

# **Sensitivity, exposure, and vulnerability of gravel beaches to petroleum pollution, Avalon Peninsula, Newfoundland, Canada**

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## **Abstract**

The Avalon Peninsula lies directly adjacent to a major trans-Atlantic shipping route, and to offshore petroleum development and areas of ongoing exploration. The cultural and socio-economic significance of the established fisheries, increased tourism, and endemic petroleum pollution exemplified by the arrival of oiled seabirds on the Avalon beaches, indicate that the potential impact of petroleum contamination is significant. Study of gravel beaches showed differences in morphology, sedimentology, energy regime, and sediment transport. These characteristics change the fate and effect of petroleum contamination on each beach. Beaches have been ranked on their sensitivity to oil pollution based on their physical characteristics. The beaches are gravel dominated, reflective systems, with sediment transport varying from shore normal on some beaches to both shore normal and shore parallel transport on others. The movement of sediment, litter, and seaweed in the nearshore and beach environments provides analogies for how oil will behave. Lower energy beaches will not self-clean as well as the high energy, steeper sloping, highly reflective beaches, and are thus more sensitive to pollution. Petroleum contamination potentially can come from both offshore and terrestrial sources. For a particular beach, the risk of contamination depends upon the population demographics, socio-economic circumstances, type and intensity of economic activity, location with respect to shipping lanes and petroleum development, transport regime, and beach dynamics. The degree of exposure to potential petroleum contamination from both offshore and terrestrial sources has been categorized, and forms a basis for assessment of the risk of contamination on each beach. Consideration of the risk of contamination from all sources, in combination with sensitivity analysis, allows a vulnerability assessment. The vulnerability assessment can be used as a basis for planning and allocation of resources, to cope with both endemic oil pollution and to promote an effective response to a potential major event.

*Keywords:* beaches, petroleum pollution, Avalon Peninsula, Newfoundland, vulnerability, sensitivity.



## 1 Introduction

For most of the plant and animal species, and for the human occupants, life in Newfoundland, eastern Canada, revolves around the coastal environment. The deeply embayed coasts provided safe harbours for fishing vessels, with suitable onshore areas for drying and processing cod and for construction of the necessary stages, stores, and other buildings. Local fishing grounds supported inshore fisheries for cod, flatfish, herring, and crab, and capelin spawned on gravel beaches. The historical, cultural, and economic place of the coastal zone in Newfoundland has been thoroughly documented (Rowe [1], Handcock [2]).

Although the heritage of the fishery remains central to the culture of Newfoundland, its economic importance has diminished in recent years. The collapse of the northern cod stocks led to the imposition of a moratorium on cod fishing in 1992. The shift to harvesting of previously under-utilized species, coupled with growing interest in aquaculture, has led to a new evaluation of the significance of the coastal zone. The demise of the northern cod fishery and the shift towards tourism, combined with a growing environmental consciousness, has resulted in increased interest in the coastal zone. Realization of the impacts of petroleum pollution both from marine and terrestrial sources has also spurred interest. A further factor is the increasing utilization of coastal sites for residential and commercial construction.

This study focuses on the sensitivity, exposure, and vulnerability to petroleum contamination of gravel beaches along the coastline of the Avalon Peninsula, eastern Newfoundland (Figure 1). The 10,000 km<sup>2</sup> Avalon Peninsula is home to more than 300,000 residents, approximately 60% of the total population of Newfoundland and Labrador, including St. John's.

The coastline includes segments with small embayments with gravel pocket beaches, steep bedrock cliffs locally exceeding 70 m in height, and embayed shorelines flanked by bedrock veneered by coarse glacial till, with gravel and mixed gravel-and-sand baymouth, mid-bay, and bay head bars.

Predictions concerning the effect of petroleum impact on beaches require understanding of the dynamics of particular shorelines. Most of the Avalon Peninsula beaches are gravel dominated, the results of glacial processes bringing large volumes of predominantly coarse sediment to coastal areas (Boger [3], Catto *et al.* [4], Pittman [5]). Catto *et al.* [4] divided the shorelines of eastern Newfoundland into 24 classes based on sediment texture, coastal morphology (width and slope), and the nature of substrate, and assessed the vulnerability of shoreline classes to petroleum contamination (Table 1).

The fate and effect of oil on the shoreline varies greatly depending on the type of shoreline, as some Avalon Peninsula shorelines are less sensitive to oil spills than others. The shoreline type, geomorphology, its substrate, grain size, tidal elevation, origin, exposure to waves, reflective or dissipative energy regime, tidal energy, and currents greatly influence the amount of time required for natural removal, breakdown, or dispersion of petroleum. Owens [6] provides a thorough review of all the factors involved in assessment of the impact of crude petroleum and petroleum products of differing viscosities under differing



temperature conditions on shorelines throughout Canada. In the wake of responses and long-term results of tanker disasters and clean-up efforts, a large body of information now exists concerning the impact of oil on marine life, its residence time in the water column and substrates under various marine conditions, and the ability of beach environments to be self-cleaned (e.g. Spaulding [7], Sobey [8], Sobey and Barker [9]).

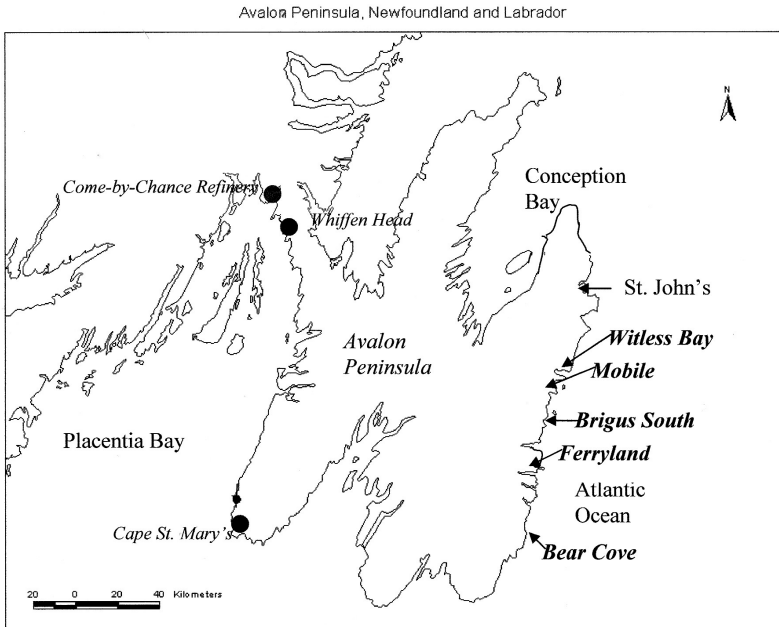


Figure 1: Location of Southern Shore Beaches, Avalon Peninsula, Eastern Newfoundland.

Petroleum pollution in the waters around the Avalon Peninsula is a growing potential problem. The Avalon Peninsula lies adjacent to the major trans-Atlantic shipping lanes connecting eastern North America with northwestern Europe. The combination of international traffic with substantial local vessel traffic, largely fishery-related, results in the potential for both accidents involving petroleum spillage and deliberate discharge of oiled bilgewater. Incidents and legal proceedings associated with discharge of petroleum-laden bilge by offshore vessels, and the onshore consequences (Wiese and Ryan [10]; Canadian Coast Guard [11]), have been noted along shorelines from Cape Race to Placentia Bay. Although the fisheries around the Avalon Peninsula unfortunately have declined since initial concerns were raised (Scarlett [12], Paine *et al.* [13]), sensitivity remains high.

Development of the offshore Hibernia, Terra Nova, and White Rose oilfields represents another potential source of petroleum pollution, both from production operations and the necessary vessel traffic. Tanker traffic through Placentia Bay

to the Whiffen Head trans-shipment terminal and the Come-by-Chance oil refinery, located in Arnold's Cove, has increased substantially since 1990. The Eastern Canada Response Corporation (ECRC) is mandated to respond to requests for assistance in dealing with incidents of petroleum contamination along the Placentia Bay shore. In addition to offshore events, accidental discharge of petroleum and gasoline at the shoreline during refinery and tanker operations (Williams *et al.* [14]), removal and disposal of waste from vessels in port (Olson [15]), and leakages from strictly terrestrial sources, are also matters of concern.

Table 1: Sensitivity to petroleum contamination for shoreline classes.

<i>Very Low (1):</i> Resistant Rock Cliffs; Rock Platforms; Cobble Gravel over Wide Rock Platforms; Gravel over Narrow Rock Platforms
<i>Low (2):</i> Friable Rock Cliffs; High-Moderate Energy Steep Gravel Beaches; High Energy Gravel Pocket Beaches; Steep Sand and Gravel Beaches with Gravel>Sand; Narrow Gravel Flats; Wide Gravel Flats w. Cobbles>Granules; Pebble Gravel over Wide Rock Platforms
<i>Low to Moderate (2.5):</i> Low Energy Steep Gravel Beaches; Moderate Energy Gravel Pocket Beaches; Wide Gravel Flats w. Pebbles>Cobbles Steep Sand and Gravel Beaches w. Sand>Gravel
<i>Moderate (3):</i> Sand and Gravel over Rock Platforms, Gravel>Sand; Sand and Gravel Pocket Beaches; Narrow Sand and Gravel Flats, Gravel > Sand; Wide Sand and Cobble Gravel Flats; Wide Gravel Flats w. Granules>>Cobbles; Low Energy Fine Gravel Pocket Beaches
<i>Moderate-High (3.5):</i> Narrow Sand and Gravel Flat w. Sand > Gravel; Wide Sand and Gravel Flats w. Gravel > Sand; Sand and Cobble Gravel Pocket Beaches, Sand > Gravel; Sand and Gravel over Rock Platforms, Sand>Gravel
<i>High (4):</i> Bouldery Tidal Flats; Mudflats; Sand over Narrow Rock Platforms; Sand Beaches at Base of Rock Cliffs; Wide Sand and Gravel Flats w. Sand > Gravel; Mixed Sand and Pebble Gravel Pocket Beaches, w. Sand > Gravel; Narrow Sand and Pebble Gravel Flats, w. Sand > Gravel
<i>Extremely High (5):</i> Sand over Wide Rock Platforms; Sand Beaches and Flats; Estuaries; Fringing Lagoons



Petroleum products can thus arrive at Avalon Peninsula shorelines from both offshore and onshore sources. Assessment of the sensitivity, degree of exposure, sources, and vulnerability to petroleum contamination is of importance to the ECRC, vessel owners and operators, fish harvesters, coastal residents, and all who use or rely on the coastline of the Avalon Peninsula.

## 2 Investigation of gravel beaches

Following the general categorization of the sensitivity and vulnerability to petroleum contamination of all beaches along the Avalon Peninsula (Catto *et al.* [4]), five beaches along the Southern Shore were selected for detailed study. The five beaches, Witless Bay, Mobile (Catto [16]), Brigus South, Ferryland (Pink and Catto [17]), and Bear Cove (Strickland [18]) were chosen to represent a variety of energy regimes, surface textures, slopes, degree of exposure to wave action, and styles of sediment transport ranging from shore-parallel to shore-normal. The beaches also varied in the degree of potential exposure to petroleum contamination from offshore sources, including fishery-related traffic, trans-Atlantic vessel movement, and oilfield operations; and to petroleum contamination from terrestrial sources. Study of these beaches forms the first phase of a broader project designed to assess beaches throughout the Avalon Peninsula, including those along the high-traffic area of Placentia Bay. Table 2 summarizes these parameters for the five studied Southern Shore beaches.

All of the shorelines are microtidal and are dominated by wave energy. Wave energy is not distributed evenly along all shorelines. This generally is the result of wave refraction around an offshore island or rocks, over submerged bathymetric highs or lows, or as the result of local orientation of the coast. Wave energy levels range from low through moderate to high, depending on wind strength and level of exposure of the beach. In more sheltered settings, oil will persist longer, but burial is less likely because of the low wave energy. In higher energy environments, deeper burial is possible if the oil is deposited at the beginning of accretion, but most will be removed by the next storm.

All of the beaches investigated in this paper are steep, reflective systems, with the exception of the gently-sloping, low energy reflective Brigus South. Reflective gravel beaches show size and shape sorting on steep beach faces, with multiple cusped berms, and a narrow directional width of incoming wave angle, usually shore-normal.

Petroleum may percolate to several tens of centimetres depth in gravel beaches. The sorting of the beach material is important in terms of penetration rate, as poorly sorted gravel sediment has less porosity and permeability than does well sorted material. Gravel tends to be highly mobilized during peak and waning periods of storm activity. Granules, pebbles, and small cobbles are readily moved by normal wave activity on the Avalon Peninsula beaches. There is high potential for oil burial by accretion in gravel systems. All of the beaches are dominated by swash/backwash, shore normal sediment transport, although some experience shore parallel sediment movement as well.



Table 2: Characteristics and vulnerability assessment, southern shore beaches.

<i>Beach</i>	<i>Energy Level</i>	<i>Clast Texture</i>	<i>Exposure</i>	<i>Sediment Transport Pattern</i>	<i>Sensitivity</i>	<i>Likelihood of Pollution</i>	<i>Vulnerability</i>
<i>Brigus South</i>	Low	Fine sand to large cobbles; Pebble-dom.	Low; Sheltered opening to east	Little wave action	<i>Very high</i>	<i>Low</i>	<b>Low</b>
<i>Witless Bay</i>	Mod. to high	Sand to cobbles. Pebble-Cobble dom.	Moderate Slightly sheltered by island	Shore normal with minor shore-parallel	<i>Moderate to high</i>	<i>Moderate</i>	<b>Moderate to High</b>
<i>Ferryland</i>	Low-high	Medium sand to cobbles. Cobble dom.	High Open to east	Shore normal and shore parallel	<i>Moderate</i>	<i>Low</i>	<b>Moderate</b>
<i>Mobile</i>	Mod. to high	Medium sand to boulders. Pebble-cobble dom.	Moderate Open to northeast and east	Shore normal with shore parallel	<i>Low</i>	<i>Moderate</i>	<b>Low to Moderate</b>
<i>Bear Cove</i>	High	Pebbles to boulders. Cobble dom.	High Open to north, east, and south	Shore normal; limited shore parallel	<i>Very Low</i>	<i>Moderate</i>	<b>Low to Moderate</b>

Consideration of the sensitivity and degree of exposure to petroleum contamination of beach systems can lead to an overall assessment of vulnerability, as the combination of both the sensitivity and likelihood of pollution. A beach can be very sensitive to oil pollution, but the likelihood of a contaminant arriving on that beach (for various reasons) may be very low. The five Southern Shore beaches exhibited a range of vulnerability to petroleum contamination, as discussed individually below.

## 2.1 Brigus South

The beach at Brigus South, the most sheltered low-energy beach of the five investigated, is classified as being very sensitive to oil pollution. A relatively flat beach, with very little wave activity, it is not a reflective system: in October 1992, when waves last washed over the beach during storm events, they did not reflect seaward due to the shallow slope of the beach face. The sheltered beach,



with only a narrow eastward opening to the sea, is not exposed to oil arriving from the open Atlantic Ocean, unless under very stormy conditions. Brigus South beach has not been disturbed by any storm events since 1992, including those that affected the other southern shore systems (Catto *et al.* [4]). Observations since 1989 indicate that no debris of offshore origin collects here.

Hydrocarbon pollution introduced into this environment would persist, as the open-worked gravel would allow for easy penetration. In addition, oil pollution on the Brigus South beach could be buried over time by fluvial sediment. The beach at Brigus South would not clean naturally and therefore is considered very sensitive to oil pollution.

Although hydrocarbon pollution offshore could result from illegal or accident dumping, bilge pumping, structural damage causing leaks, and major accident spills, the offshore installations are more than 300 km southeast of Brigus South, and the prevailing current direction is southward. There is the possibility for hydrocarbon contamination from a terrestrial or local source on this beach. Although there are houses, vehicles, and a (usually inactive) fish plant, the community is small and has very little economic activity. The likelihood of a terrestrial-based spill is low, and if an incident did occur it would be of a small magnitude. Thus, although the beach at Brigus South is very sensitive to oil pollution, the degree of exposure to hydrocarbon pollution is low. Considering both the likelihood and sensitivity to oil pollution the vulnerability to hydrocarbon contamination at Brigus South is relatively low.

## 2.2 Witless Bay

The beach at Witless Bay is sheltered from the full strength of the wind and wave activity by an island. Even though the beach is slightly sheltered, it is a reflective, moderate to high-energy system, and is capable of some self-cleaning. Although Witless Bay beach is pebble and cobble dominated, sands in the flat intertidal and nearshore area would not be self-cleaned by wave action as easily as the higher pebble-cobble sections. The sand could be penetrated by oil over time, and is buried by cobbles in the fall, allowing previously oiled sands to remain in place. Oil on the beach could potentially quickly penetrate the cobble layers, slowing in its downward migration as it came into contact with the sand. The gravel sections of the middle and upper beach are not influenced by wave action except during storms, so oil on these sections of the beach would have time to penetrate deeply into the sediment. If oil were transported to the backbeach area by storm washover, it would remain until removed by humans. Overall, although Witless Bay is a steep, reflective, moderate to high-energy beach that could self-clean in part, it is classified as moderate to high in terms of sensitivity.

It is very unlikely a spill at sea from one of the offshore installations would significantly impact the beach at Witless Bay, as the prevailing currents flow south and east and the beach is slightly sheltered from the open ocean. A small recreation vehicle park situated directly adjacent to the Witless Bay beach is a potential source of hydrocarbon contamination, albeit of small magnitude. The likelihood of an oil spill is moderate because even though there is a very little



chance of a spill from any of the sources mentioned, there is potential for both land-based and marine contamination.

The Witless Bay beach is classified as moderate to high in terms of vulnerability to oil pollution. The bathymetry and flanking topography direct wave energy into the cove, regardless of the initial direction of the prevailing storm winds. The beach at Witless Bay is therefore affected by a variety of wind directions, not only easterlies. Although the beach is sheltered, it could receive oil pollution from many directions. In addition the beach is moderately to highly sensitive to oil contamination and the likelihood of a spill is moderate. These factors in combination make the vulnerability to hydrocarbon pollution at Witless Bay relatively high.

### 2.3 Ferryland

The beach at Ferryland has a steeper slope, is more reflective, and is a higher energy system than is Witless Bay. The Ferryland beach is the widest of all the beaches examined and it is subject to longshore sediment transport. Oil would be transported along the shore, polluting the entire beach, resulting in difficulties in cleansing.

The western end of the beach is dominated by cobbles. This steeply sloping segment would generally be effectively self-cleaned by wave action, although a severe storm could overwash oil across the beach crest. Oil could penetrate the well sorted pebbles and cobbles. In contrast, the lower energy, flat, sandy eastern section, towards which the longshore transport is directed, would take longer to clean. The breakwater flanking the eastern margin would contain the oil on the east end of the beach. Ferryland beach is ranked as moderate in terms of sensitivity to hydrocarbon pollution.

Although Ferryland beach is more exposed than Witless Bay or Brigus South, monitoring of beach debris concentrations (Pink and Catto [17]) indicates that it is not a collector beach. Debris concentrations are extremely low and are exclusively derived from local, terrestrial sources. As no debris arrives on the beach from the offshore environment, it is unlikely that offshore hydrocarbon pollution would arrive at the beach in Ferryland either. The likelihood of a terrestrial based petroleum spill is low, as there is no adjacent potential source. Therefore, the beach at Ferryland has a low degree of potential exposure to oil.

Ferryland beach is classified as moderate in terms of vulnerability to hydrocarbon pollution. It is exposed, open to the east, and is the longest beach of the five studied, providing more area for potential pollution. As the beach is moderately sensitive to oil contamination and the likelihood of hydrocarbon pollution is low, the overall vulnerability to oil pollution is moderate.

### 2.4 Mobile

Mobile beach is a steep, cobble-dominated, reflective, high energy system (Catto [16]), with large flat boulders and exposed bedrock in the intertidal and supratidal zones subject to wave action. The cobbles would allow oil to penetrate quickly, but wave action is likely to remove the oil before it penetrated





the beach. If oil stayed on the beach it would very likely be removed during the next strong storm, a frequent occurrence at Mobile (Catto [16]). The sensitivity to oil pollution on the beach at Mobile is low.

Potential hydrocarbon contamination sources deemed important in the Mobile area included shipping traffic, offshore installations, and terrestrial sources. The predominant southerly current offshore, and the limited concentrations of debris derived from offshore sources to the southeast, including the offshore oil installations, together indicates that offshore activities appear to represent a lesser threat of oil pollution. Mobile Brook enters a small lagoon at the southern end of the beach, and is potentially an outlet for a terrestrial source of hydrocarbon pollution from the community or the adjacent highway. As Mobile beach could receive oil contamination from both terrestrial sources and marine sources the likelihood of oil contamination is moderate.

Mobile is an exposed beach, open to the east and northeast. Oil in waters adjacent to Mobile could be transported onto the beach from either the east or northeast. Considering the beach is ranked low in terms of sensitivity and moderate in terms of degree of exposure, the beach is classified as low to moderate in terms of vulnerability to hydrocarbon pollution.

## 2.5 Bear Cove

Bear Cove, an exposed, steep, reflective system, is the highest energy beach of the five studied. Hydrocarbon pollution introduced onto the beach at Bear Cove would be cleaned naturally by wave action quickly before it had the opportunity to penetrate the sediment. Thus, Bear Cove beach is ranked very low in terms of sensitivity to oil pollution.

Hydrocarbon contamination is of concern on the Bear Cove beach from shipping traffic, offshore installations, and land-base structures and activities. Oil pollution from ships traveling along the shipping lanes adjacent to the Bear Cove beach is possible, as it is very exposed, open to north, east, and south. Contamination from the offshore installations to the southeast is only possible after a period of pronounced southeasterly winds, which climate records indicate are uncommon on the southern Avalon Peninsula (Catto et al. [4]). Two culverts and the stream that bisects the beach could carry oil from the adjacent highway, but an oil spill from this source has both a low probability and a low magnitude. Although significant terrestrial contamination is thus unlikely, the open nature of Bear Cove renders it moderately exposed to petroleum contamination.

Oil arriving at Bear Cove would be cleaned rapidly by wave reworking. Considering both the sensitivity and the degree of exposure, Bear Cove beach would rank as low to moderately vulnerable to oil pollution, because the beach is so effective at self-cleaning.

## 3 Discussion

The five Southern Shore beaches examined show differences in energy levels, grain size, slope, aspect, and sediment transport which results in differences in



their sensitivity, degree of exposure, and vulnerability to oil pollution. These adjacent beaches show substantial variability in exposure, sensitivity, and vulnerability to petroleum contamination. The higher energy, coarser grained, steeper, more exposed, strongly reflective beaches such as Bear Cove and Mobile would fare much better in responding to hydrocarbon pollution than would low energy, finer grained, flat, sheltered beaches with little sediment transport, such as Brigus South. Bear Cove, Mobile, and other similar beaches would be rapidly cleaned by natural wave action, whereas beaches similar to Brigus South could suffer from oil contamination for prolonged periods. Even slight differences in energy regime, beach slope, sediment texture, and nature of transportation can produce very different results in the event of an oil spill.

Oil pollution along the Southern Shore of the Avalon Peninsula has the potential to become an increasing problem, especially with increased shipping activity from the offshore oil industry. Study of beach properties and dynamics allows classification of the sensitivity, degree of exposure, and vulnerability of the systems to oil contamination. Self-cleaning of Avalon beaches would be more effective during the fall and early winter, the periods of highest wave energy, mirroring conclusions elsewhere (Owens *et al.* [19]). The periods of high wave energy are also those where accidental spills offshore are most likely to occur.

Cleaning of oiled areas can be handled by a number of approaches, and different shorelines and beaches will respond differently to oil contamination. Steep, high-energy, reflective, shore normal beaches, such as Witless Bay, Ferryland, Mobile, and Bear Cove, would clean very easily under natural processes with little need for human intervention in the cleanup. In contrast, on a flat, low-energy, dissipative, sandy beach, human cleaning efforts may be useful and necessary. Sandy beaches, such as parts of Witless Bay and Ferryland, are sensitive to human activity, and if an oiled beach experiences extensive human activity during a cleanup there may actually be more damage done to the area than if the beach had been left to natural cleaning (Baker [20]).

Further research will investigate the sensitivity, exposure, and vulnerability of beaches throughout the Avalon Peninsula, including those adjacent to the shipping routes in Placentia Bay. The data collected and future studies in combination will allow the ECRC to have more insight into how oil would behave in and around Avalon Peninsula beaches, facilitating response efforts in the event of an accidental oil spill. By considering the sensitivity of each particular beach system, better response decisions could be made.

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