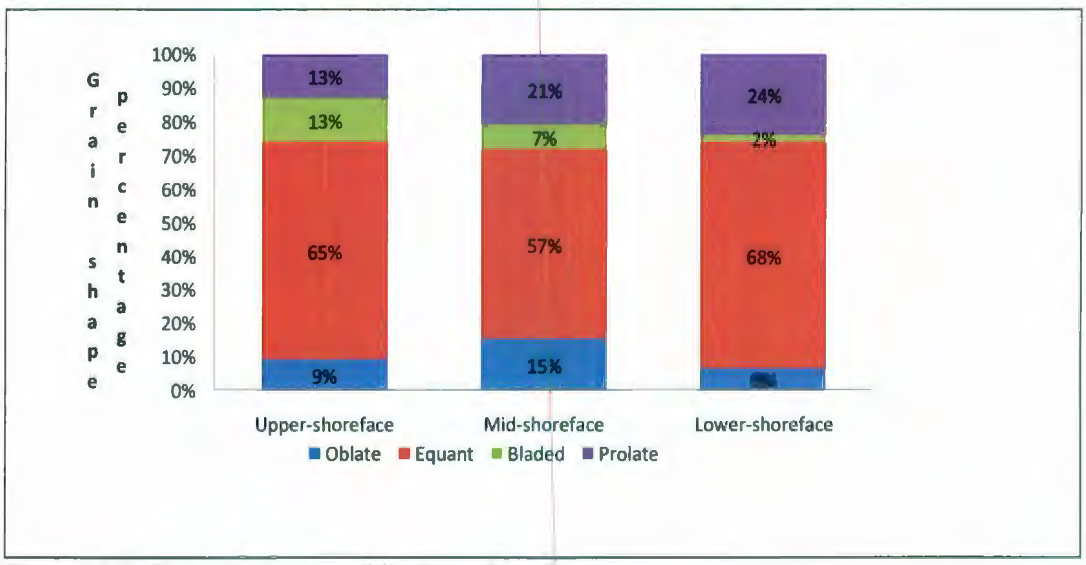


Figure 4.3. Grain shape Arnold's Cove beach

Infill amongst the cobbles of Arnold's Cove beach contained a mixture of sand, granules, and pebbles. The presence of finer sediments within the sediment matrix indicate a higher number of grain-to-grain contacts and a higher clast surface area than would occur on a purely pebble or cobble beach. As a result, oil sequestration would likely be limited. However, the observed changes in the distribution of shoreface sediments indicate the potential for oil burial as a result of reworking.

4.1.2 Distribution of marine debris

Marine debris occurred in varying concentrations, depending on survey date, transect, and area of shoreface surveyed. Snow and ice cover during February 2007 surveying did not permit for marine debris observations. In terms of total litter abundance, the least amount and lowest concentrations of debris were recorded during the December 2006 survey (Table 4.1). This may be partly attributed to the relatively high wave energies during late December which may act to remove debris from the shoreface and decrease the residence time for debris. Between December 2006 and April 2007, the quantity of observed debris increased by 549%. The greater amount of debris during the April 2007 survey is likely related to the longer period available for the retention of debris as a result of the presence of snow and ice. Protected from beach processes which, in the absence of snow and ice, would otherwise act to remove the debris, debris may have accumulated over the winter months to levels greater than that normally observed. Following the melting of snow and ice, the winter accumulation of debris was deposited on the beach. Between April 2007 and September 2007, the quantity of debris decreased by 66% as normal beach processes acted to remove any excesses of debris. Considering a total survey area of 480 m^2 (120 m^2 per transect), Arnold's Cove recorded an average litter concentration of 0.36 items/m^2. Pink (2004) recorded similar results, reporting 439 pieces of litter over 4773.6 m^2 (0.092 items/m^2) during December 2003 surveying and 873 pieces of litter over 10343.2 m^2 (0.084 items/m^2 during April 2004 surveying).

Survey Date	December 2006	April 2007	September 2007
Quantity	55 items	357 items	119 items
Concentration	0.11 items/m^2	0.74 items/m^2	0.25 items/m^2

Table 4.1. Total abundance of marine debris observed at Arnold's Cove

Laterally, debris was concentrated on the eastern side of Arnold's Cove beach during December 2006 and on the western side during September 2007 (Figure 4.4). In April 2007, the highest concentrations were found at the centre of the beach. The observed distribution suggests an east-west transport mechanism. This is supported by the observed prevalence of oblique, north-northwest incident wave angles. Differing wind directions and current activities also likely contribute to the observed distribution.

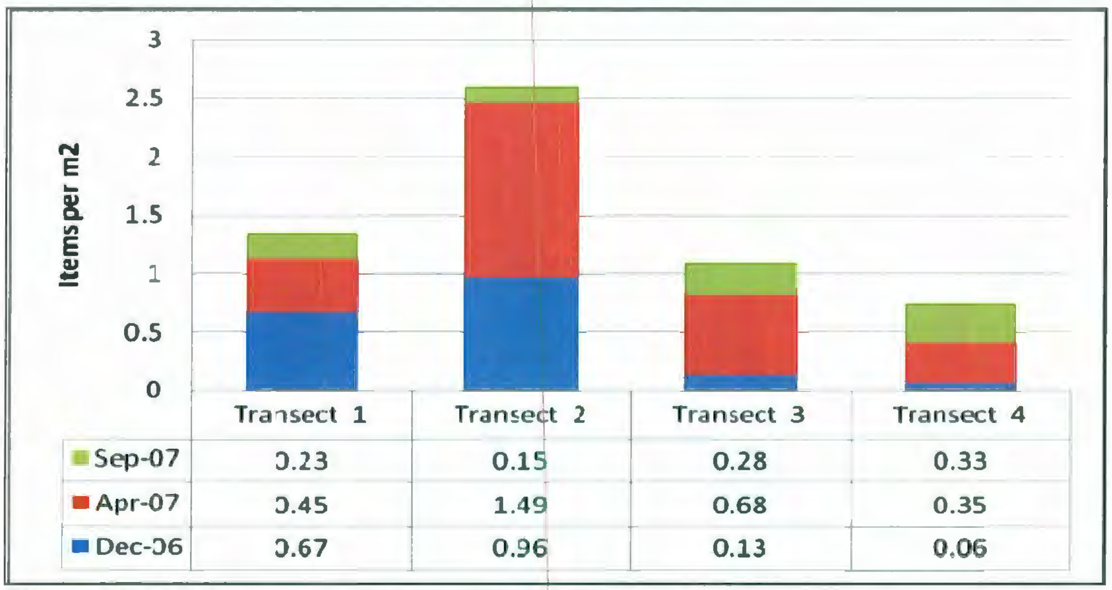


Figure 4.4. Debris concentrations over time by transect

Approximately 99% of total recorded debris was deposited in the backshore and upper-shoreface (Figure 4.5). During surveying on December 23, 2006 all visible debris was observed in the backshore. This is likely the result of the relatively higher energy conditions associated with the fall and early winter; debris having been removed from the shoreface or pushed inland and deposited in the backshore. The highest quantities and concentrations of debris observed in the backshore and upper-shoreface were recorded during April of 2007. Upper-shoreface concentrations of marine debris exceeded backshore debris concentrations during the September 2007 survey. This may be the result of the relatively calm energy conditions associated with the preceding summer months where the dominant energy regime was less able to transport marine debris beyond the upper-shoreface limit. The observed distribution of marine debris on Arnold's Cove beach is best explained by a general lateral progression east to west interrupted by high energy events where shore-normal transport dominates.

	Backshore	Upper-shoreface	Mid-shoreface	Lower-shoreface
Sep-07	0.29	0.69	0	0
Apr-07	1.63	1.32	0.03	0.01
Dec-06	0.47	0	0	0

Figure 4.5. Debris concentrations over time by shoreface division

The most abundant litter group was plastic (Figure 4.6). Pink (2004) also reported that plastics accounted for most of the beach litter at Arnold's Cove. This is similar to other studies which report plastic as contributing the most to marine debris (Frost and Cullen, 1997; Whiting, 1998). Much of the observed plastic debris, such as fish tags, buoys, nylon netting, lines, and plastic containers/buckets used as markers or bailers, could be associated with the local fishing industry. These results are similar to that reported by other studies which have found that at sites adjacent to fishing areas, the fishing industry is usually one of the main contributors of marine debris (Slip and Burton, 1991; Otley and Ingham, 2003). Other common plastic objects such as shotgun shells were more related to recreation. Anthropogenic wood was also very common and usually took the form of cut creosote timber ends commonly used in marine infrastructure developments. Metal primarily took the form of small food containers and metal beverage cans. Cardboard and glass were also observed in relatively small quantities. Debris composition and proportions varied little between survey dates. However, heavier debris such as wood and metal were present in higher proportions in the upper-shoreface relative to other areas of the beach during each survey.

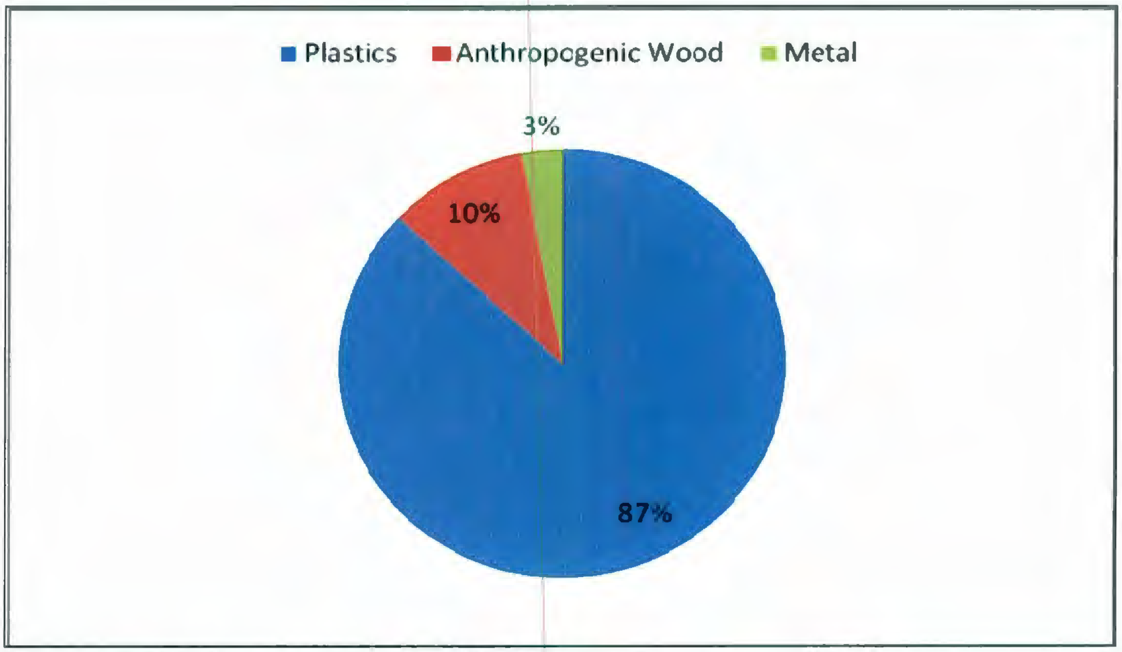


Figure 4.6. Debris composition Arnold's Cove beach

The majority of debris could be classified as indicator items. For instance, during the April 2007 survey, 88% of observed debris fell under the classification scheme proposed by Ribic *et al.*, (1997) and could be classified as indicator items. In total, approximately 87% of observed debris on Arnold's Cove beach was classified as indicator items. Sourcing of indicator items revealed that the majority of observed debris was ocean-based (Figure 4.7). Some of the debris was foreign. For instance, the text on several pieces of observed food packaging was written in an East Asian language. As well, several fish tags were imprinted with licencing information from the State of Maine. Other items, such as fish tags imprinted with the federal Department of Fisheries and Oceans licencing information, were clearly domestic. In other instances, no clear marine-based origin point could be determined at all. Given this variety, it is likely that most of the observed debris originates from a variety of offshore and nearshore sources. The majority of items categorized as 'general' were plastic bottles, such as soft drink and bottled water containers. Land-based items consisted primarily of metal beverage cans. With the exception of an increase in the proportion of items classified as 'general' during the April 2007 survey, the proportions of debris contributed by each source varied little between survey dates.

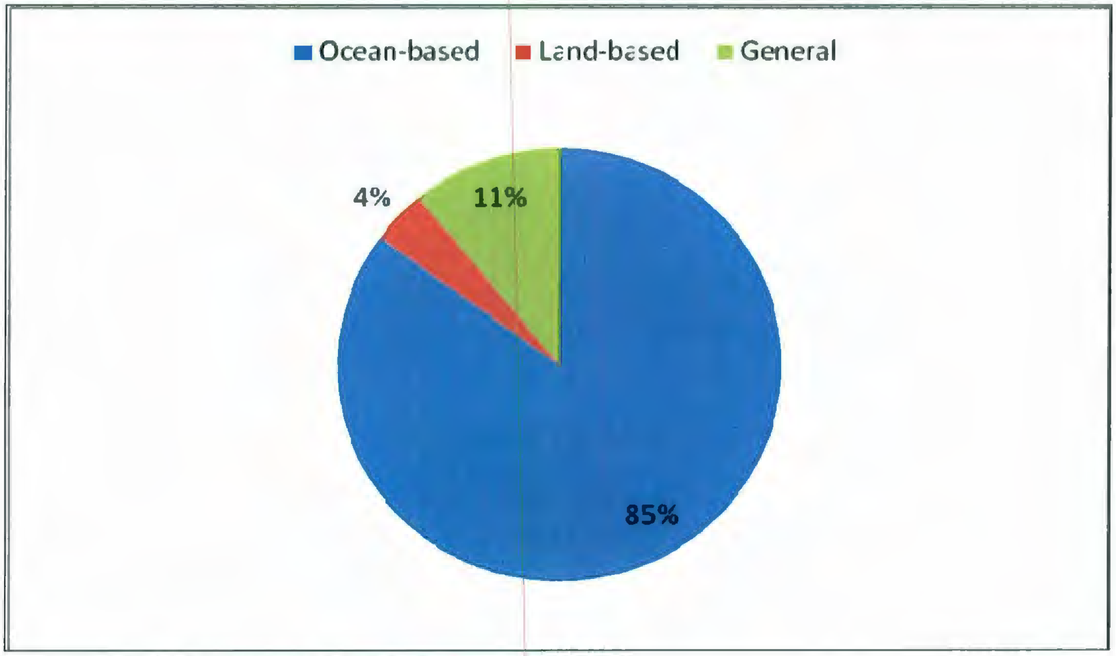


Figure 4.7. Debris source Arnold's Cove beach

Relative to the other study beaches, Arnold's Cove recorded the greatest quantities of marine debris. Pink (2004) reported a similar finding in a study of 4 Avalon Peninsula beaches which included Arnold's Cove. The prevalence of ocean-based debris and the relatively large quantity of debris suggests that an oil spill in Placentia Bay would impact Arnold's Cove beach. The proximity to shipping lanes, oil handling facilities, and southwest exposure further increase this likelihood.

Seaweed was observed both surficially and subsurface. Distribution was generally shore parallel in bands approximately 1 m wide along the mid and upper-shoreface. Seaweed distribution may be described as sporadic (c.f. Owens and Sergy, 2000), covering 1-10% of the shoreface. The distribution of debris and seaweed suggests that oil would be distributed longitudinally over the shoreface with greatest concentrations found in the upper-shoreface and backshore.

4.1.3 Morphology and wave energy

Beach slope varied over the beachface as well as over time. The upper-shoreface exhibited the greatest variation during each survey, particularly along the western side of the beach. The eastern transects showed little variation over time and slope was relatively constant to the waters edge. Overall, the largest slopes were observed in the upper-shoreface and decreased shoreward (Figure 4.8). The greatest observed slope, 14°, was measured during the April 2007 survey and the lowest, 2°, during the September 2007 survey. Mean shoreface slope ranged between 9° and 11° in the upper-shoreface; 5° and 9° in the mid-shoreface; and 4° and 6° in the lower-shoreface.

With the exception of the February 2007 survey, berm development was observed during each site visit. During February 2007, large cusps were present in a vertical wall separating the vegetated backshore from the upper-shoreface. An ice-foot was also present (Figure 4.9). Berm development was absent and the shoreface frozen. During the other surveys, berm development was observed beginning at transect 2. Development appeared to increase westward with the number of observable berms increasing between transect 2 and 4. Cusps were also observed throughout the shoreface west of transect 2, with the number of tiers of cusps increasing westward. Overall, cusp wavelength increased shoreward, although no clear lateral trend was evident. The largest cusps were recorded during February 2007, where two days before a large storm had impacted Placentia Bay. Observations of berms, cusps, seaweed accumulation and burial, shoreface undulations, and overwash fans suggest greatest sediment accumulation along the western portion (transects 3 and 4) and a net westerly transport of sediment on Arnold's Cove beach.

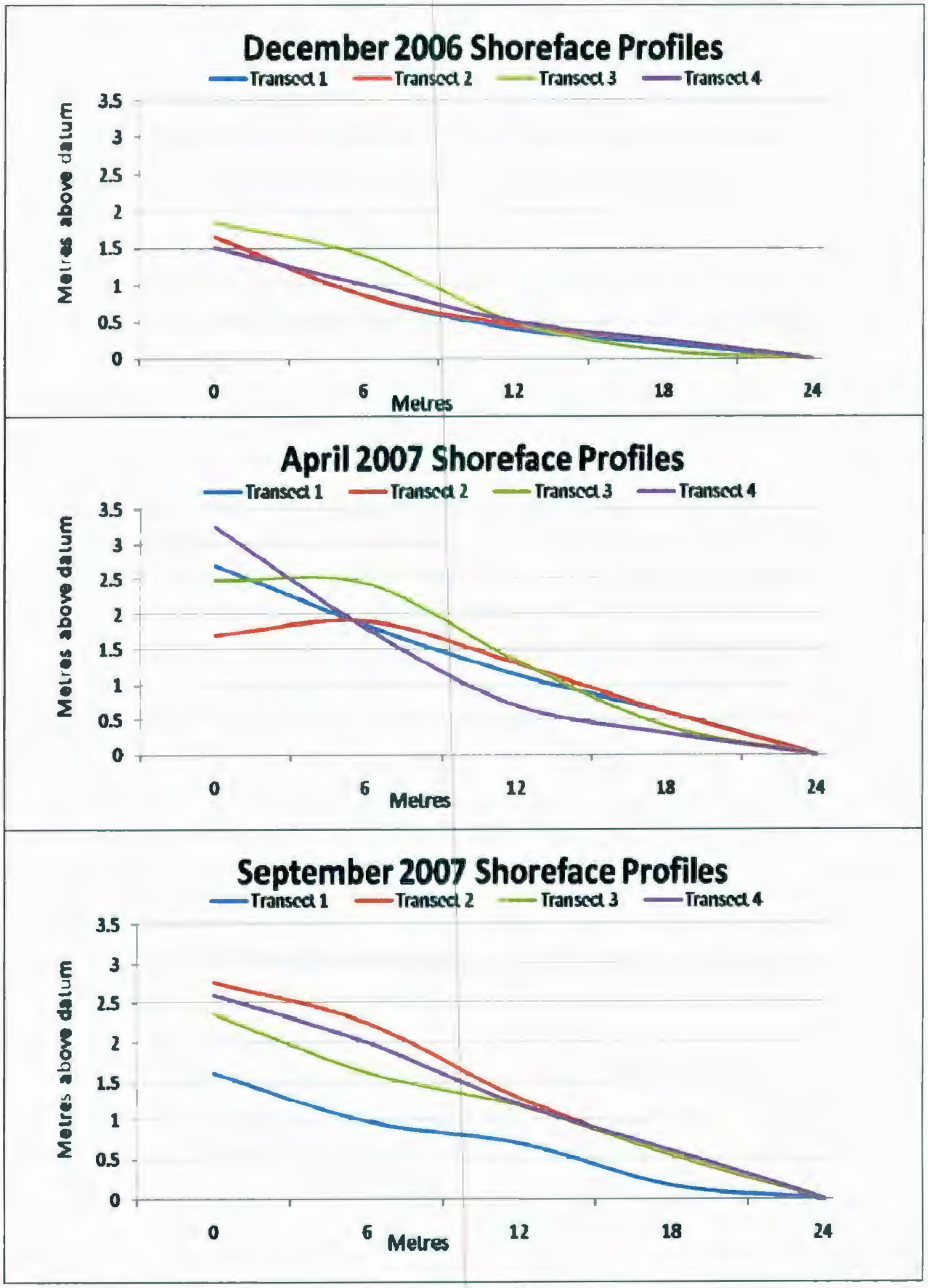


Figure 4.8. Beach profiles of Arnold's Cove beach

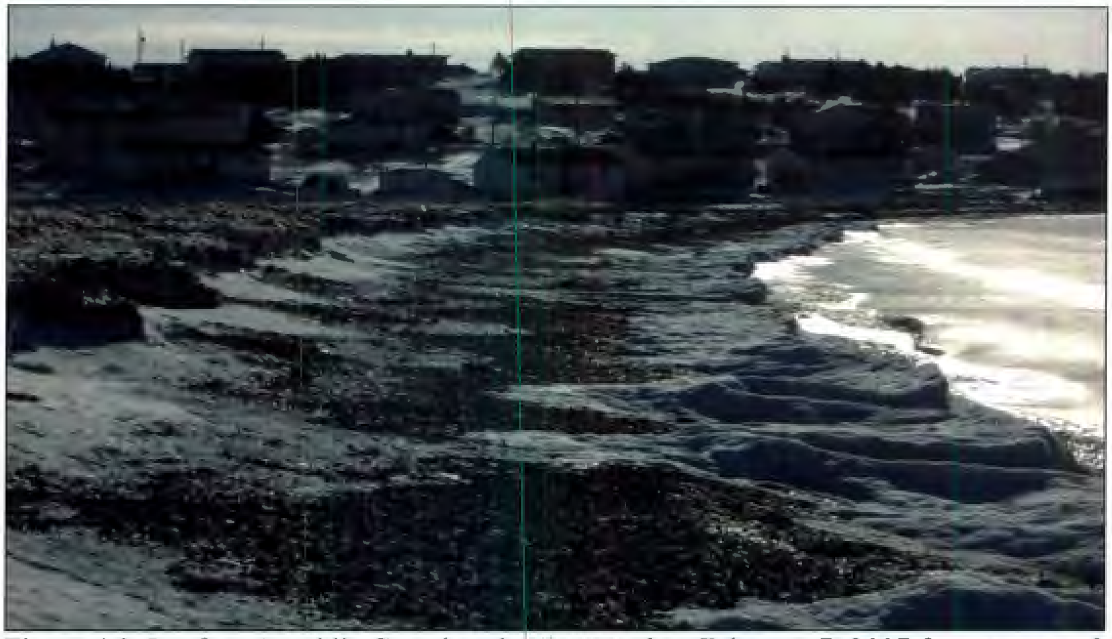


Figure 4.9. Ice-foot Arnold's Cove beach. Picture taken February 7, 2007 from transect 3 looking east

The presence of accretionary features and the temporal variability of these features indicate a relatively low energy system subject to high energy events. The highest wave energies and greatest beach slopes are associated with the winter and spring months, although surf scaling parameter calculations consistently indicated a reflective system; Ω never exceeding 0.04 (Table 4.2). Considering all these factors, self-cleaning would likely not be an effective agent of oil removal in the event of a spill. The presence of multiple tiers of berms and cusps suggest that oil would be deposited in the upper-shoreface and backshore during storm events. This is supported by the large quantity of marine debris found in these areas of the beach. Furthermore, these features suggest that oil would be subject to burial, increasing the likelihood of long-term (months to years) persistence. Observations of the westward increase in sediment accumulation suggest that oil retention would be greater in this area than on the eastern portion.

Date	Surf Scaling Parameter	Wave Energy Density	Wave Power	Longshore Current Velocity	Longshore Wave Power
12/23/2006	$\Omega = 0.04$	314 J/m^{-2}	984 kW/m	0.5 m/s	168 kW/m
02/06/2007	$\Omega = 0.03$	805 J/m^{-2}	200 kW/m	0.4 m/s	82 kW/m
04/13/2007	$\Omega = 0.04$	13 J/m^{-2}	39 kW/m	1.1 m/s	15 kW/m
09/07/2007	$\Omega = 0.02$	66 J/m^{-2}	208 kW/m	0.2 m/s	11 kW/m

Table 4.2. Energy regime variables Arnold's Cove beach

Evidence of an east-west longshore current was also observed at Arnold's Cove beach. Observed incoming waves were generally out of the southwest. Oblique angles with the beach ranged between 3° and 10°. The observed longshore current is likely partially responsible for the westward increase in sediment accumulation along the shoreface. The presence of such a current also suggests that oil would be distributed longitudinally along the shoreface with greater deposition along the western shoreface of the beach relative to the east.

The lagoon behind Arnold's Cove beach could also be subject to marine based oil spill contamination. High wind and wave energy could move oil over the vegetated backshore and deposit it in the lagoon. The presence of antecedent overwash fans, particularly at the western end of the beach support this possibility (Figure 4.10). However, during the surveys conducted for this study no evidence was found of recent overwashing, which suggests such high energy events are uncommon. Generally speaking, oil pollution would be confined to the lagoon. However, the presence of an outlet, as was observed in September 2007, would allow oil in the lagoon to contaminate the beach. Finally, Arnold's Cove beach is a moderately used recreational beach. Oil spill contamination would decrease its utility to local users as well as tourists.

Figure 4.10. Shoreward extent of overwash fans (highlighted in red) observed at Arnold's Cove beach (Source: Google Earth, 2008)

4.2 Come by Chance

Come by Chance beach is located approximately 1 km to the southwest of the community of Come by Chance. For the purposes of this study, the easternmost boundary is located at N47.82783°, W53.99867° and the westernmost at N47.82953°, W53.99831°. At approximately 205 m in length it is the second longest study beach. The shoreface is generally characterized by pebble-cobble sediments although coarse grained sand and granules are also present (Figure 4.11). Seaweed is a common feature along much of the shoreface. The backshore consists of a anthropogenic riprap and a gravel roadway along the eastern side and grass vegetation along the western side. The easternmost area of the beach is marked by an anthropogenic breakwater. Anthropogenic marine debris, cusps, and berms are also common features along much of the beach.

Figure 4.11. Come by Chance beach. Picture taken April 25, 2007 from transect 1 looking north.

A total of 3 transects spaced approximately 50 m apart were used to study the beach at Come by Chance (Figure 4.12). Datum was determined from tide tables for Come by Chance. Profiles were plotted based on spring low-tide conditions. Over the course of surveying, transect width increased from 9 m to 24 m in length along the eastern side of the beach and from 6 m to 18 m along the western side. The widths of the upper-, mid-, and lower-shoreface were kept roughly equal in proportion to the width of the beach at the time of surveying. Surveys were undertaken on December 12, 2006, April 25, 2007, and September 7, 2007. This section summarizes data collected during these surveys. Sediment characteristics, the type and distribution of marine debris, beach morphology, and energy characteristics recorded during each survey date are presented.

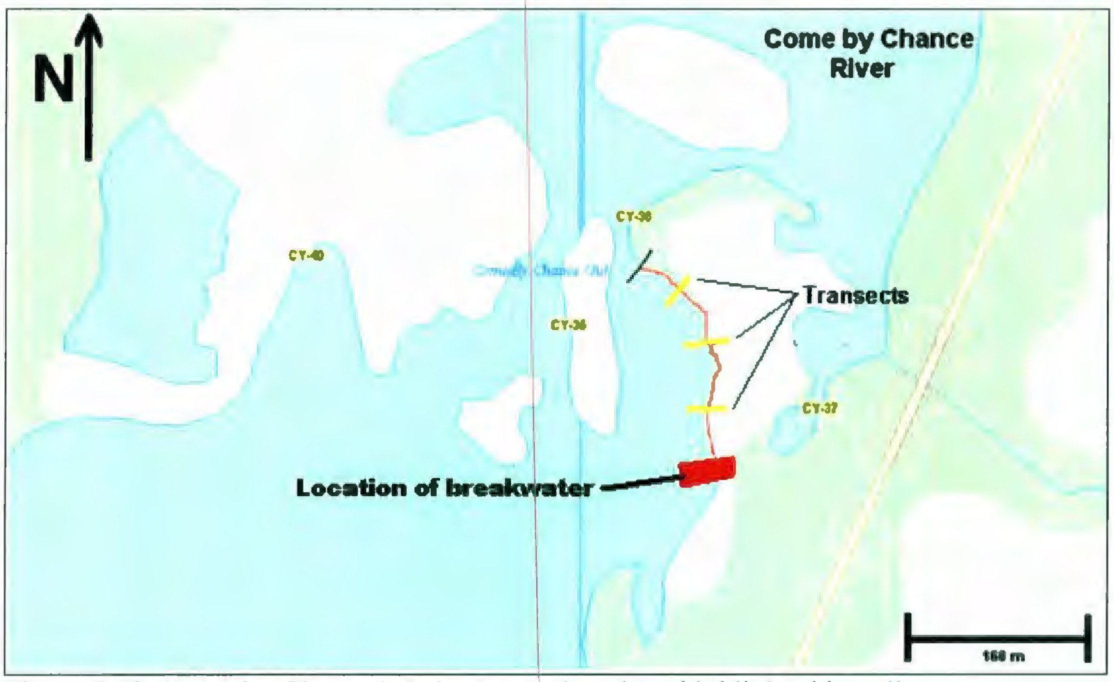


Figure 4.12. Come by Chance beach transect locations highlighted in yellow

4.2.1 Sediment Composition

Similar to Arnold's Cove, Come by Chance beach is largely characterized by pebble-cobble sediment. Coarse sand and granules were also observed, particularly in the mid-shoreface and upper-shoreface. The highest proportions of cobble were observed near the waters edge. Laterally, the proportion of observable cobble clasts was greatest along the eastern and central portions of the beach. The proportion of finer sediments increased westward and were greatest along transect 3. This distribution is likely the result of the southwest oriented fetch of Come by Chance beach. Wind and waves approach the eastern side of the beach generating an east-west longshore current. As a result, smaller sediments such as pebbles, granules, and coarse sand remain entrained within the current and are deposited further west amid lower energy conditions. This process is very similar to that reported for Arnold's Cove.

Clast shape was dominated by equantic clasts (Figure 4.13). The distribution of clasts over the shoreface is very similar to observations at Arnold's Cove beach. For instance, prolate clasts were most prevalent in the lower-shoreface while oblate and bladed clasts were more commonly observed in the mid and upper-shoreface. Different shapes settle out of the water column at different rates. Flatter shapes settle at a slower rate than rounder shapes. This accounts for the observed distribution. The proportions of high sphericity to low sphericity grains were generally equal. Clast roundness ranged from sub-angular to well-rounded over the entire shoreface.

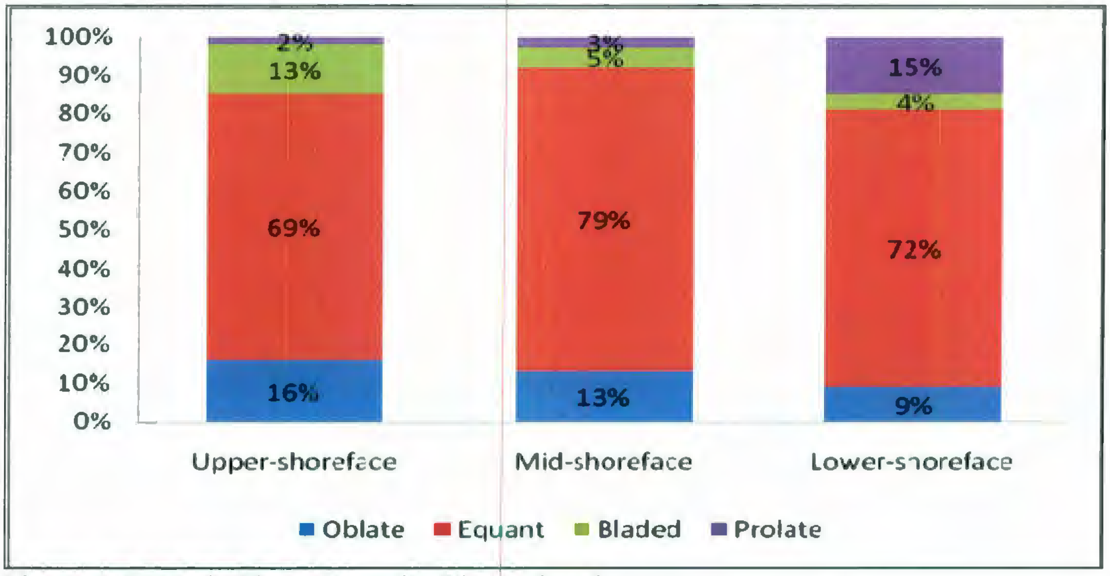


Figure 4.13. Grain Shape Come by Chance beach

Sediment infill amongst the cobbles consisted of sand, granules, and pebbles. The distribution of fine textured sediments, particularly in the mid and upper-shoreface of Come by Chance beach, could act to limit oil sequestration. Shoreface sediment composition varied only modestly. This appeared especially true along the eastern and central portion of Come by Chance beach, which displayed very little change. For example, along transect 1 and 2, a gently sloped veneer of pebble and cobble appeared to overlay waterlogged granules and coarse textured sand during each survey. This general arrangement did not change between December 2006 and September 2007. Changes in the composition of shoreface sediments were more evident along the western portion of the beach where sediment reworking was more prevalent. Thus, the potential for oil burial would likely be greater along the western side of the beach than the eastern or central portions.

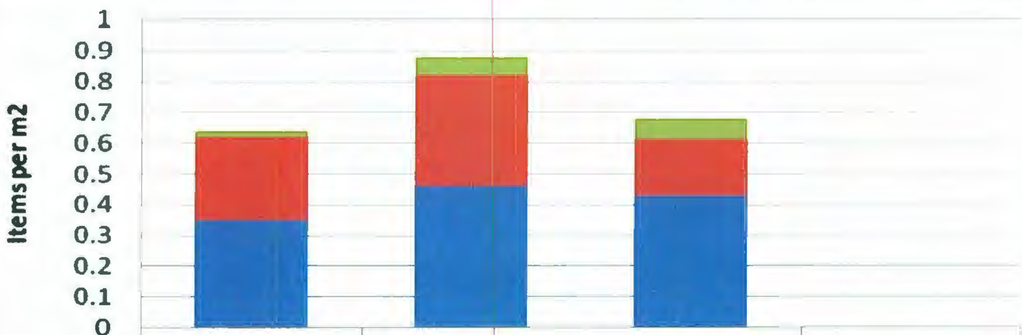
4.2.2 Distribution of marine debris

Concentrations of marine debris varied by survey date, transect, and area of shoreface surveyed. The highest quantities and concentrations of debris were recorded during the April 2007 survey (Table 4.3). The greater amount of debris during the April 2007 survey is likely related to the longer period of time available for the retention of debris as a result of the presence of snow and ice. Protected from beach processes which, in the absence of snow and ice, would otherwise act to remove the debris, debris may have accumulated over the winter months to levels greater than that normally observed. Following the melting of snow and ice, the winter accumulation of debris was deposited on the beach. The lowest amounts of debris were recorded during the September 2007 survey, likely the result of relatively low summer wave energies transporting lesser amounts of debris to the beach and a larger survey area as a result of beach accretion. During the study period, Come by Chance recorded an average litter concentration of 0.24 items/m^2; 0.12 items/m^2 less than that observed at Arnold's Cove over the same period.

Survey Date	December 2006	April 2007	September 2007
Quantity	50 items	63 items	15 items
Concentration	0.41 items/m^2	0.27 items/m^2	0.05 items/m^2

Table 4.3. Total abundance of marine debris observed at Come by Chance beach

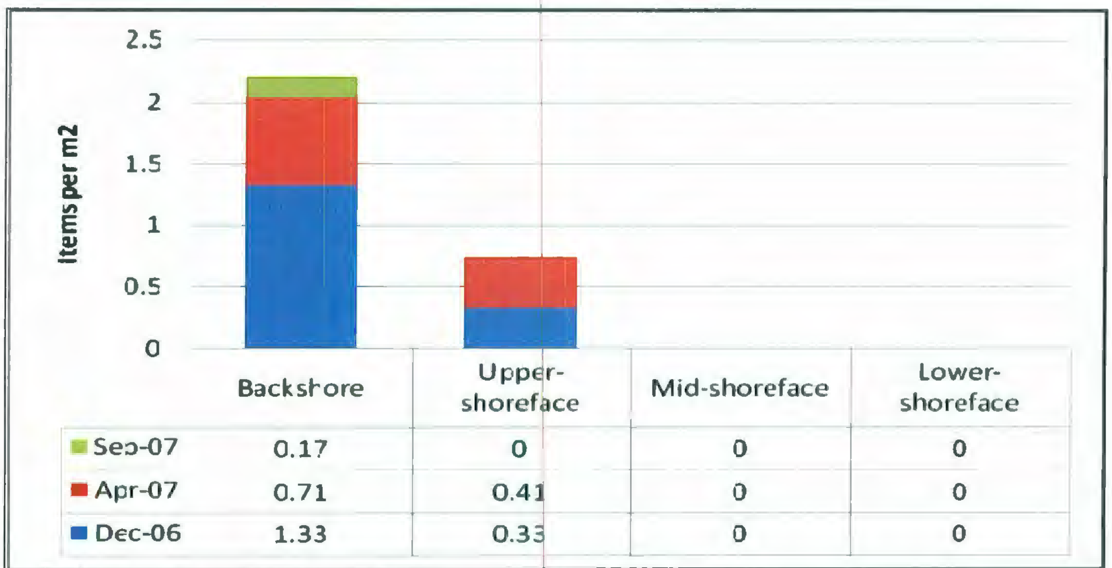
Laterally, the greatest quantities and concentrations of debris were observed at the centre and western portion of the beach (Figure 4.14). The eastern section of the beach has a greater SW oriented fetch and as a result is more exposed to the predominant wind direction than is the western section. Waves generated as a result of these winds impact the eastern side of the beach at an oblique angle. The oblique incident wave angles may help to generate an east – west longshore current, which aids the longitudinal distribution of debris over the shoreface from the eastern to the western portion. The result is a net movement of debris away from the eastern portion of the beach further west. These characteristics may help to explain the observed distribution.



	Transect 1	Transect 2	Transect 3	Lower-shoreface
Sep-07	0.02	0.06	0.07	0
Apr-07	0.27	0.36	0.18	0
Dec-06	0.35	0.46	0.43	0

Figure 4.14. Debris concentrations over time by transect

All of the recorded debris observed at Come by Chance was deposited in the backshore and upper-shoreface (Figure 4.15). During surveying in September 2007, all visible debris was observed in the backshore. During the December 2006 and April 2007 surveys, 40 pieces of debris were observed in the backshore. However, because the survey area was smaller in December 2006 the concentration of debris was higher. The observed distribution of marine debris at Come by Chance beach may be best explained by the predominance of relatively low energy conditions depositing minimal marine debris interrupted by sporadic, relatively high energy events which deposit larger amounts of debris in the backshore and upper-shoreface.



	Backshore	Upper-shoreface	Mid-shoreface	Lower-shoreface
Sep-07	0.17	0	0	0
Apr-07	0.71	0.41	0	0
Dec-06	1.33	0.33	0	0

Figure 4.15. Debris concentrations over time by shoreface division

Similar to results reported for Arnold's Cove, the most abundant litter group observed on Come by Chance beach was plastic (Figure 4.16). The majority of the observed plastic debris could be associated with the local fishing industry. Rope, nylon netting, fish tags, and buoys were common. Other plastic debris included plastic shopping bags which were observed entangled in the vegetation of the backshore, particularly in trees which surrounded the backshore of the study area. Anthropogenic wood formed the next most abundant litter group. The majority of observed debris in this group were comprised of the remains of lobster pots and cut timber ends. Several metal beverage cans were observed during surveying in December 2006.

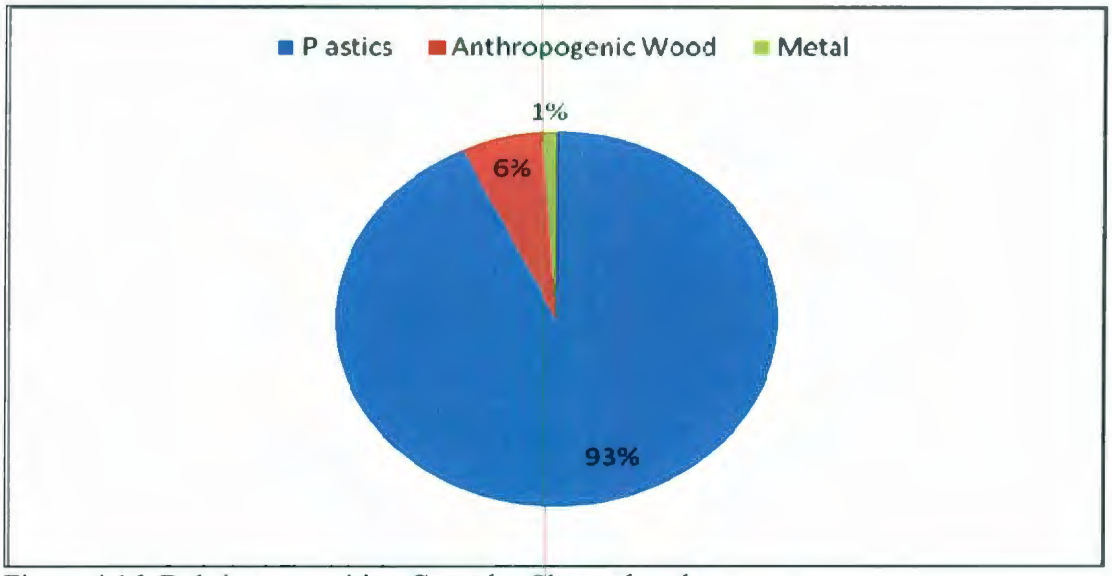


Figure 4.16. Debris composition Come by Chance beach

The majority of debris could be classified as indicator items. For instance, during the April 2007 survey, 94% of observed debris fell under the classification scheme proposed by Ribic *et al.*, (1997) and could be classified as indicator items. In total, approximately 80% of observed debris on Come by Chance beach were classified as indicator items. Sourcing of indicator items revealed that the majority of observed debris was ocean-based (Figure 4.17). Much like Arnold's Cove, the majority of items categorized as 'general' were plastic bottles, such as soft drink and bottled water containers. Land-based items consisted primarily of plastic shopping bags. Unlike Arnold's Cove, no debris identifiable as foreign or originating from an offshore source were observed at Come by Chance. Commonly observed items such as rope, netting, plastic containers, and oil containers are likely domestic and originating from nearshore sources such as the fishery and other local area sources. The relative homogeneity of the type of observed debris also suggests a common, local source.

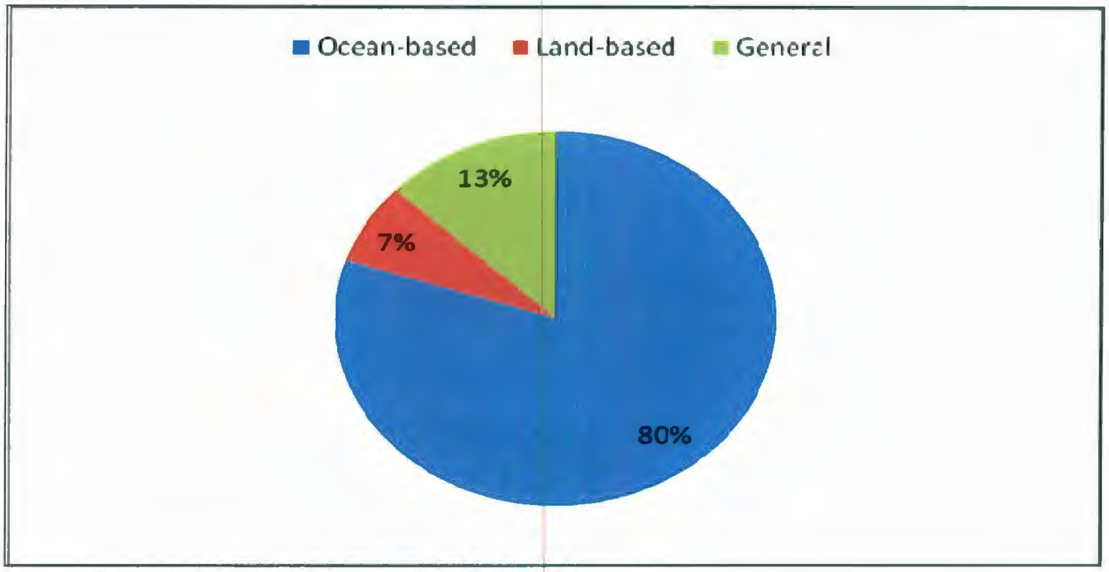


Figure 4.17. Debris source Come by Chance beach

Come by Chance beach recorded lower concentrations of debris per m^2 of area surveyed relative to Arnold's Cove beach. Ocean-based debris dominated on both beaches. It is likely that Come by Chance is less impacted by offshore sources comparative to Arnold's Cove beach where debris associated with both nearshore and offshore sources were more commonly observed. The prevalence of ocean-based debris associated with nearshore sources suggests that nearby shipping lances and oil handling facilities would likely pose the greatest threat of oil contamination to Come by Chance beach. The concentrations and sources associated with the observed debris suggest that the potential for exposure to contamination is less than at Arnold's Cove. However, depending on wind and wave conditions at the time of a spill, the large southwest exposure associated with Come by Chance could allow oil contamination from sources further out in Placentia Bay to impact the beach.

Seaweed observed both surficially and subsurface. The largest amounts of seaweed were observed along the western portion of the beach. Cover in this area may be described as patchy covering approximately 50% of the shoreface. Cover thinned considerably along the eastern portion of the beach. In this area seaweed was concentrated along the lower-shoreface of the beach where it may be described as sporadic, covering 1-10% of the shoreface. Sub-surface seaweed was not observed in this area.

4.2.3 Morphology and wave energy

Unlike Arnold's Cove, shoreface width varied over time and by transect. The greatest widths were present along transect 1 and 2 and narrowest along transect 3. Between surveys, widths increased along each transect. Shoreface width increased by approximately 166% along transects 1 and 2 between December 2006 and September 2007. Over the same time period, width along transect 3 increased by approximately 200%. Slope was greatest in the upper-shoreface of each transect with a general decreasing seaward trend during each survey (Figure 4.18). The greatest observed slope, 15°, was measured during the December 2006 survey and the lowest, 1°, during the April 2007 survey. During each survey, average shoreface slope increased from east to west. Mean slope ranged between 7° and 9° in the upper-shoreface; 5° and 11° in the mid-shoreface; and 3° and 11° in the lower-shoreface.

Berm and cusp development was not observed along the eastern and central portion of the beach. However, several tiers of berms were observed along transect 3. Cusps could be found within each berm as well as within the interface between the upper-shoreface and backshore. The largest observed cusps were located within this interface. The presence of accretionary features such as berms, cusps, and shoreface undulations suggest greater sediment accumulation along the western portion of Come by Chance beach. The absence of such features along the eastern and

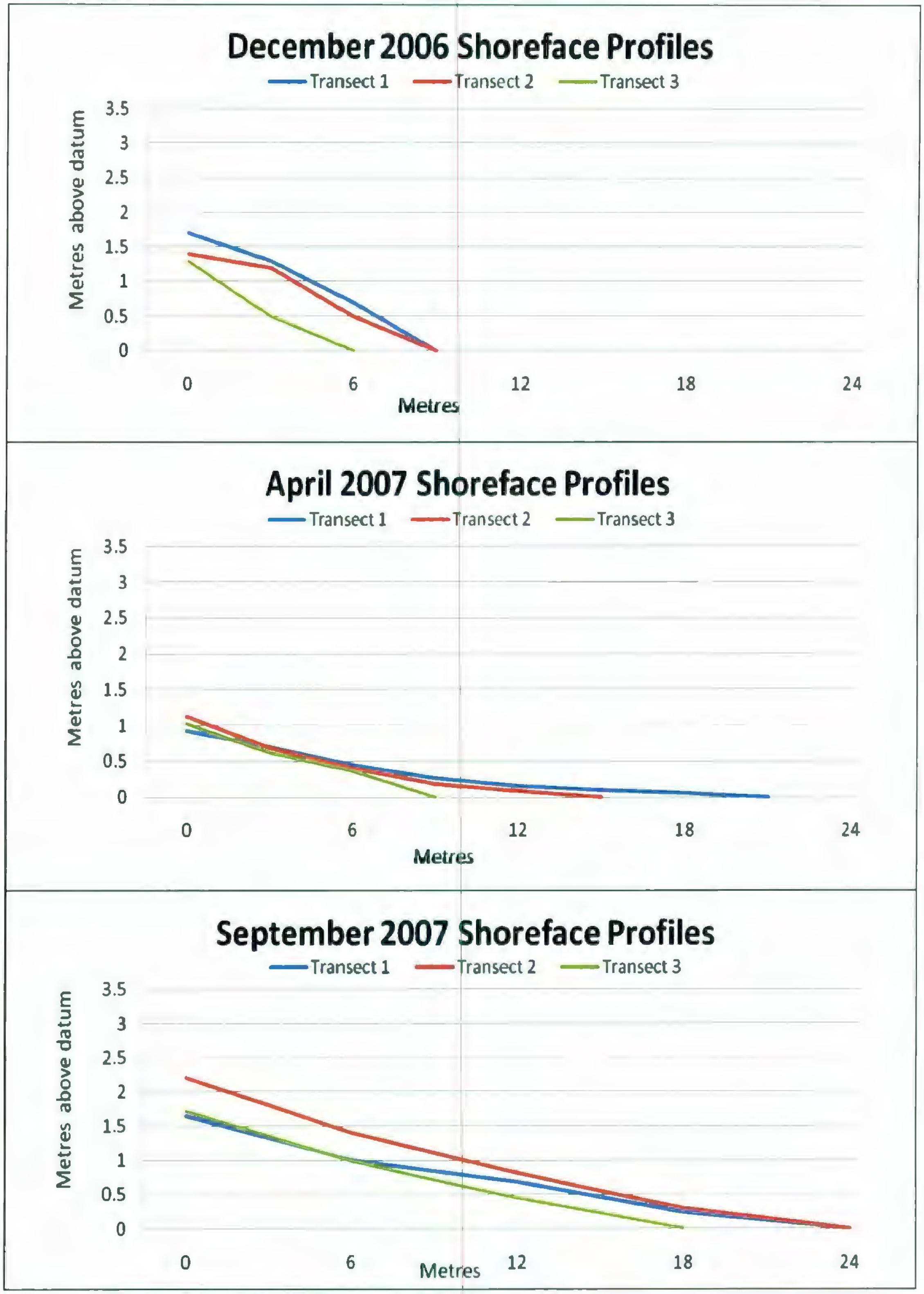


Figure 4.18. Beach profiles of Come by Chance beach

central portions of the beach indicate that sediment accumulation is limited in these areas. Greater western sediment accumulation may be attributed to the interplay of 2 factors:

1. presence of an anthropogenic breakwater along the eastern extremity of the beach

2. net east-west transport mechanism.

As previously mentioned, overall shoreface width increased during the course of surveying along the entire beach, which suggests an overall positive sediment supply. The breakwater present along the eastern portion of the beach may act to interfere with normal wave action. This causes entrained sediments to be deposited on the leeward (eastern) side of the breakwater. As a result, sediment supply to the eastern portion of the beach (forward side of the breakwater) is decreased. A net east-west transport of sediments further limits accretion in this area by transporting sediments from the eastern side of the beach to the western side. Combined, these factors help to explain the lateral differences observed at Come by Chance beach.

The spatial and temporal distribution of these features suggests that Come by Chance is a relatively low energy system. Similar to Arnold's Cove, the highest wave energies are associated with the winter and spring months. However, the greatest beach slopes are associated with the winter and fall months (Arnold's Cove greatest slopes are associated with winter and spring months). Surf scaling parameter calculations consistently indicated a reflective system; Ω never exceeding 0.07 (Table 4.4). Taking into consideration these factors, self-cleaning at Come by Chance beach would likely not be an effective agent of oil removal in the event of a spill. The presence of marine debris in the upper-shoreface and backshore suggests that oil would be deposited primarily in these areas. The absence of accretionary features and subsurface seaweed along the eastern and central portions of Come by Chance beach suggest that oil sequestration and burial would be limited in this area.

Date	Surf Scaling Parameter	Wave Energy Density	Wave Power	Longshore Current Velocity	Longshore Wave Power
12/12/2006	Ω = 0.07	113 J/m^{-2}	354 kW/m	1.0 m/s	114 kW/m
04/25/2007	Ω = 0.02	79 J/m^{-2}	246 kW/m	0.7 m/s	62 kW/m
09/07/2007	Ω = 0.02	36 J/m^{-2}	114 kW/m	1.0 m/s	37 kW/m

Table 4.4. Energy regime variables Come by Chance beach

Oil contamination in this area would instead be largely surficial. The likelihood of burial would be greater along the western side of Come by Chance beach, as indicated by the presence of berms, cusps, and sub-surface seaweed. The presence of an east-west longshore current suggests that oil contamination along the eastern side of the beach would be transported to the west. Oil contamination in Come by Chance estuary would have detrimental effects on local wildlife, particularly birds. However, the possibility of oil contamination in this area as a result of overwash of the study beach is considered low. The backshore area is large and vegetated by grass, shrubs, and trees, suggesting a stable environment. Features indicating high wave energies such as overwash fans were not present. However, oil deposition on the landward side of the backshore would still have negative impacts on local wildlife, birds, and recreational users which utilize the area.

4.3 Hollett's Cove

Hollett's Cove beach is located along the southern shore of Southern Head approximately 6 km to the southwest of Come by Chance beach. The purposes of this study, the area surveyed lay between N47.80021°, W54.05599° and N47.80046°, W54.05535°. At approximately 55 m in length, Hollett's Cove is the shortest study beach. The shoreface is characterized by pebble-cobble sediments and minor bedrock outcrops (Figure 4.19). Seaweed and other natural marine debris are common in the upper-shoreface and backshore. Minor amounts of grass vegetation exist in the backshore. A small lagoon backs the western portion of the beach and flows to the ocean via a small stream. The eastern area of the beach is marked by bedrock outcrops. Berms and overwash features are also common.

Figure 4.19. Hollett's Cove beach. Picture taken March 22, 2007 from Profile 1 looking east

A total of 3 transects spaced approximately 28 m apart were used to study the beach at Hollett's Cove (Figure 4.20). Tide data were not available for Come by Chance. As a result, datum was determined from tide tables for Come by Chance. Profiles were plotted based on spring low-tide conditions. The surveyed shoreface was again divided into three, shore parallel sections of roughly equal width. Observations were undertaken on March 22, 2007. This section summarizes data collected during this survey. Sediment characteristics, the type and distribution of marine debris, beach morphology, and energy characteristics recorded during each survey date are presented.

Figure 4.20. Hollett's Cove transect locations (Source: Google Earth, 2008)

4.3.1 Sediment composition

Hollett's Cove beach was composed primarily of pebble-cobble sediments. Cobble was present in larger proportions than pebbles throughout the shoreface along the eastern and western transects. However, the lower-shoreface of transect 2 was dominated by coarse textured pebbles, likely the result of a near-shore bedrock extrusion reducing incident wave energy (Figure 4.21). The size and relative homogeneity of sediment characteristics over the shore-face both laterally and perpendicularly indicates a well-sorted, relatively high energy system where shore-normal processes dominate.

Figure 4.21. Near-shore bedrock outcrop transect 2. Picture taken March 22, 2007

Clast shape was dominated by bladed and equant shaped clasts (Figure 4.22). Prolate shaped clasts were more commonly found nearer the ocean. Bladed and oblate shaped clasts dominated the upper-shoreface. The clasts of the upper-shoreface were also imbricated. High sphericity grains dominated the lower-shoreface. The proportions of high to low sphericity grains were roughly equal in the mid and upper-shoreface. Clasts ranged from rounded to well-rounded. These factors suggest an environment dominated by wave energy.

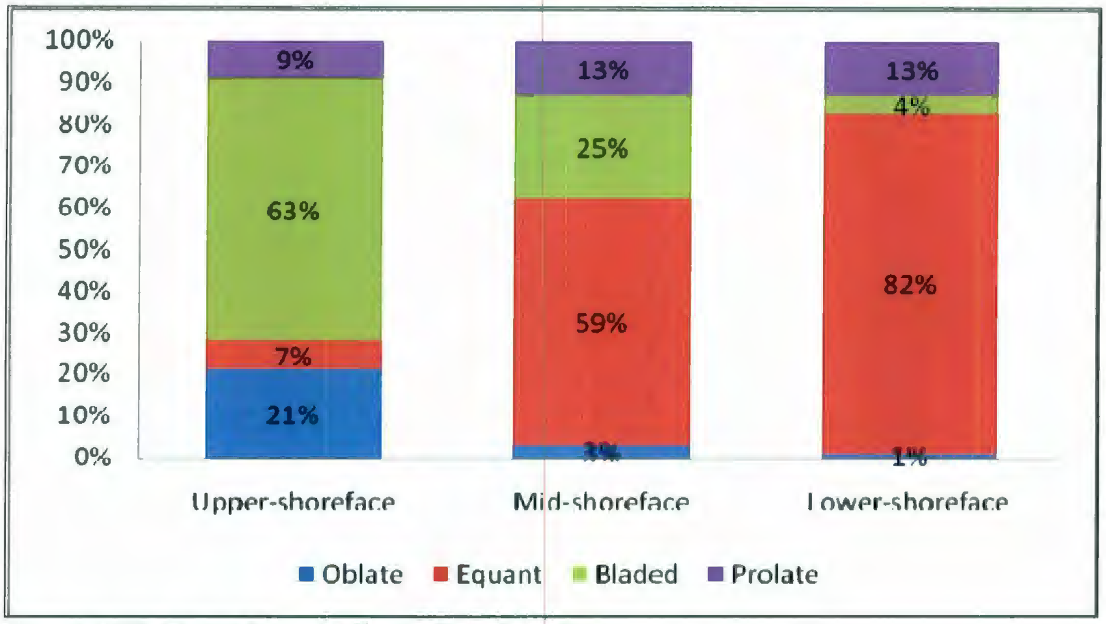


Figure 4.22. Grain shape Hollett's Cove beach

Infill amongst the sediments of Hollett's Cove beach consisted of medium to coarse textured pebbles. Due to the absence of finer textured sediments such as those present on Arnold's Cove and Come by Chance, the number of grain-to-grain contacts are lower than would occur on a mixed sediment beach. As a result, sediment permeability is likely higher on Hollett's Cove beach, enabling the infiltration of oil contamination. Burial would also be likely as a result of sediment re-working. However, due to the exposed nature of the beach, frequent sediment shifting could potentially limit oil burial time by cycling oil out of beach sediments.

4.3.2 Distribution of marine debris

In terms of total litter abundance, Hollett's Cove beach recorded 0.09 items/m^2. This represents a relatively low value when compared to the results reported for Arnold's Cove and Come by Chance. A relatively low quantity of anthropogenic marine debris was observed (26 items). Although not quantitatively assessed, Hollett's Cove beach was dominated by natural marine debris such as driftwood and seaweed. In fact, most of the backshore was covered by driftwood. Ross *et al.*, (1991) found that lighter debris, such as plastics, do not have the ability to substantially accumulate on exposed, rocky, high wave energy systems. Thus, the relative absence of anthropogenic marine debris and prevalence of natural marine debris on Hollett's Cove beach may be attributed to the exposed nature of the beach.

The majority of anthropogenic debris was observed in the backshore (Figure 4.23). The vast majority of observed natural marine debris was also observed in the backshore. This suggests that most of the debris was deposited under high energy conditions. Laterally, anthropogenic debris was concentrated along the western side of the beach. However, the dominance of anthropogenic debris along transect 1 is likely more related to the conditions under which that debris was deposited rather than indicative of shore-parallel processes. Sedimentological, natural marine debris, and morphological features suggest that shore-normal processes dominate Hollett's Cove beach.

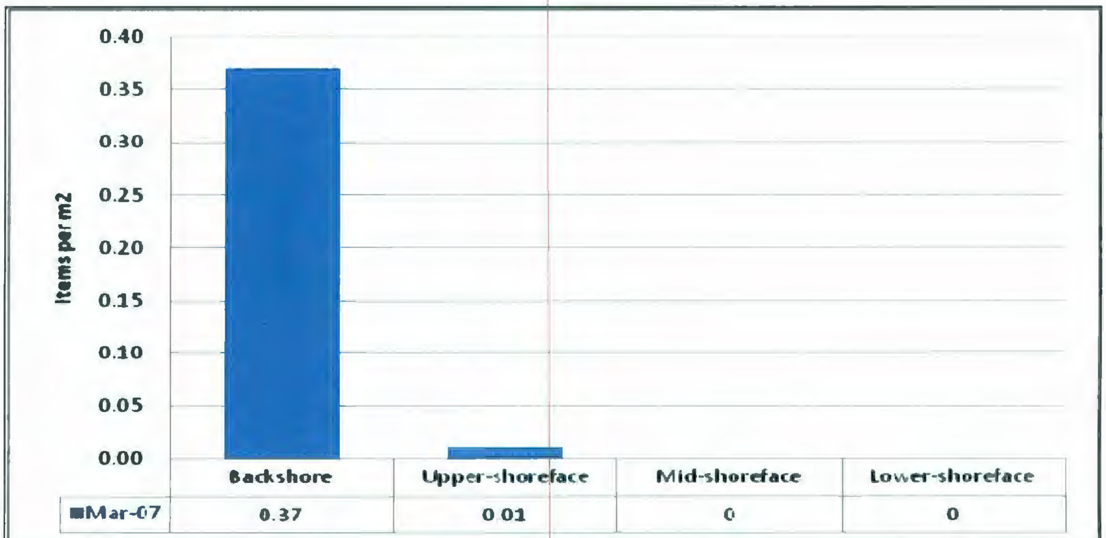


Figure 4.23. Debris concentrations by shoreface division

Like Arnold's Cove beach and Come by Chance beach, the most abundant litter group observed at Hollett's Cove beach was plastic (Figure 4.24). The majority of plastic debris consisted of plastic containers associated with the local fishing industry. Rope and expelled shotgun shells were also commonly observed. Only a few pieces of metal and anthropogenic wood debris were observed. Of these items, approximately 58% could be classified as indicator items. The majority of indicator items, 93%, were ocean-based (Figure 4.25).

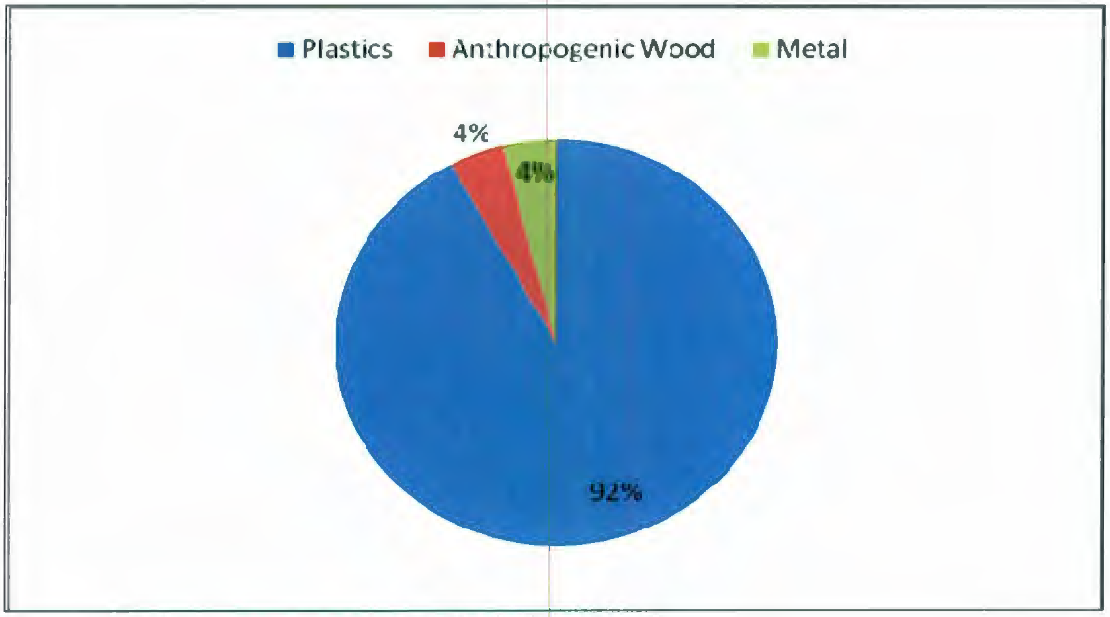


Figure 4.24. Debris composition Hollett's Cove beach

Because the type of debris suggests a near-shore, ocean-based source, it is reasonable to assume that an oil spill in Placentia Bay would impact Hollett's Cove beach. Large amounts of natural debris also suggest this likelihood. The low quantities and concentrations of anthropogenic debris are likely the result of the dominance of high energy events where the likelihood of plastic debris being deposited on the shoreface is relatively low. Based on the distribution of all types of debris, the greatest concentrations of oil contamination encountering Hollett's Cove beach would be deposited in the upper-shoreface and backshore.

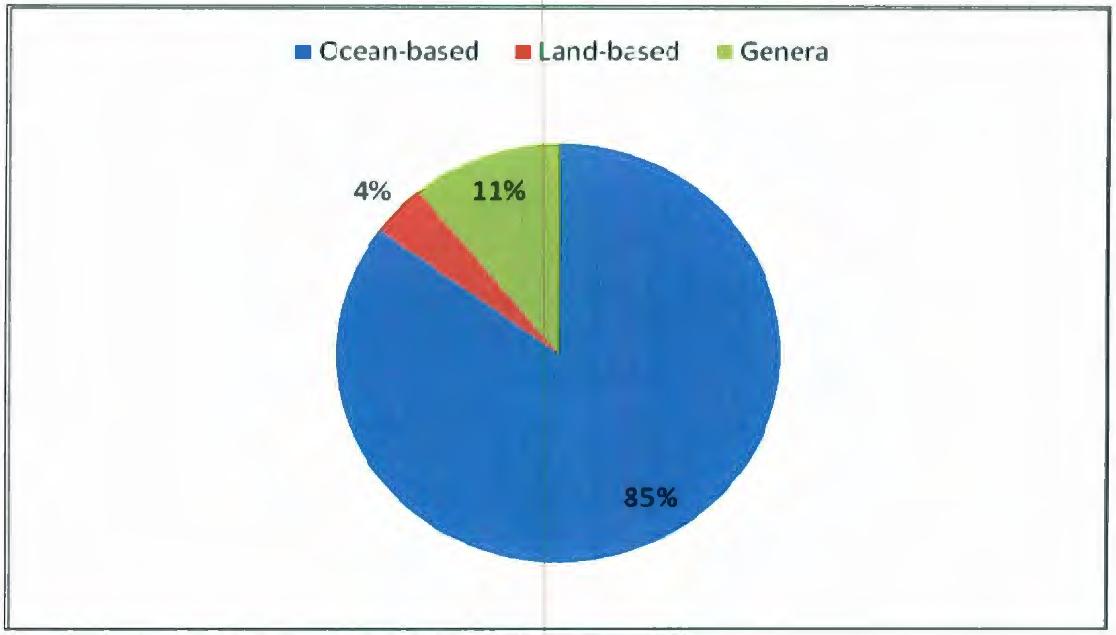


Figure 4.25. Debris source Hollett's Cove beach

4.3.3 Morphology and wave energy

The width of the shoreface was consistent at 18 m (Figure 4.26). At 14°, the slopes of the lower- and mid-shoreface were relatively steep comparative to the same areas of the other study beaches. Unlike the other study beaches, a decreasing seaward trend in slope was not evident. The slope of the shoreface continued at roughly the same angle to the waters edge. Two berms were observed at approximately 4 m and 5 m above datum. Cusps were not present within either berm, although shoreface undulations and features suggesting cusp development were observed over the lower- and mid-shoreface. No clear lateral trend was evident in any of the morphological features observed at Hollett's Cove beach. Shore-parallel processes are likely limited by surrounding headlands and nearby bedrock outcrops.

Weather conditions were calm during initial surveying. However, wave energy conditions were relatively high (Table 4.5). Several hours after the survey, weather conditions had deteriorated substantially. Observed from a distance of several hundred metres, wave energy appeared substantially higher. Beach slope, location of accretionary features, and the presence of

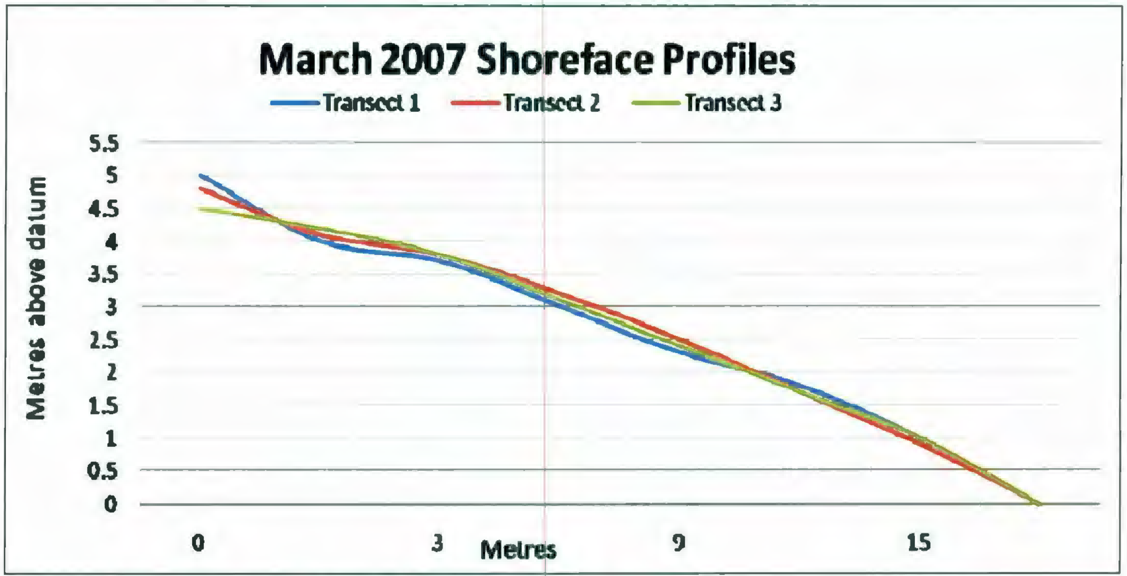


Figure 4.26. Beach profile of Hollett's Cove beach

large pieces of driftwood in and over the backshore indicate a relatively moderate energy beach dominated by shore-normal processes subject to relatively high energy conditions. Taking these factors into consideration, self-cleaning would likely be an effective agent of oil removal in the event of a spill. Sediment characteristics suggest that oil burial and infiltration would be likely. However, oil residence time could be reduced through constant sediment reworking as a result of the dominant wave energy regime.

Date	Surf Scaling Parameter	Wave Energy Density	Wave Power	Longshore Current Velocity	Longshore Wave Power
03/22/3007	Ω = 0.15	314 J/m^{-2}	984 kW/m	nil	nil

Table 4.5. Energy regime variables Hollett's Cove beach

The lagoon located behind Hollett's Cove beach would also likely be subject to marine based oil contamination. The presence of marine debris in this area suggest that incident waves have the potential to move oil over the backshore and into the lagoon. Surrounding topography would ensure that oil pollution would largely be confined to that area. A small stream exiting along the western side of the beach could allow oil in the lagoon to contaminate the beach.

4.4 Goose Cove

Goose Cove beach is located along the western shoreline of Northern Harbour approximately 7 km northwest of Hollett's Cove beach. For the purposes of this study, the area surveyed lay between N47.85970°, W54.09775° and N47.85972°, W54.09529°. At 184 m, it is similar in length to Come by Chance beach. The shoreface is characterized by coarse grained pebbles with lesser amounts of fine textured cobble (Figure 4.27). Boulders and bedrock outcrops were present at each of the beach. Located several metres offshore from the central region of the beach is an area of bedrock with protrudes slightly above the waters surface. A wooden retaining wall separates the beach from a road and several houses.

Figure 4.27. Goose Cove beach. Picture taken March 13, 2007 from transect 1 looking east

A total of 3 transects spaced approximately 50 m apart were used to study the beach at Goose Cove (Figure 4.28). Tide data were not available for Goose Cove. As a result, datum was determined from tide tables for Northern Harbour; located several hundred metres south of Goose Cove. Profiles were plotted based on spring low-tide conditions. The shoreface was divided into three, shore parallel sections of roughly equal width. Slope was approximated using a compass. A survey was undertaken on March 13, 2007. The presence of snow in the upper-shoreface hindered observations in this area. This section summarizes data collected during this survey. Sediment characteristics, the type and distribution of marine debris, beach morphology, and energy characteristics recorded during each survey date are presented.

Figure 4.28. Goose Cove transect locations (Source: Google Earth, 2008)

4.4.1 Sediment composition

Goose Cove beach was composed of a mixture of coarse pebbles with lesser amounts of granules and fine textured cobble sediments. The lower-shoreface contained higher proportions of cobble sediments relative to other areas of the beach while the mid-shoreface contained larger proportions of granules. Laterally, this general arrangement of clasts by size varied little. The beach was bordered on each side by large angular cobbles and boulders which appear to have been deposited as a result of weathering of surrounding bedrock extrusions. The lateral homogeneity of sediments suggests that energy is distributed relatively evenly along this section of shore. Grain angularity suggests a relatively low-energy environment where sediments are not subject to erosion caused by sediment reworking. Clast shape was dominated by equant shaped clasts with lesser amounts of prolate shaped clasts (Figure 4.29). A slightly larger percentage of prolate shaped clasts were observed in the mid-shoreface comparative to the lower-shoreface, suggesting deposition under relatively energetic wave conditions. High sphericity grains were present in greater proportions. Sediments ranged from angular to sub-rounded. Due to the mixed nature of the observed sediments, permeability of Goose Cove beach sediments is relatively low. As a result, oil infiltration and sequestration would likely be limited. The relative absence of sediment reworking suggest that the probability of oil burial is also relatively low.

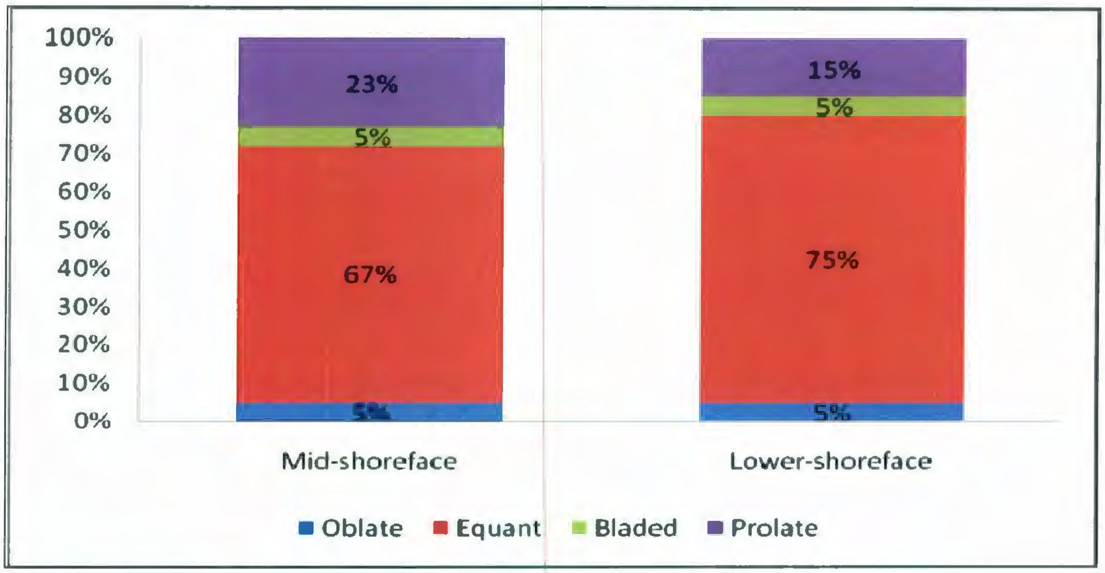


Figure 4.29. Grain shape Goose Cove beach

4.4.2 Distribution of marine debris

Anthropogenic marine debris was not observed along the shoreface during March 13, 2007. Similar observations were noted during a brief foot survey in May of 2007. During March 2007 seaweed was present in two longitudinal bands, one in the lower-shoreface and one in the mid-shoreface. Seaweed cover may be described as sporadic covering approximately 1-10% of the exposed shoreface. Foot surveys conducted in May 2007 along the entire shoreline of Northern Harbour revealed greater marine debris accumulation along the eastern shoreline comparative to the western shoreline where Goose Cove is located. The presence of marine debris in this area may be attributed to the relatively exposed nature of the shoreline, particularly to the predominant southwesterly wind direction. Thus, the location and orientation of Goose Cove may act to decrease the marine debris supply available for deposition. It is likely that Goose Cove beach would be relatively sheltered from oil spill contamination originating in Placentia Bay. In the event of contamination seaweed distribution suggests that oil would be spread longitudinally over the beach at least as far back as the mid-shoreface. Sub-surface seaweed was not observed.

4.4.3 Morphology and wave energy

The morphology of the shoreline of Goose Cove beach was spatially variable, ranging between 8 and 10 m. The wide western and central areas appear to be the result of a west-east longshore current. Given the predominant southwesterly wind direction for this region of Placentia Bay, it is reasonable to assume that the predominant wave angle of approach is to the north-northwest, as observed on March 13, 2007. Sediments entrained within these waves may be initially deposited along the western area of the beach. Oblique waves likely generate a longshore current which transports sediment from this area eastward along the shoreline, depriving the area between the western extremity and central region of the beach of sediment. The offshore bedrock extrusion near the centre of the beach causes sediments entrained within the longshore current to accrete, causing shoreface width to increase again in this area. Because sediment is deposited in the central region, the area immediately east of the centre is deprived of sediment, causing shoreface width to again narrow. These factors may contribute to the shoreline morphology observed during surveying.

The berm observed along Goose Cove beach appeared to be located at the high tide mark, approximately 2 m above datum. Erosional features as a result of melting ice were observed above the berm. This suggests that normal wave action does not generally extend beyond the berm. Wind speed and direction conditions obtained from Environment Canada (2008) for the two week period preceding surveying were conducive to wave formation near Goose Cove beach (Table 4.6). Coupled with the observed absence of any accretionary or overwash features, this may suggest that Goose

Cove beach is indeed sheltered and not normally exposed to higher than normal wave activity.

Date	Maximum Daily Temperature C	Mean Wind Speed (km/h)	Mean Wind direction
1-Mar-08	-1.6	17	N
2-Mar-08	-0.6	20	N
3-Mar-08	1.7	54	SE
4-Mar-08	2.2	43	S
5-Mar-08	-0.4	50	SW
6-Mar-08	-0.3	43	SW
7-Mar-08	-4.1	72	W
8-Mar-08	-7.5	61	W
9-Mar-08	-5.0	44	W
10-Mar-08	0.3	41	W
11-Mar-08	5.3	41	SW
12-Mar-08	4.7	41	N
13-Mar-08	0	20	SW

Table 4.6. Data represents values reported for Argentia, Newfoundland and Labrador (Source: Environment Canada, 2004)

In fact, Goose Cove beach recorded the lowest wave energy conditions of all the study beaches (Table 4.7). Thus, it is likely that overall exposure to oil contamination would be low. Self-cleaning would therefore likely not be an effective agent of oil removal in the event of contamination at Goose Cove beach. In the event of a spill where the beach is exposed to oil, incident waves could be expected to distribute oil longitudinally over the beach. The presence of a backshore wall would likely limit oil contamination beyond the upper-shoreface into the residential area.

Date	Surf Scaling Parameter	Wave Energy Density	Wave Power	Longshore Current Velocity	Longshore Wave Power
03/13/2007	$\Omega = 0.02$	28 J/m^{-2}	88 kW/m	1.0 m/s	40 kW/m

Table 4.7. Energy regime variables Goose Cove beach

5.0 Discussion

5.1 Sensitivity assessment

The texture, shape, and sorting of shoreface sediments are important factors affecting oil infiltration and burial. Generally speaking, large, round, well-sorted clasts such as cobble, offer more pore space for oil to penetrate. Hollett's Cove provides a good example of a beach with a well-sorted, cobble dominated sediment regime. The presence of finer textured sediments can act to decrease oil infiltration. Fine textured sediments, such as sand, were observed during surveying along the beaches of Come by Chance and Arnold's Cove. Although classified as pebble-cobble beaches, sand within the interstitial spaces between larger shoreface clasts would help to limit the effect of oil infiltration on these two beaches relative to Hollett's Cove. However, such sediments are generally well mobilized by storm activity which increases the likelihood of burial. Goose Cove beach is the least sorted of all beaches, dominated by relatively fine textured pebbles and granules. However, the predominance of weak wave energies would limit burial and allow oil to reside on the shoreface for a longer period of time, increasing the likelihood of infiltration.

Morphology provides insight into the processes which shape the beach. Changes in shoreface width and slope may provide evidence of both erosion and accretion. For example, increases in the thickness of shoreface profiles along sections of Arnold's Cove and Come by Chance are indicative of sediment accretion, which increases the probability for oil burial in these areas. The distribution of other morphological features such as berms, cusps, and overwash fans provide additional information on sediment accretion and erosion rates as well as energy conditions. For example, several tiers of berms and cusps, and the presence of overwash fans at Arnold's Cove further indicate an accretionary environment but also suggest that the beach is subject to intermittent high energy events. The upper-shoreface positioning of berms and strong overwash features present at Hollett's Cove beach also suggest an accretionary environment but one in which high wave energies occur more frequently. In such environments, oil pollution can be expected to contaminate much of the shoreface in addition to being buried. High energy beaches such as Hollett's Cove are generally steeply sloped and considered reflective with much of the incident wave energy reflected back to sea. Exposed, reflective beaches are usually dominated by wave energy. On such beaches, self-cleaning can be an effective agent for the removal of oil contamination. Burial is also likely as sediments are constantly reworked by incident waves. However, such reworking often occurs in cycles and much of any buried oil will eventually be removed naturally. Oil persistence would be greater along less exposed beaches which are subject to lower wave energies, such as Goose Cove and Come by Chance.

Considering the morphologic and sedimentologic characteristics of each study beach, Hollett's Cove is considered the least sensitive to oil contamination while Goose Cove is considered the most sensitive. Arnold's Cove and Come by Chance fall between these two extremes with the latter considered more sensitive than the former (Table 5.1).

The higher wave energies associated with the beaches of Hollett's Cove and Arnold's Cove constantly re-work shoreface sediments, helping to remove fine sediments such as sand and sorting the larger pebbles and cobbles. Along the beaches of Come by Chance and Goose Cove, wave energies are not generally high enough to remove and sort shoreface sediments. This helps to explain the relationship between observed sediment characteristics and the dominant energy regime present at each beach. Generally speaking, higher energy beaches dominated by well-sorted, coarse sediments will be less sensitive to oil contamination than lower energy, poorly sorted, mixed sediment beaches.

	Increasing Sensitivity ⟶			
Beach	**Hollett's Cove**	**Arnold's Cove**	**Come by Chance**	**Goose Cove**
Sediment Characteristics	Well sorted coarse sediments	Moderately sorted mixed sediments.	Moderately sorted mixed sediments.	Poorly sorted mixed sediments.
Average Slope	14°	7°	7°	6°
Cusps/berms/sediment reworking	Cusps and berms present. Evidence of sediment reworking moderate-high	Cusps and berms present. Evidence of sediment reworking low-moderate.	Cusps and berms present. Evidence of sediment reworking low-moderate.	Cusps and berms generally absent. Minimal evidence of sediment reworking.
Energy Regime	Persistent high energy conditions. Frequent high energy events. Reflective	Persistent moderate energy conditions. Infrequent high energy events. Reflective.	Persistent low – moderate energy conditions. Infrequent high energy events. Reflective.	Persistent low energy conditions. Infrequent high energy events. Reflective.
Relative Sensitivity	Low	Moderate	Moderate-high	High

Table 5.1. Relative sensitivity index of 4 Placentia Bay North study beaches

5.2 Exposure assessment

The likelihood of oil spill contamination may be determined by understanding factors related to beach exposure. Assessing the likelihood of contamination was determined largely through the observation of marine debris. Sourcing of deposited debris helped provide an understanding of where oil pollution could potentially originate. For instance, the near-shore and offshore sources associated with the debris at Arnold's Cove suggest the potential exposure area from which oil pollution could originate would be greater than the exposure area for Come by Chance beach, where the majority of debris was associated with nearshore sources. Thus, oil pollution originating from virtually anywhere in Placentia Bay would be expected to contaminate Arnold's Cove. Come by Chance, however, would be most likely contaminated if the source were relatively near-shore. The quantity of debris is also an important factor to consider. The relatively large quantity of debris observed at Arnold's Cove and Hollett's Cove suggest that oil contamination would be more likely at these beaches than Come by Chance or Goose Cove (Table 5.2). Comparative to average litter concentrations recorded by Pink (2004), the beaches considered in this study returned higher values, suggesting a higher potential for oil spill contamination in the event of a spill (Table 5.3).

	Increasing Exposure →			
Beach	**Goose Cove**	**Come by Chance**	**Arnold's Cove**	**Hollett's Cove**
Debris Source	Ocean-based	Ocean-based	Ocean-based	Ocean-based
Debris Quantity	Low	Moderate	High	High
Proximity to potential source	> 10 km	< 5 km	< 10 km	< 5 km
Relative Exposure	Low	Moderate	High	High

Table 5.2. Relative exposure index of 4 Placentia Bay North study beaches

The most probable source for petroleum contamination of the 4 beaches considered in this study is associated with the general operations of nearby oil handling facilities. This includes oil tankers which traverse the shipping lanes near Arnold's Cove. These tankers may anchor for days near Arnold's Cove and Hollett's Cove awaiting the opportunity to berth. An increase in tanker density may increase the likelihood of an accidental spill. Accidents at the refinery and transshipment terminal, illegal dumping, bilge washing, and poor housekeeping on-board tankers are all potential sources of hydrocarbon pollution.

Beach	Study	Average litter concentration
Arnold's Cove	Pink (2004)	0.08 items/m^2
Ferryland	Pink (2004)	0.01 items/m^2
Portugal Cove	Pink (2004)	1.69 items/m^2
St. Brides	Pink (2004)	0.02 items/m^2
Arnold's Cove	This study	0.36 items/m^2
Come by Chance	This study	0.24 items/m^2
Hollett's Cove	This study	0.07 items/m^2
Goose Cove	This study	nil

Table 5.3. Anthropogenic beach litter concentrations of selected Avalon Peninsula beaches

Proximity to these facilities and relatively unimpeded southwest fetch increase the likelihood that Arnold's Cove and Hollett's Cove would be contaminated in the event of a spill at or near the head of Placentia Bay. Although Come by Chance beach is within 5 km of the nearest the oil handling facility and anthropogenic marine debris were observed at higher concentrations than at Hollett's Cove, the large amount of natural marine debris at Hollett's Cove suggest that the potential for contamination is higher than at Come by Chance (Table 5.2).

A small proportion of the debris observed at each beach was associated with land-based sources. With the exception of Hollett's Cove, each beach is accessible directly by road. Thus the possibility exists of a land-based source for contamination. Accidents or discharges from machinery and oil trucks near the shoreline could potentially impact these beaches. Hollett's Cove, considered generally removed from access by land, is not currently threatened by land-based contamination. However, with the addition of the proposed refinery at Southern Head, the overall relative exposure rating for Hollett's Cove would likely increase.

5.3 Vulnerability assessment

Vulnerability is a function of sensitivity and exposure. A beach may be considered to have a low vulnerability, despite being sensitive to oil contamination, if the likelihood of exposure is very low. Such a situation is present at Goose Cove, which is considered the least vulnerable of each study beach. Similarly, a beach which is expected to be contaminated due to a high exposure may have only a moderate vulnerability if sensitivity is low, as is the case with Hollett's Cove. The most vulnerable beach would be one with both a high sensitivity and exposure. Arnold's Cove most closely recreates these factors and is thus considered to be the most vulnerable of all the study beaches to oil contamination (Table 5.4).

	Increasing Vulnerability →			
Beach	**Goose Cove**	**Hollett's Cove**	**Come by Chance**	**Arnold's Cove**
Relative Sensitivity	High	Low	Moderate-high	Moderate
Relative Exposure	Low	High	Moderate	High
Relative Vulnerability	Low	Moderate	High	High

Table 5.4. Summary of relative sensitivity, exposure, and vulnerability index of 4 Placentia Bay North study beaches

5.4 Applying vulnerability to other beaches

Bear Cove beach is a high energy, reflective system located along the southeastern shoreline of the Avalon Peninsula (Figure 5.1). The shoreface is comprised primarily of pebble-cobble substrate, although boulders are also present at each end of the beach and near the lower-shoreface (Etheridge, 2005). Following the coastal classification scheme proposed by Catto *et al.*, (2003), Bear Cove may be classified as a gravel and sand beach on a narrow rock platform. Etheridge (2005) has classified Bear Cove as low to moderately vulnerable to oil pollution relative to the five Southern Shore beaches. Considering all the beaches discussed in this study, vulnerability of Bear Cove may be considered low. Bear Cove is expected to be very effective at self-cleaning.

Marine debris was not observed by Etheridge (2005) which suggests that the beach does not act as a collector of marine debris and thus would not be exposed to marine oil pollution. The beach is not located near any communities and the only source of land-based pollution would be two culverts. Bear Cove provides a good example of a Newfoundland beach system which would be considered to have a low oil spill vulnerability rating (Table 5.5).

Figure 5.1. Selected Avalon Peninsula beaches (Source: Google Earth, 2008)

According to Pink (2004), St. Bride's is a relatively high energy, reflective beach system located along the Cape Shore of the eastern shoreline of Placentia Bay (Figure 5.1). Shoreface substrate is comprised of medium grain sand to boulders (Pink, 2004). Following the coastal classification scheme proposed by Catto *et al.*, (2003), St. Bride's may be classified as a gravel beach with a rock cliff. Oil would be expected to penetrate the pore spaces between the boulders and cobbles. Mobilization of sands and pebbles during periods of high wave energy would also cause burial; although long-term persistence as a result of burial would not be expected due to the continual reworking of shoreface sediments. Considering these factors, St. Bride's is considered moderately sensitive to oil pollution.

Similar in size to Arnold's Cove beach, St. Bride's was part of beach litter study conducted by Pink in 2004. In terms of quantity, St. Bride's recorded the second largest amount of debris (Pink, 2004). Offshore marine sources were not particularly prevalent, a result attributed by Pink to northerly wind and current patterns in Placentia Bay. The primary composition of the debris suggested casual littering and unregulated waste disposal at, or near-shore by citizens and recreational users (Pink, 2004). However, Pink (2004) acknowledges that St. Bride's may act as a temporary site for debris accumulation before it is removed by the sea. Taking into consideration these factors, the predominant wind and current patterns, and proximity to shipping lanes, St. Bride's may be considered moderately exposed to oil pollution.

Given the moderate sensitivity and exposure assessment for St. Bride's, vulnerability is also considered moderate (Table 5.5). Although close to shipping lanes and exposed to the southwest, the dominant wind and current patterns would likely act to transport spilled oil northwards, away from St. Bride's. Much of any oil contaminating the beach would likely be cleaned by wave activity and sediment reworking.

Brigus South is located along the Southern Shore of the Avalon Peninsula (Figure 5.1). According to Etheridge (2005), the beach is considered a low energy system. It is dominated by pebbles and fine textured cobbles with lesser amounts of finer and coarser textured clasts varying seasonally (Catto *et al.*, 2003). It is very protected and considered to have a low exposure assessment. As a result, Etheridge (2005) considered vulnerability to be low (Table 5.5). Although the beach is considered to be very sensitive to oil pollution the likelihood of being contaminated is very low. Marine-based contamination would, generally, only be able to impact the beach during high energy events. However, reported storm activity impacting Brigus South beach is rare and waves usually break 20 – 50 m seaward of the open harbour (Catto and Thistle, 1993). Evidence suggests that storm activity has not been present at Brigus South beach since 1966 (Etheridge, 2005). High energy storm events between 1992 and 2003 that impacted other Southern Shore beaches studied by Etheridge (2005) did not impact the beach at Brigus South (Catto *et al.*, 2003).

Witless Bay is a relatively high energy, steep, reflective beach system (Etheridge, 2005; Catto *et al.*, 2003) located along the eastern shoreline of the Avalon Peninsula (Figure 5.1). The shoreface consists primarily of coarse grained pebble and cobble, although seasonal coarse grained sand may be found in the lower-shoreface (Etheridge, 2005). The ability of Witless Bay beach to clean itself of oil contamination is limited. Oil in the lower-shoreface and backshore would likely persist, the latter of which would likely require removal by hand. Although somewhat protected from offshore contamination sources, the funneling effect caused by the physical characteristics of Witless Bay increases the potential exposure area beyond what would normally exist. Considering these factors, Etheridge (2005) considered Witless Bay to be highly vulnerable. However, relative to the other beaches considered in this study, vulnerability is considered moderate.

Point Lance beach is located on the southern tip of the Cape Shore (Figure 5.1). Two rocky headlands exist at each end of the approximately 1500 m wide beach. The beach is trisected by two streams exiting the beach near the western and eastern extremities. During periods of low wave activity, shoreface substrate is generally dominated by a mixture of pebble and cobble with a veneer of finer textured sand (the result of an ample supply of sand in the backshore – Catto, personal communication, 2008). Storms and periods of increased wave activity often remove this veneer, exposing the underlying coarser textured pebble and cobble. In terms of sensitivity, finer textured sediments such as sand generally resist penetration in the short term. However, lighter oils could penetrate these sediments. Sediment reworking would likely bury sediment and allow penetration of the larger clasts, resulting in increased persistence. Oil could also mix with the finer sediments present within the interstitial spaces between the pebbles and cobbles, creating a mixture resistant to wave action and decreasing the ability of the beach to self-clean. Taking all these factors into consideration, Point Lance may be considered very sensitive to oil pollution.

Point Lance has a very large, exposed southwest fetch. It lies adjacent to major shipping lanes, including those associated with large tankers entering Placentia Bay. Ships often travel very near the coast in this location before entering Placentia Bay to help minimize travel time and to avoid winter and early spring storms (Graham Thomas, , Environment Canada, Environmental Emergencies Coordinator, personal communication, 2007). Oil pollution commonly washes up on nearby sections of shore such as St. Brides and Branch during this period. The community of Point Lance backing the western side of the beach also provides a potential source of hydrocarbon contamination. All Terrain Vehicles are commonly rode on the beach. Taking into consideration these factors, the beach at Point Lance is considered highly exposed to oil contamination.

Point Lance beach represents one of the most sensitive shoreline types on the Avalon peninsula in terms of oil spill sensitivity. Oil would be expected to persist through burial, penetration, and sequestration. Interaction with finer sediments could potentially produce materials resistant to removal by wave action. Considering the sensitivity of the beach, and the general likelihood of exposure, Lance Cove beach may be considered the most vulnerable of all the beaches considered in this study to oil spill contamination.

	Beach	Sensitivity	Exposure	Vulnerability	Source
Increasing Vulnerability	**Bear Cove**	Low	Low	Low	Etheridge 2005
	Brigus South	Very high	Very low	Low	Etheridge 2005
	Goose Cove	High	Low	Low	This study
	Witless Bay	Moderate	Low - moderate	Moderate	Etheridge 2005
	Hollett's Cove	Low	High	Moderate	This study
	St. Bride's	Moderate	Moderate	Moderate	Pink 2004
	Come by Chance	Moderate - high	Moderate	High	This study
	Arnold's Cove	Moderate	High	High	This study
	Point Lance	Very high	High	Very high	Catto, 2008, personal communcation

Table 5.5. Summary of relative sensitivity, exposure, and vulnerability indexes of selected Avalon Peninsula beaches

5.5 Comparing beach vulnerability

In order to produce an accurate vulnerability assessment methodology for beaches it was important to establish baseline beaches. That is, a beach which measured both lowest and highest in terms of sensitivity and exposure relative to the gravel dominated beaches likely to be encountered during an oil spill along the Avalon Peninsula. As the least vulnerable beach, Bear Cove is a high energy beach where self-cleaning would be very effective and the probability of exposure is low. At the opposite end of the vulnerability scale is Point Lance. Despite a large fetch and the presence of relatively high energy conditions, oil is expected to persist given sedimentologic conditions. Combined with a high exposure, Lance Cove is the most vulnerable beach considered. Relatively minor variations in sensitivity and exposure produce different vulnerabilities for similar beach systems. For instance, despite a similar sensitivity, Brigus South is much less vulnerable than Point Lance because it is very sheltered from potential sources of contamination. Goose Cove is another sensitive beach, but due to increased likelihood of exposure relative to Brigus South, ranks higher than that beach in terms of vulnerability. Hollett's Cove, which is considered highly exposed to potential oil spill contamination, ranks only moderate in terms of vulnerability because like Bear Cove, high energy conditions cause sensitivity to be very low. Conversely, Witless Bay is considered to have a higher sensitivity to oil contamination than Hollett's Cove, but has a lower vulnerability because the likelihood of contamination is considerably less. Both St. Bride's, and Come by Chance are less likely to be exposed to oil pollution than Hollett's Cove but still have a higher vulnerability because oil would be expected to persist much longer in these systems.

Thus, it becomes evident that close scrutiny of the variables contributing to oil spill vulnerability is important when comparing beaches. Although the beaches considered in this study are generally representative of the gravel dominated beaches found along the Avalon Peninsula and Placentia Bay shorelines, there may be some beaches which rank lower or higher than the baseline beaches considered above (e.g. Salmon Cove, Conception Bay). The inclusion of such beaches will only act to improve the accuracy of a vulnerability assessment.

6.0 Conclusion

6.1 General trends

The construction and eventual operation of an additional refinery at Southern Head, a Liquid Natural Gas Storage Facility at Grassy Point, and a proposal to increase the refining capacity of the existing North Atlantic Refinery near Come by Chance will add to the total number of vessels visiting Placentia Bay annually. As the number of vessels and large tankers traversing these waters increases, so will the probability of oil spill contamination. Consequently, an increase in the understanding of the factors important to the study of shoreline oil spill vulnerability on Placentia Bay beaches is required. An increase in the likelihood of contamination should lead to an increase in the understanding of the system in which in the increased contamination is possible. This study has contributed to that understanding by assessing, at a finer scale than currently exists, the sensitivity, likely exposure, and resultant vulnerability of beach types common to Placentia Bay.

The 4 beaches considered in this study, and the additional 5 beaches to which the vulnerability assessment was applied, are representative of the beaches of Placentia Bay. A variety of sensitivities and exposures highlight much of the spectrum of possible vulnerabilities along the shoreline. Exposed, mixed sediment beaches such as Point Lance and Arnold's Cove, are generally representative of the more vulnerable beach types while less exposed, coarse textured beaches such as Bear Cove and Hollett's Cove, are generally representative of the least vulnerable beach types. Site specific factors, such as the very protected nature of Brigus South beach, exemplify variations which may change the general relationship between vulnerability and the factors affecting vulnerability. Relative to the dominant types of beaches present throughout Placentia Bay, the majority of Placentia Bay beaches will be moderately sensitive to oil spill contamination.

The southwest – northeast orientation of Placentia Bay, combined with the dominant wind and current directions, and proximity to shipping lanes, suggest that beaches along the eastern shoreline of the Bay will be relatively exposed to oil contamination; a fact supported by the higher number of identified beaches along the eastern shoreline containing significant amounts of marine debris (Department of Fisheries and Oceans, 2004). Beaches along the western shoreline are offered protection by the multitude of islands, distance from shipping channels, and southward flowing current of the area. Because of higher sensitivities and exposures, vulnerabilities will generally be higher amongst eastern shoreline beaches relative to beaches along the western shoreline.

Ideally, oil spill prevention is the best approach to reducing the impacts of oil spills. Prevention is possible through a variety of means including education, increased surveillance and continual improvement of traffic management. In the event of a spill, the most appropriate response is dependent on the environment in which the spill occurs. Considering the variety of beaches in Placentia Bay, responses may vary. In some instances, an actual cleanup operation on the beach may not be best response as oil spill cleanup could potentially cause further damage. For beaches such as Point Lance, it may be more effective to prevent oil from reaching the beach completely. Other beaches, such as Hollett's Cove, will generally self-clean effectively. The majority of beaches in Placentia Bay would require some level of human intervention if oiled, including manual cleaning.

Oil impacting the coarse sediment beaches of Placentia Bay would generally persist for a considerable amount of time. Persistence would be greater along beaches which are more protected from the abrasive action of wave energy such as Goose Cove. In such environments, oil could persist for decades. In general, the majority of the Placentia Bay shoreline would be capable of self-cleaning over a period of a few years, as was witnessed along the Chedabucto Bay shoreline of Nova Scotia during the 1970 Arrow spill. Residual oil would persist largely subsurface or on the surface in the form of asphault pavements and tar mats. An oil spill in Placentia Bay would likely have greater implications from a socio-economic perspective. Ocean related activities account for a substantial portion of the areas total labour income and employment (Department of Fisheries and Oceans, 2005). Industry, fisheries, aquaculture, as well as recreation and tourism would all be negatively affected. Depending on the extent of a spill, this could be detrimental to the ability of the local population to generate income.

6.2 Suggestions for future research

Assessment of the sensitivity of beaches throughout the Placentia Bay region should be continued. The majority of shoreline sensitivity data currently in use for oil spill response purposes is inaccurate and out of date. Site specific studies of the shoreline which generate larger scale data will allow for more effective emergency oil spill response planning. More effective response planning will also require that recent and future shoreline sensitivity data be compiled in a central database in a format compatible with that used by the major response organizations such as Eastern Canada Response Corporation, Environment Canada, and the Canadian Coast Guard.

Additionally, further studies assessing the types, volumes, and sources of marine debris present along Placentia Bay beaches should be undertaken. The methodology for determining vulnerability presented in this study utilized marine debris as an indicator of exposure to oil pollution. A lack of available marine debris data limits the applicability of this method.. This data is relatively easy to collect and can be done in conjunction with the collection of sensitivity data. Access to sensitivity, exposure, and vulnerability data will provide oil spill response planners and responders with an effective means to help manage and mitigate the impacts associated with an oil spill in Placentia Bay.

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