

4.0 ENVIRONMENTAL SETTING

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4.0 ENVIRONMENTAL SETTING

This chapter describes the biophysical environmental setting of the SOEP study area. SOEP will have some impacts on this environment and a number of environmental factors will affect the Project design and operations. Knowledge of existing environmental conditions is necessary for assessment of potential environmental impacts of the project.

The following sections provide descriptions of various physical and biological components, both for marine and terrestrial, and how they interrelate in an ecosystem and interact with the project activities.

This chapter is divided into the following main sections:

1. Marine Physical Environment
 - meteorology and climatology
 - air quality
 - physical oceanography
 - marine chemistry
 - geology, geomorphology and sediments
2. Marine Biological Environment
 - ecosystem considerations
 - marine benthos
 - marine fish
 - marine reptiles
 - marine-related birds
 - marine mammals
 - Sable Island
3. Terrestrial Physical Environment
 - meteorology and climatology
 - air quality
 - geology and soil
 - aquatic environment
4. Terrestrial Biological Environment
 - ecosystem considerations
 - flora (plants, wetlands, rare plant species)
 - fauna (mammals, reptiles and amphibians, birds, rare and endangered species)

5. Protected Areas or Special Places
6. Fisheries and Aquaculture

These are described in the following sections.

4.1 MARINE PHYSICAL ENVIRONMENT

The components of the physical marine environment in the SOEP study area and their relationships are discussed in the following sections on meteorology and climatology, air quality, the physical and chemical marine environments, and geology and sediments. The large-scale phenomena and driving forces of the physical environment, e.g. regional weather systems, North Atlantic/Scotian Shelf oceanic circulation are discussed. It provides an input for discussions of the biological environment (section 4.2).

The discussion of Meteorology and Climatology (section 4.1.1) provides baseline meteorological features of the region in general and the study area in particular. Baseline conditions of winds, air temperature, precipitation, visibility and atmospheric forces of storms and winds as they affect the sea state and ocean currents are discussed. The air quality of the region is described in section 4.1.2. Existing emissions and the provincial air quality standards are reviewed.

The discussion on Physical Oceanography (section 4.1.3) provides baseline information and expands on discussions of water column structure, currents and circulation of water masses, water level variation, wave climate, sediment transport, sea ice and iceberg distribution. Both normal and extreme conditions are discussed.

Chemical Marine Environment (section 4.1.4) presents ambient levels of chemical components of the water column and sediments, and provides background for assessing the future physical and biological impacts of liquids, solids and gaseous discharges from the SOEP facilities.

The section on Geology, Geomorphology and Sediments (section 4.1.5) presents the geological and geomorphic background for the SOEP Project area. The dynamic process of sediment transport and the geotechnical engineering concerns, ice scour and seismic characteristics of the area are also discussed.

4.1.1 Meteorology and Climatology

4.1.1.1 Introduction

The description of the meteorological and climatological setting of the region and the study area is provided as a background to the physical environmental component of the study. It provides descriptions of weather patterns and storms, normal and extreme conditions, and discusses the primary atmospheric forces of storms and winds which drive ocean waves and currents. Due to the large-scale nature of the weather system, this section covers both the marine and land areas.

Meteorology is the study of the earth's atmosphere and its phenomena. It examines the variations in solar energy, temperature, humidity, precipitation and winds that interact to produce weather. Climatology uses accumulated weather data to establish the daily, monthly and seasonal patterns -- and occasional departures from them -- that over the long term constitute climate. Of particular importance to this project, knowledge of storm climatology and extreme weather events is required for planning, design and operations of offshore facilities. An extensive database is currently available for the study area, consisting of long-term meteorological observations, ship reports, buoys and rigs measurements and model hindcasting studies.

The discussion of meteorology and climatology, which also affect air quality, establishes baseline conditions for the assessment of the impact of the project on the environment and also provides environmental design data for the proposed facilities and their operations.

The meteorology and climatology information provided in this document covers baseline conditions of weather patterns, air temperature, pressures, precipitation, visibility and air quality, and the atmospheric forces of storms and winds which influence ocean waves and currents.

An extensive meteorological data bank is available for land stations along the coast of Nova Scotia and for Sable Island from the Atmospheric Environment Service (AES) of Environment Canada. Furthermore, the density of ship traffic and frequent scientific surveys have provided a wealth of meteorological and oceanographic information for the corridor and adjacent seas, from Canadian, American and international sources. The proximity of the Sable Island meteorological station to the SOEP offshore sites provides a database of over 100 years for the area (1891-present). Observations from the offshore exploration facilities make a useful addition to this database in predicting conditions at the six offshore sites. Sable Island climatological records are considered representative of offshore conditions because Sable Island is a narrow strip of land no more than 25 m above sea level; its presence, therefore, has little effect on air mass characteristics. Short-term records from other drilling sites near Sable Island were also used to provide site-specific data for each location.

Most of the meteorological and climatological data and studies used were from the AES, Environment Canada. Other data sources include Canadian Forces, Meteorological and Oceanographic Centre (METOC) in Halifax, Mobil Oil Canada, Ltd., Shell, Petro-Canada and other offshore operators, Marine Environment Data Service (MEDS), Fisheries and Oceans Canada, Ottawa; Bedford Institute of Oceanography (BIO), Dartmouth, Nova Scotia; Dalhousie University, Department of Oceanography, Halifax, Nova Scotia; and the National Climate Centre, United States Department of Commerce, Asheville, North Carolina. Additional data were collected in the study area after 1983 from continued offshore exploration activities up to the late 1980s. LASMO Nova Scotia Limited has also collected vast amounts of data over the last 5 years at the Cohasset-Panuke site. These data were utilized in the present assessment.

4.1.1.2 Air Masses and Circulation Patterns

The General Circulation

Canada and the United States lie in the belt of circumpolar westerlies that dominate middle and subpolar latitudes. The westerlies, which enter Canada from the Pacific, comprise an entraining or confluent current. They tend to drag along with them tributary airstreams from the Arctic to the north and from tropical sources to the south (Figure 4.1-1). Consequently, the surface westerlies that pass over the Atlantic may be composed of several different airstreams, separated by boundaries or fronts. The surface climate of the study area depends on the interaction between these airstreams and their fronts.

The general circulation consists of two components:

- (1) Transient disturbances associated with frontal activity in the westerlies which affect the study area for only a few days at any one time.
- (2) Quasi-permanent or long-standing features.

Two of these long-standing features of major importance are:

- (1) **The Icelandic Low**, a large low-pressure system normally located near Iceland and southern Greenland, although in midsummer, when it is at its weakest, its centre may lie as far west as the Hudson Strait. It exerts a major influence on the tracks of lows passing through the Scotian Shelf, and fosters the strong outflow of cold Arctic air across the study area in winter and early spring.

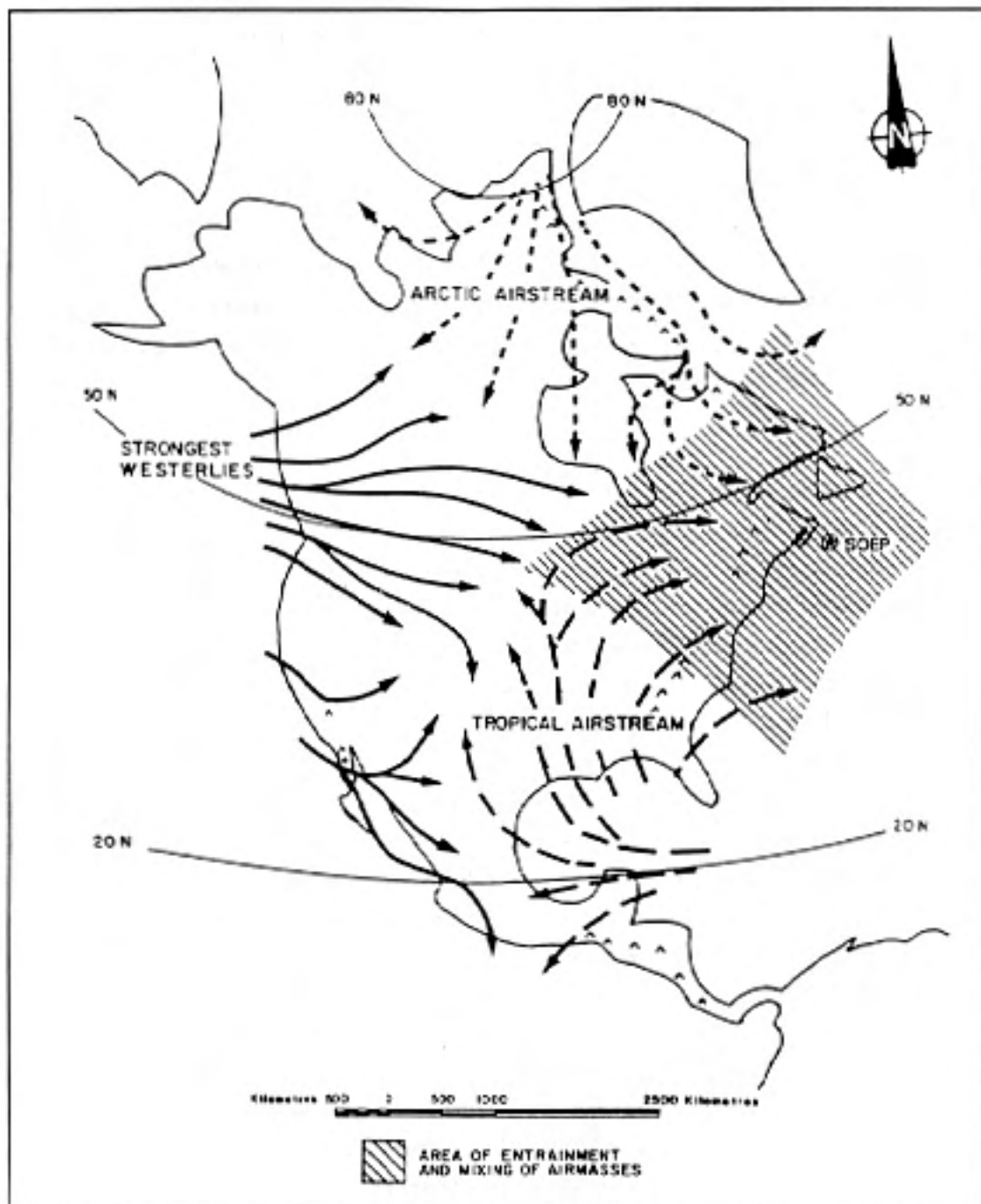


Figure 4.4-1 Atmospheric Circulations over North America

- (2) **The Bermuda High**, a semi-permanent high-pressure area with its mean centre lying east of Bermuda and southwest of the Azores. It plays a major role in the climate of eastern Canada in spring and summer, when it is most persistent. It causes air of tropical origin to penetrate the southern United States and move northward to become entrained in the westerlies. This air gives periods of warm humid weather and heavy precipitation to the Maritimes.

Characteristics of Air Masses Affecting the Study Area

Air masses that affect the study area are described below.

- (1) **Continental Arctic** air spreads southward from Arctic regions across Quebec and the Maritimes bringing cold, clear weather in winter. As it moves off the coast, it picks up moisture and heat in the lowest levels over the relatively warm open sea. The results are instability, gusty winds, and low-level turbulence. Convective clouds develop and bringing scattered showers and flurries over the sea.
- (2) **Maritime Arctic** air enters Canada from the higher latitudes of the Pacific Ocean. Originally a cold moist airstream, it becomes considerably modified by the time it reaches the east coast. In winter, having passed over the ice and snow-covered land, it is cold and dry. In summer it is mild and moist, due to passage over the warmer land and open water surface of the interior and Hudson's Bay. Weather associated with this system is somewhat similar to that of the Continental Arctic but not so rigorous. In summer it usually lies north of the study area, but it is often encountered in the spring and fall seasons.
- (3) **Maritime Polar** is the mild moist air of the Pacific midlatitudes. In winter it is cooled and dried in transit but in summer it is warmed and somewhat moister. Weather varies considerably in this airstream. Contact with Maritime Tropical air results in periods of rain and shower activity. With an overwater trajectory it can give rise to low stratus and fog in the spring and early summer. More generally, the weather is fair with convective cloud developing during the afternoon, particularly in summer.
- (4) **Maritime Tropical**, from sources south of Bermuda or from the Gulf of Mexico, affects the area mainly in summer. It is warm, moist and in the upper levels often unstable. Over the cold waters of the Scotian Shelf, the lower levels become stabilized by cooling, forming low stratus cloud and extensive fog banks. This air is responsible for the greater part of the precipitation in the area and some of the most active weather is experienced when it is present in the warm sector of cyclonic disturbances passing throughout the Scotian Shelf.

Although the general movement of air is from west to east, there can be situations when air from the North Atlantic affects the region during the transit of cyclones and anticyclones over the sea. Slow moving cyclonic disturbances over the Grand Banks and high pressure over Labrador can cause an unusually persistent easterly or northeasterly flow of cool Atlantic air across the Maritimes. This air has Maritime Arctic characteristics in winter and Maritime Polar in summer. In winter it is a cold

moist airstream with mixed wintry precipitation. In summer it produces cloudy and cool weather, with drizzle and reduced visibility from mist and fog, in offshore and coastal regions.

4.1.1.3 Climate Controls and Variations

Offshore Atlantic Canada, which is highly influenced by the ocean, has some of the most complex and unpredictable weather in the world. The violent East Coast climate is influenced by two very different currents of water: the Gulf Stream and the Labrador Current.

The major factors determining climate in the Maritimes are: solar heating, migrating mid-latitude pressure systems, air/sea energy exchange, and topography. All these factors are to some degree interrelated and are applicable to the study area.

The annual variation in solar heating due to the sun's motion causes an associated north-south displacement of temperature and atmospheric pressure distribution. The long-wave pressure patterns exist along seaboard of continents. One such trough, found along the east coast of North America, has a major impact on the seasonal climatic changes on the Scotian Shelf. Lying offshore or close to the coast in winter, it affects the predominant storm track and facilitates the outflow of Arctic air across the study area. It migrates landward as the winter season passes, allowing the Bermuda anticyclone to dominate the summer climate with persistent intrusions of modified tropical maritime air reaching into the Maritimes.

The amplitude of the foregoing trough is deeper and its gradient stronger in winter than in summer. This produces strong north-to-south flow of air in winter, a more moderate south-to-north flow in late spring and summer and weaker west-to-east flow in late summer and fall.

The impact of sea-surface temperature distribution on the climate of the study area is significant both seasonally and geographically. In winter, cold Arctic air gains heat and moisture from the open sea, causing instability in the lower boundary layer (i.e. turbulence, convective cloud and precipitation) which increases seaward in the pipeline corridor. In summer, the predominantly tropical air is cooled at the surface, causing stratiform cloud and extensive fog banks. As later statistics will show, the proximity of the Gulf Stream to the study area can cause considerable variance in weather conditions.

Topography can influence seasonal and short-term climatic changes in the coastal areas. Sea fog often penetrates well inland in estuaries and bays. The orientation of high ground may affect wind speed considerably, for example where funnelling occurs, or where a lee is created to the prevailing winds. It can also affect the direction and velocity of the coastal sea breeze experienced in summer, resulting in an offshore component of 5 to 8 m•s⁻¹ (10 to 15 kts) in some harbours such as Halifax and Chedabucto Bay.

4.1.1.4 Regional Climatology

The geographical location of the study area endows it with a particular set of climatic conditions. This climate is most affected by the differing characteristics of the dominant air masses, the modification of these air masses over the sea areas around the Maritimes, and the transitory systems

that pass through or nearby, causing rapid wind and weather changes. The well-defined seasons are winter and summer; fall and spring are less clear-cut.

Winter. Winter is the season of high winds and storms. Winter season (i.e. daily mean temperature 0°C or less) lasts for about 100 days along the eastern shore of Nova Scotia, 110 days along Cape Breton, and 80 days in the vicinity of Sable Island. Throughout the winter, storms approaching from the southwest bring in warmer air for short periods, causing wide variability in temperature and precipitation. Temperature records at AES observing stations show that changes of 15°C in 24 hours are not uncommon in the coastal region. Precipitation may start as snow, turn to wet snow, then to drizzle or rain, then back to snow flurries as the cold air reasserts itself. A period of freezing rain or drizzle may occur in this sequence. Thaws are more frequent in the Sable Island area, but temperature ranges are not as extreme, and solid precipitation not quite as frequent or heavy as onshore.

Spring Shoulder. The spring shoulder begins shortly after the snow cover has disappeared, usually mid-April along the coast, but at Sable Island almost a month earlier. Cyclonic storms become less intense and their tracks are more inland and north of the producing area. Winds begin to moderate and southerly winds become more prevalent. Inland, this season is quite short (30 to 40 days) with a rapid change to the summer regime. Along the coast it may last 60 to 70 days and in the Sable vicinity over 100 days. Intrusions of warm moist air, with low cloud, fog and drizzle, increase on the Scotian Shelf.

High Summer. High summer (i.e. mean daily maximum temperature 18.5°C or more) inland may last 80 to 100 days and be continuous throughout, but along the coast it may last no more than 60 days and be intermittent because of sea fog and cool sea breezes. This season is of similar duration in the pipeline corridor and offshore fields area. Moderate southerly winds prevail, and precipitation is usually drizzle or showers. By August the sea temperature usually reaches 14 to 16°C on the shelf, and winds tend to be more offshore, making for less low cloud, fog and precipitation.

Fall Shoulder. Fall shoulder occurs when the Pacific westerlies again become more pronounced and Arctic air moves southward along with the predominant storm tracks; the major track is still to the north of the area. This is the period when tropical cyclone and extratropical storms from the south may pose a threat to the Maritimes. Winds accelerate at sea, a marked increase in the frequency of winds over 15 m•s⁻¹ (30 kts) in October and November. This season averages 70 days inland and about 80 to 90 days offshore.

4.1.1.5 Climatic Summaries

The following climate statistics were calculated from measured data from a number of meteorological stations operated by AES, Environment Canada; these are: The Sable Island Station, Port Hastings and Canso stations representing Canso area, Ecum Secum representing the Eastern Shore (Country Harbour), and Shearwater-Halifax. Also data from Beaver Island and Hart Island were used (1988-1995) which represent the offshore/coastal areas of Country Harbour and Strait of Canso, respectively.

Daily Bright Sunshine. Mean monthly and annual hours of daily bright sunshine for Shearwater and Sable Island are given in Table 4.1-1. It shows lower values seaward because of increased cloudiness and the incidence of fog.

Table 4.1-1 Mean Monthly and Annual Hours of Bright Sunshine, 1950-1990

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shearwater	113	130	146	158	199	215	224	225	182	154	108	96	1949
Sable Island	56	74	116	131	161	162	174	187	157	125	71	56	1471
(Source: Atmospheric Environment Service, 1993)													

Solar Radiation. Table 4.1-2 shows mean daily global solar radiation for each month for Halifax and Sable Island.

Table 4.1-2 Mean Daily Global Solar Radiation (MJ•m⁻²), 1950-1990

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Halifax	5.18	8.05	11.82	14.3	17.56	20.02	19.67	17.83	14.17	9.06	5.36	3.91	12.24
Sable Is.	4.13	6.84	11.22	14.74	18.85	20.46	20.47	17.96	14.27	8.93	4.85	3.48	12.18
(Source: Canadian Climate Data, Environment Canada, 1993)													

Precipitation. Tables 4.1-3 and 4.1-4 show the mean monthly and annual rainfall and snowfall amounts. As shown precipitation occurs at all months of the year, but winter values (rain plus snow) are usually about 30 to 50 per cent higher than in other seasons. The annual precipitation totals are fairly consistent throughout the study area (1300 to 1500 mm). November to January is usually the period of heaviest precipitation, with July and September the driest months.

Table 4.1-3 Mean Monthly and Annual Rainfall (mm), 1950-1990

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Port Hastings	83.2	57.2	92.5	109	96.7	102	88.8	112.2	102.6	137.4	165.4	122.6	1269.8
Sable Island	110.3	81.7	86.6	91.7	98.8	107.7	100.6	111.3	104.7	121	141.5	124.9	1280.9
Ecum Secum	91.2	56.9	83.2	98.9	122	114.7	115.5	136	102.8	122.7	151.3	132	1327.3
(Source: Atmospheric Environment Service, 1993)													

Table 4.1-4 Mean Monthly and Annual Snowfall (cm), 1950-1990

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Port Hastings	47.7	44.7	28.4	11.2	0.7	0.01	---	---	---	0.6	4.3	39.1	176.8
Sable Island	37.3	30	24.1	8	0.8	---	---	---	---	Trace	4	18.3	122.4
Ecum Secum	45.4	47.4	34.5	12.5	2.3	---	---	---	---	1.1	4.7	37.4	185.3
Note: 1 cm snow is approximately 1 mm liquid precipitation													
(Source: Atmospheric Environment Service, 1993)													

The greatest rainfall and snowfall amounts falling in 24 hours are shown in Table 4.1-5.

Table 4.1-5 Greatest Amounts of Rainfall (a) and Snowfall (b) in 24 hours ((Extreme Daily Precipitation, 1950-1990)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Highest
Port Hastings	a. (mm)	111.3	127.0	88.2	61.8	80.5	91.4	78.8	127.8	127.0	83.8	83.2	66.0	127.8
	b. (cm)	41.9	48.3	30.5	58.4	24.1	--	--	--	--	15.2	14.0	63.5	63.5
Sable Island	a. (mm)	99.4	58.2	87.6	66.0	99.6	140.8	85.4	155.8	99.2	166.2	84.8	77.5	166.2
	b. (cm)	61.0	45.8	45.6	23.2	15.2	--	--	--	--	0.2	25.4	66.0	66.0
Ecum Secum	a. (mm)	67.8	45.7	59.7	78.0	83.1	65.5	108.5	124.2	96.3	86.3	87.9	93.2	108.5
	b. (cm)	30.5	52.1	38.1	39.4	17.8	--	--	--	--	20.3	20.3	30.0	52.1
(Source: Atmospheric Environment Service, 1993)														

Air Temperature. Air temperature statistics in the Canso, Sable Island and Country Harbour area are shown in Table 4.1-6.

Wind. Wind is a major consideration in planning and design of marine structures and conducting operations in the study area, either directly or indirectly, as the main generator of waves and currents. The general climate of the area (cloudiness, precipitation and temperature) is also closely related to wind direction and speed, including local and temporary wind-field anomalies.

Representative Winds. When examining the subsequent data, it must be emphasized that values for land stations are affected by topography and frictional effects. They are not representative of wind over the open sea, even a few kilometres offshore. Hence, the following comments on land-station winds, obtained from references and from discussions with persons having local knowledge, are necessary in assessing the validity of the data presented.

Table 4.1-6 Monthly and Annual Temperature (°C) Statistics, 1950-1990

	Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Port Hastings (Canso)	Daily Max.	-0.9	-1.8	2.0	6.4	12.7	18.5	22.6	22.8	18.7	13.4	7.8	2.5	10.4
	Daily Min.	-8.8	-9.9	-5.8	-1.1	3.5	8.8	13.4	13.8	10.1	5.5	1.2	-4.4	2.2
	Daily Mean	-4.8	-5.8	-1.8	2.7	8.1	13.7	18.0	18.8	14.4	9.5	4.5	-0.9	6.8
	Extreme Max.	18.8	16.7	17.8	26.7	31.7	36.1	37.2	32.8	31.0	29.4	30.0	20.6	37.2
	Extreme Min.	-26.7	-26.1	-26.7	-13.8	-6.7	-2.2	-0.6	-17.8	-5.6	-7.2	-12.2	-22.8	-26.7
Sable Island	Daily Max.	2.7	1.4	3.0	5.8	9.5	13.7	18.2	20.8	18.2	14.1	9.6	5.2	10.1
	Daily Min.	-3.2	-4.2	-2.1	0.9	4.4	8.2	12.7	14.8	12.7	8.8	4.4	-0.6	4.7
	Daily Mean	-0.2	-1.8	0.5	3.4	7.0	11.0	15.5	17.6	15.5	11.5	7.0	2.8	7.5
	Extreme Max.	14.5	12.8	13.5	13.9	17.8	21.7	29.6	27.8	27.0	22.8	18.9	15.6	29.6
	Extreme Min.	-19.4	-18.8	-13.8	-8.9	-8.8	1.7	4.4	4.4	0.6	-1.2	-7.8	-16.7	-19.4
Ecum Secum (Country Harbour)	Daily Max.	-0.6	-0.9	2.4	6.2	10.9	15.5	18.8	20.0	17.9	12.8	7.6	2.2	9.4
	Daily Min.	-9.5	-9.9	-5.5	-1.1	2.8	7.8	11.8	12.8	9.1	4.5	0.8	-5.9	1.8
	Daily Mean	-5.0	-5.4	-1.5	2.6	6.9	11.4	15.1	16.2	13.5	8.7	3.9	-1.8	5.4
	Extreme Max.	13.8	12.2	15.0	22.8	26.1	30.5	32.2	30.6	28.9	25.0	21.7	13.8	32.2
	Extreme Min.	-26.1	-33.0	-28.5	-12.8	-9.4	-3.9	2.0	1.0	-2.2	-7.0	-15.0	-25.0	-33.0
(Source: Atmospheric Environment Service, 1993)														

Another important issue is the height at which the wind was measured. Wind speed varies with height above sea surface depending on atmospheric stability in the marine boundary layer (Cardone, 1969, 1978). The suggested (design) wind profiles for various wind speeds and atmospheric stability conditions (i.e. stable, neutral and unstable) are provided in Figure 4.1-2 (for marine areas).

It should also be noted that the given values vary depending on the averaging period, i.e. the values presented in the following tables or figures are the average hourly values. Conversion factors for various averaging periods are provided below (U.K. Department of Energy, 1977):

<u>Wind Speed Averaging Period</u>	<u>Conversion Factor</u>
1 hour mean	1.00
10 minute mean	1.05
1 minute mean	1.17
3 second gust	1.34

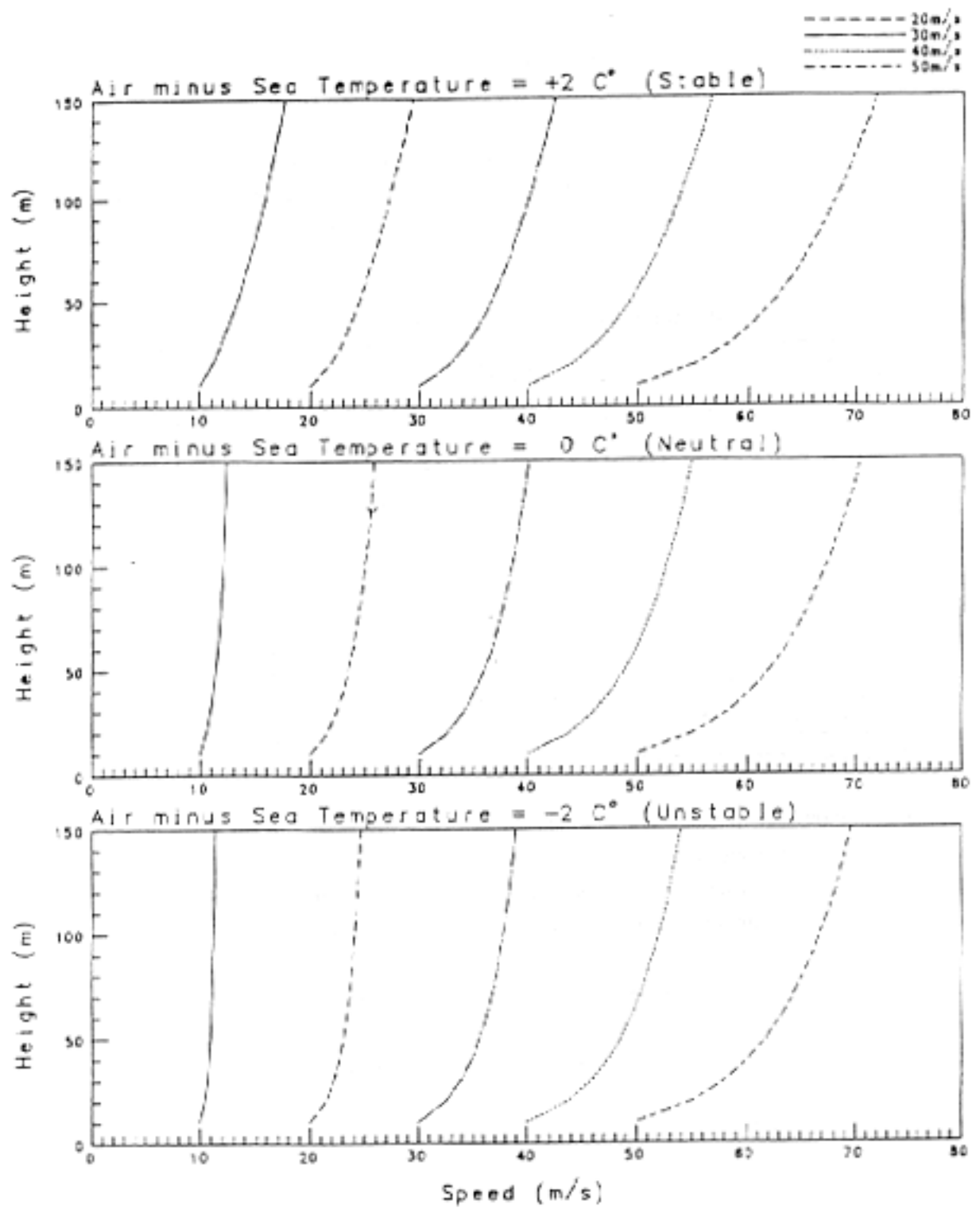


Figure 4.1-2 Wind Profiles and Function of Wind Speed and Atmospheric Stability

(Source: MacLaren Plansearch Limited, 1991; Shell Project)

Seasonal Wind Statistics. Mean and maximum monthly wind-speed statistics are shown in Table 4.1-7 for Sable Island, Beaver Island, and Hart Island.

Table 4.1-7 Mean Monthly and Annual Wind Speeds

	Wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sable Island ¹	Mean Speed (km/h)	31	31	29	26	23	20	18	18	21	25	29	31	25
	Most frequent direction	W	W	W	W	SW	SW	SW	SW	SW	W	W	W	W
	Extreme hourly speed (km/h)	103	117	100	89	77	76	74	98	95	100	130	116	130
	Direction	NW	N	W	E	SW	NW	E	SE	SW	SW	W	SW	W
Hart Island ² (Canso)	Extreme gust speed (km/h)	141	170	140	122	113	109	100	143	124	158	174	137	174
	Direction	SW	N	SW	W	NE	NW	E	SE	W	S	W	NW	W
	Mean Speed (km/h)	29	28	26	24	23	21	20	21	22	26	29	31	25
	Most frequent direction	W	NW	NW	NW	S	SW	SW	SW	SW	SW	W	W	SW
Beaver Island ³ (Country Harbour)	Extreme hourly speed (km/h)	87	93	80	72	70	70	59	70	61	78	89	100	100
	Mean Speed (km/h)	29	29	27	25	22	20	19	20	23	28	30	31	25
	Most frequent direction	NW	SW	N	SW	SW	SW	SW	SW	SW	SW	NW	NW	SW
	Extreme hourly speed (km/h)	98	96	87	74	69	65	69	67	74	82	87	85	98
¹ Sable Island weather station 1961-1990 ² Hart Island weather station 1988-1995 ³ Beaver Island weather station 1988-1995 1 km/h = 0.277 m/s 1 km/h = 0.54 knots (kts)														
(Source: Atmospheric Environment Service)														

Monthly and annual wind roses (wind speed by direction) are shown in Figures 4.1-3 to 4.1-6 for four selected marine locations: (1) along the pipeline corridor (the Coastal Area), (2) Sable Island bank area, (3) Hart Island (Chedabucto Bay) and (4) Beaver Island (Country Harbour Area). These diagrams demonstrate the prevalence of winds from westerly quadrants at all seasons, the northwest quadrant in winter and the southwest in summer and early fall. In the late fall and spring the westerlies are more variable. The frequent passage of cyclonic systems through the study area, however, can result in strong winds, usually of short duration, from easterly quadrants also. Persistent easterlies can occasionally occur when a blocking high-pressure system establishes itself over the Labrador Sea. Various wind statistics are also provided in Figures 4.1-3 to 4.1-6.

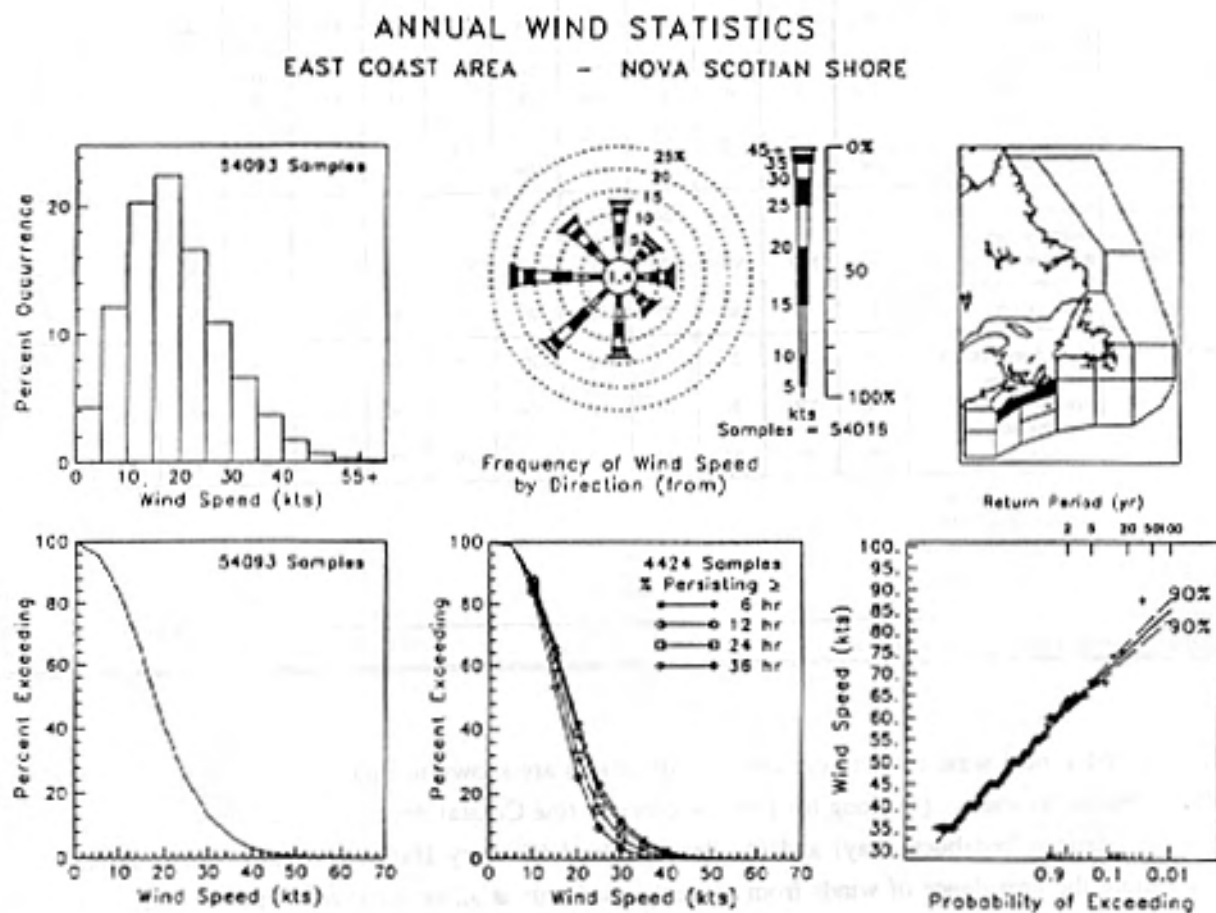


Figure 4.1-3 Annual and Monthly Wind Statistics for Nova Scotian SHore
(along the pipeline corridor)
(source: MacLaren Plansearch Limited 1991; Wind and Wave Atlas for the East Coast of Canada)

MONTHLY WIND STATISTICS
 EAST COAST AREA - NOVA SCOTIAN SHORE
 FREQUENCY OF WIND SPEED BY DIRECTION (FROM)

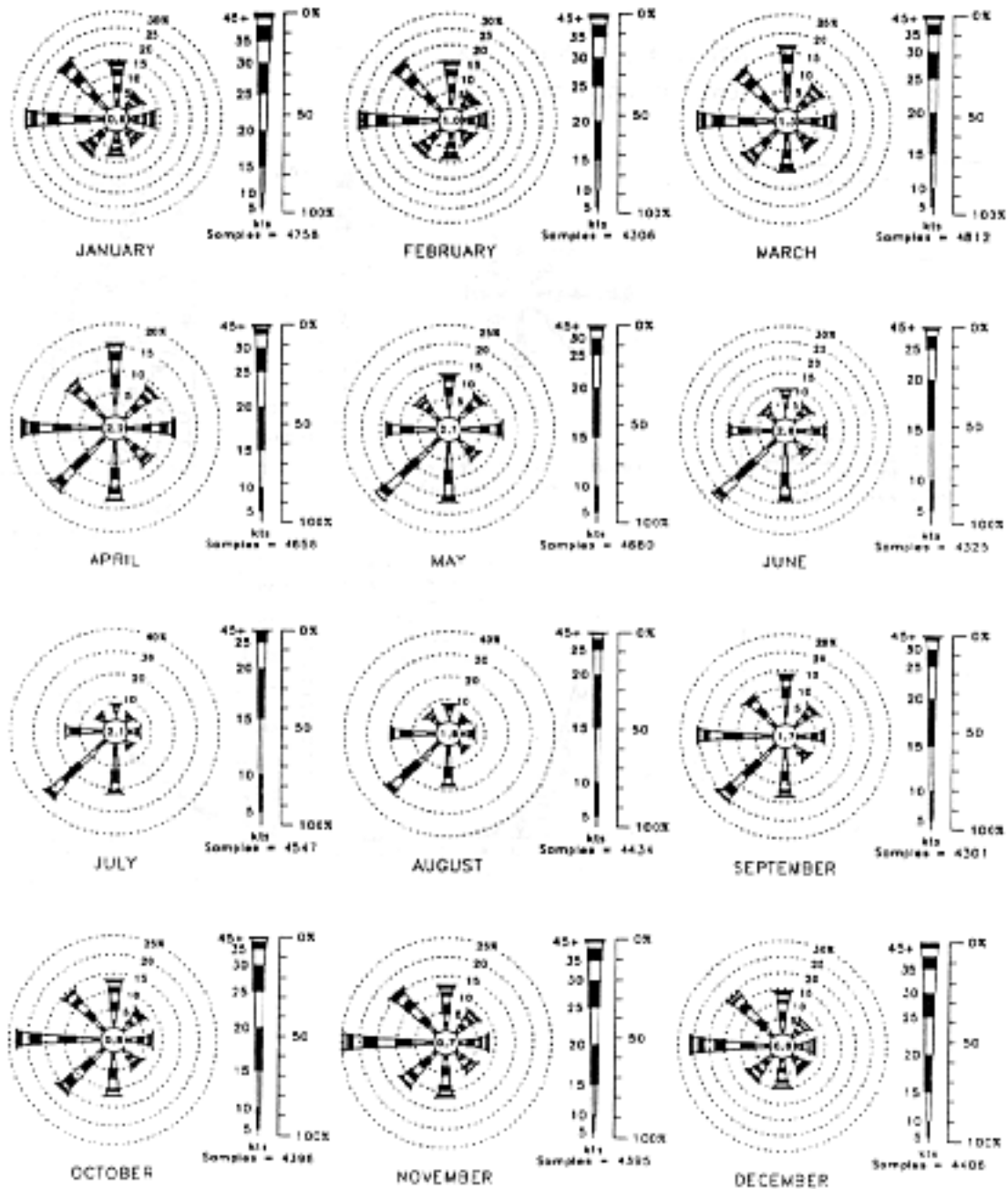


Figure 4.1-3 (cont'd)

ANNUAL WIND STATISTICS EAST COAST AREA - SABLE

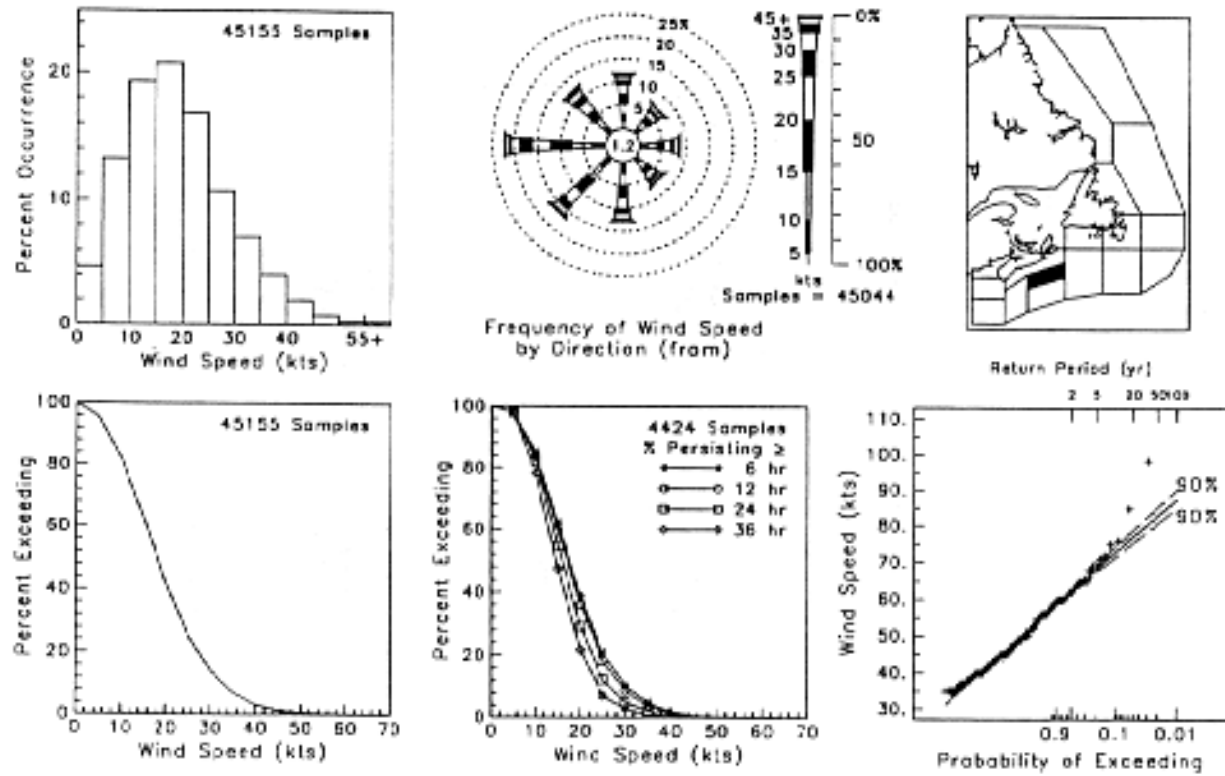


Figure 4.4-4 Annual and Monthly Wind Statistics for Sable Island Bank
(source: MacLaren Plansearch Limited 1991; Wind and Wave Atlas for the East Coast of Canada)

MONTHLY WIND STATISTICS
EAST COAST AREA - SABLE
FREQUENCY OF WIND SPEED BY DIRECTION (FROM)

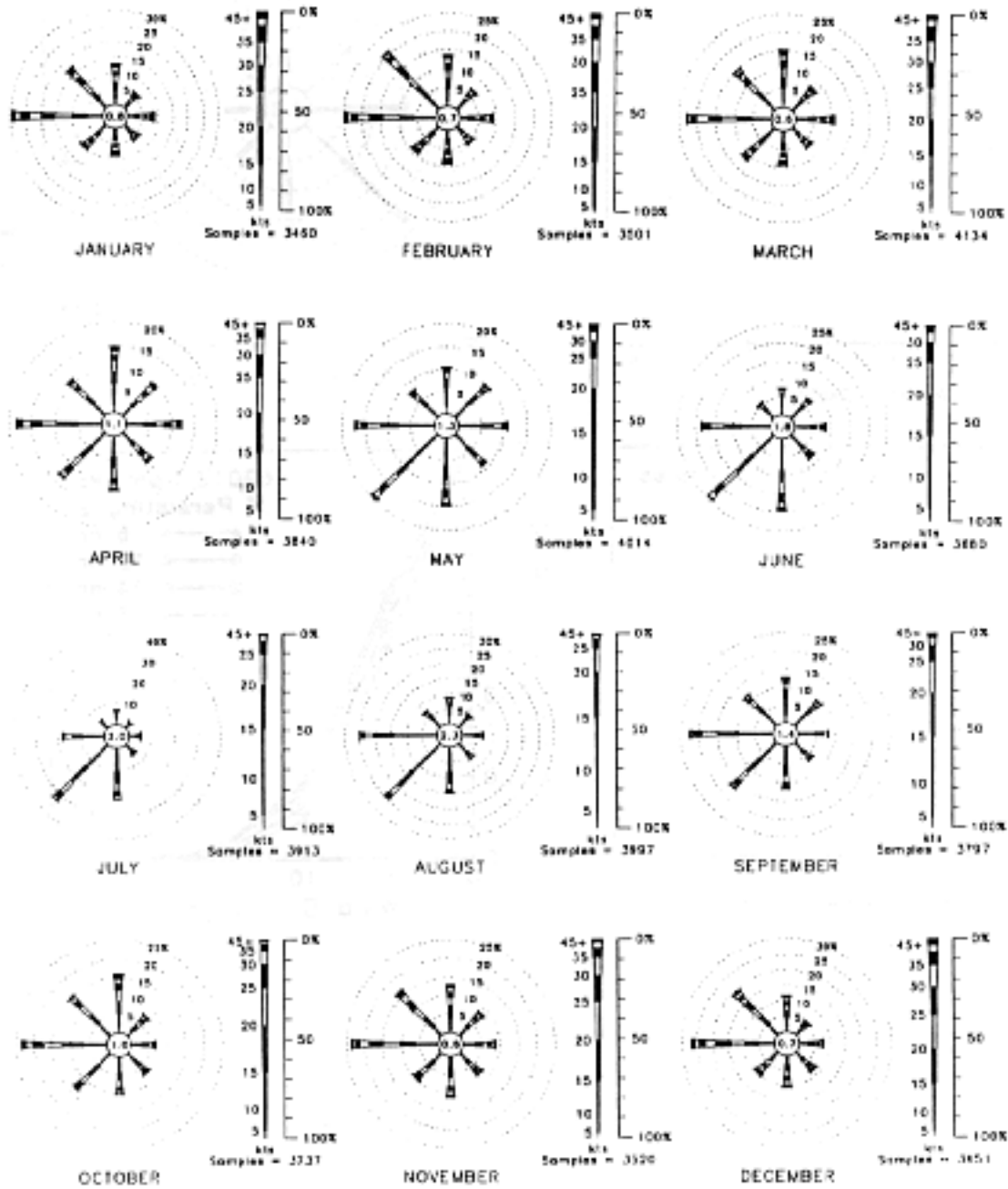


Figure 4.1-4 (cont'd)

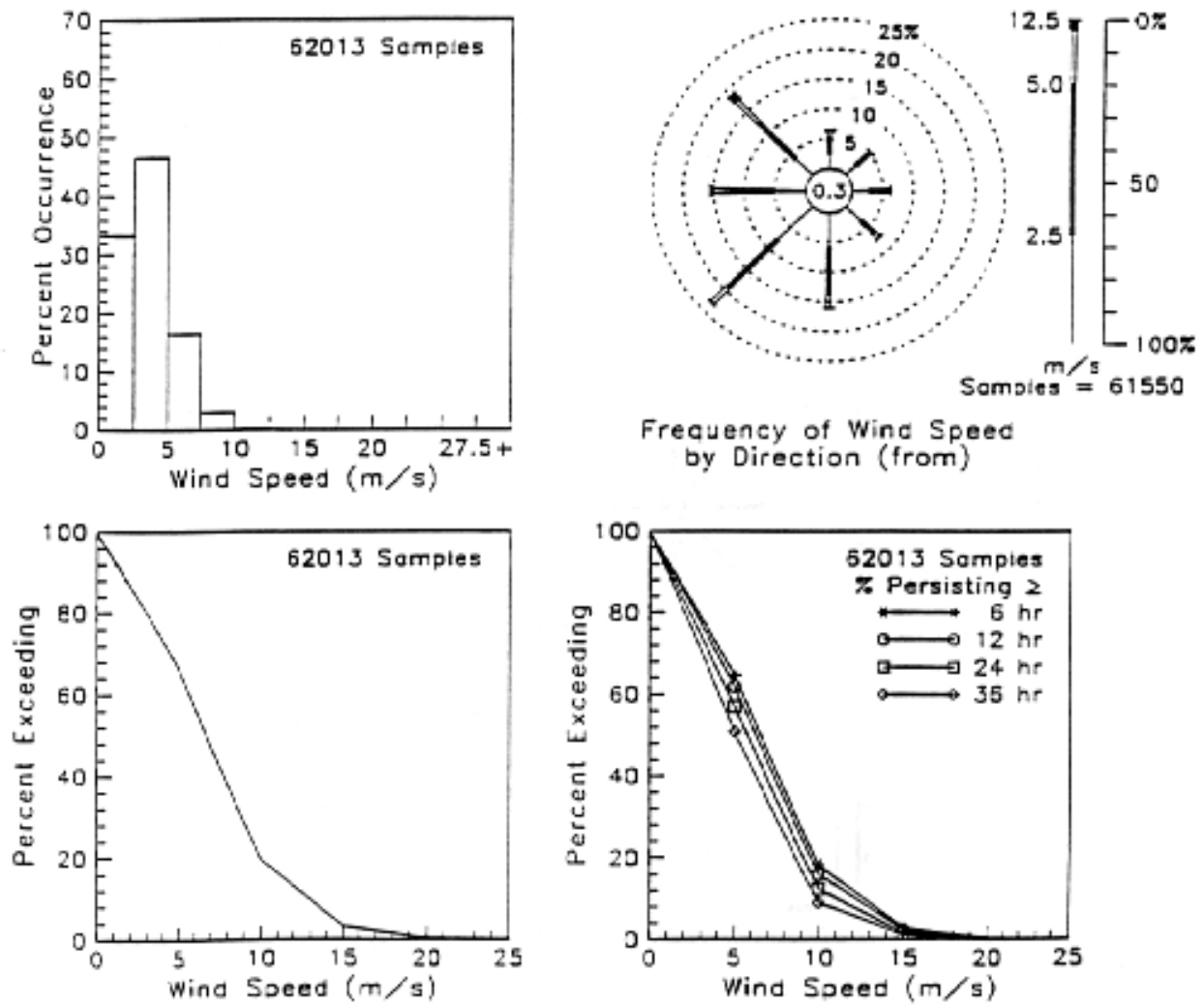


Figure 4.1-5 Annual and Monthly Wind Statistics for Hart Island (Chedabucto Bay)
 (Source: Atmospheric Environment Service, 1995)

MONTHLY WIND STATISTICS
HART ISLAND
FREQUENCY OF WIND SPEED BY DIRECTION (FROM)

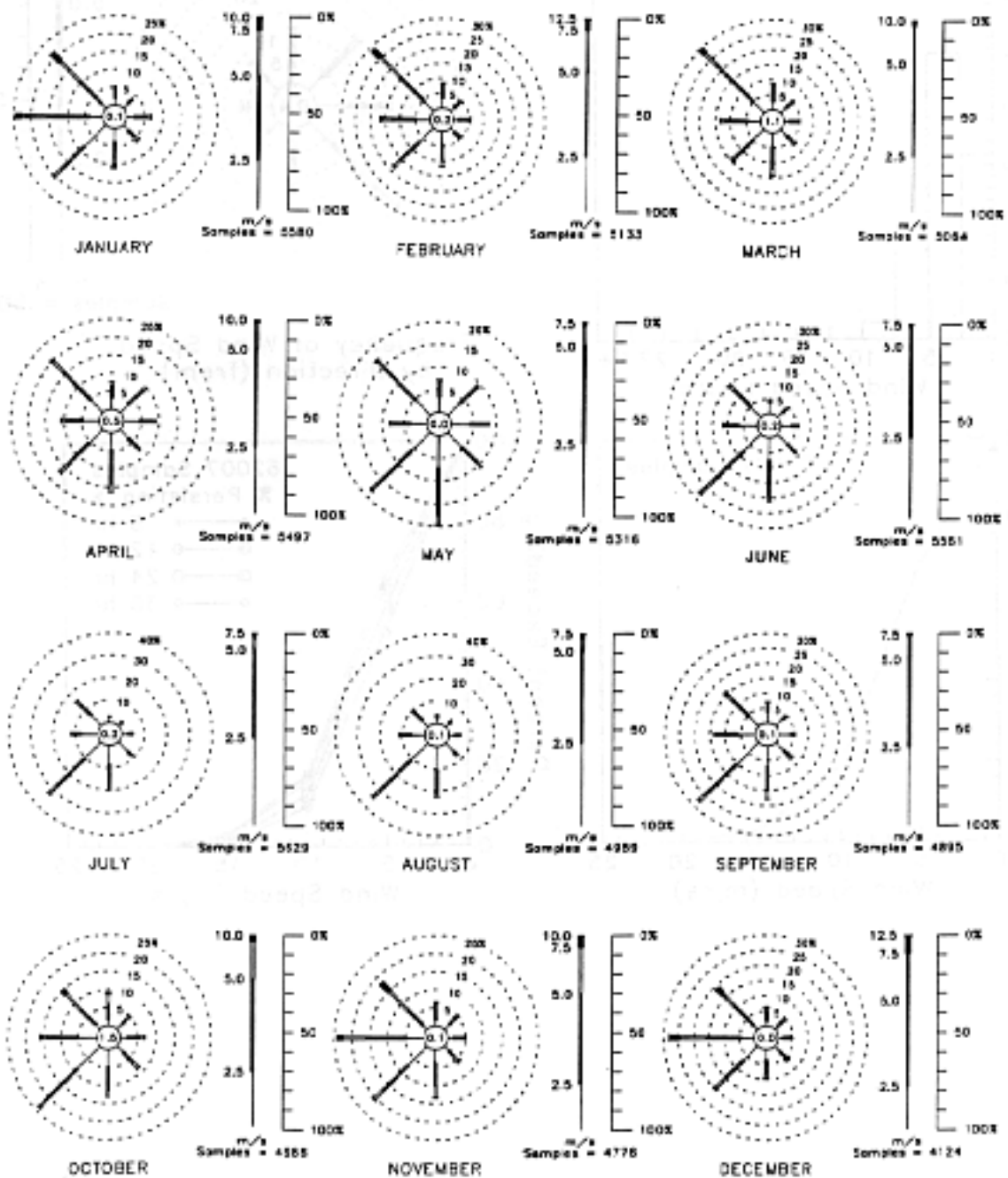


Figure 4.1-5 (cont'd)

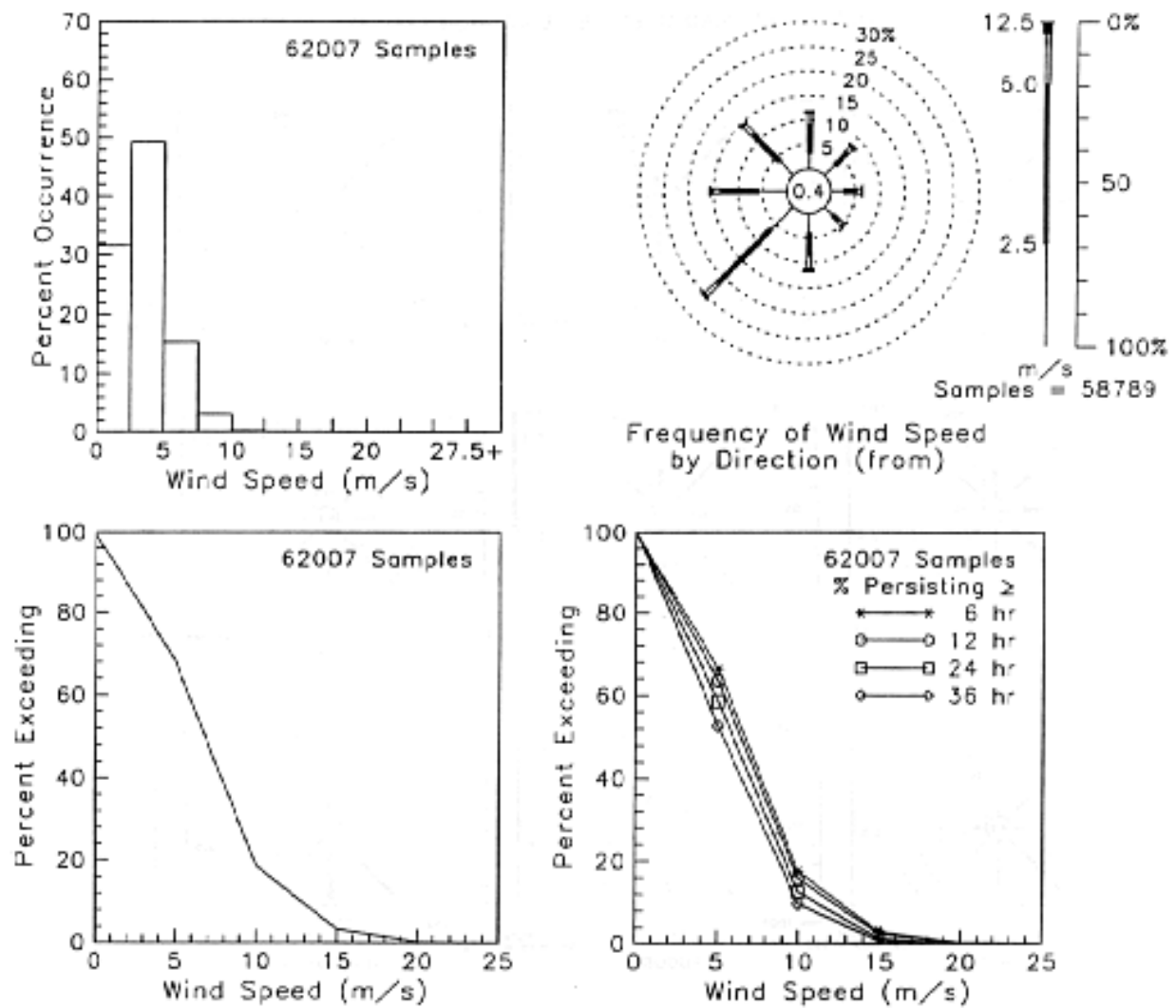


Figure 4.1-6 Annual and Monthly Wind Statistics for Beaver Island (Country Harbour Area)
 (Source: Atmospheric and Environment Services, 1995)

MONTHLY WIND STATISTICS
BEAVER ISLAND
FREQUENCY OF WIND SPEED BY DIRECTION (FROM)

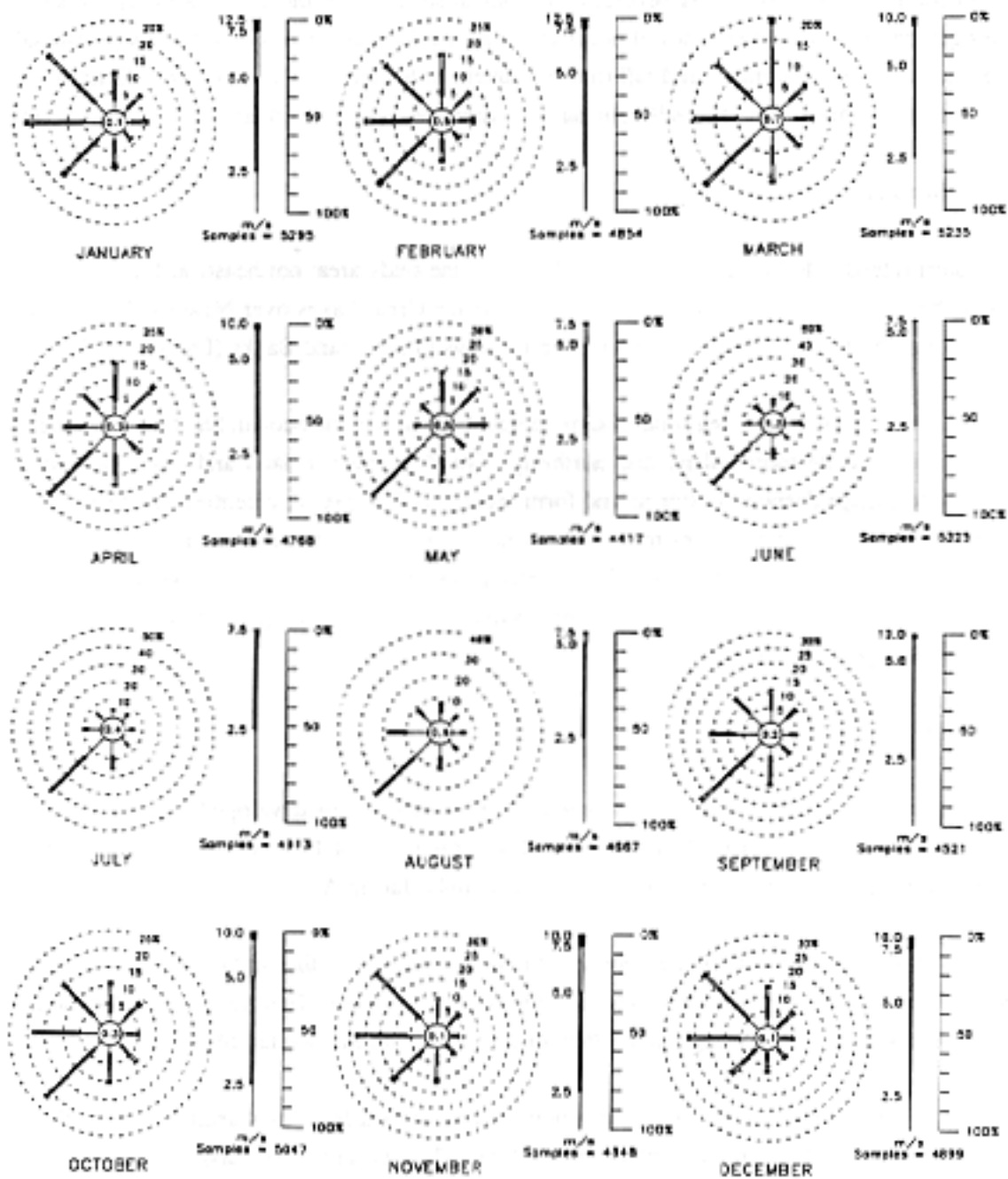


Figure 4.1-6 (cont'd)

4.1.1.6 Storms

Cyclonic Storms

It is more usual to associate the term "cyclone" with tropical storms and refer to cyclones of nontropical origin as depressions or, when especially severe, extratropical storms. Tropical and extratropical storms differ in their generation, tracks, frequency of occurrence and areal coverage. Tropical storms occasionally threaten the study area in late summer and fall (more frequent in September and October). Extratropical storms are a continuing threat, but especially during November-March, when their intensity is greatest.

Extratropical Storms

Extratropical storms tend to follow three general tracks across the study area: northeastward from the Great Lakes through the Gulf of St. Lawrence; southeastward from the Great Lakes over New England, turning northeastward over the Scotian Shelf, and from Cape Hatteras to the Grand Banks (Figure 4.1-7).

In winter, these tracks are further to the south and more storms pass over the Scotian Shelf than in summer, when the tracks tend to be more inland and northerly. The difference in land and sea temperatures, especially in winter, helps deepen the storms and form secondary low-pressure centres off the east coast of the United States. Often such centres move rapidly northeastward to become the major centre in the northwest Atlantic. Consequently, the track that usually gives rise to the most explosive deepening lies between Cape Hatteras and the Grand Banks, where systems gain added energy from the warm waters along the northern edge of the Gulf Stream.

Tropical Storms

These storms are intense cyclonic circulations generated from depressions developed in tropical waters. They are classified as tropical storms if the mean wind is in the range of 17 to 32 m•s⁻¹ (34 to 63 kts) or as hurricanes if it exceeds 33 m•s⁻¹ (64 kts). They occur mainly during August-October.

Usually these storms move westward in the tropics, then turn north to affect the Gulf of Mexico, or the east coast of North America and the sea around Bermuda the farther north onto Georges Bank. Occasionally they reach the study area. On average, more than one a year affect the Scotian Shelf.

The tropical-storm track closest to the Sable area is north-northeastward from the Carolina coast, although a few storms have approached from the south (Figure 4.1-8). They usually reach maximum intensity well south of the Scotian Shelf, and begin to lose force when they encounter the colder coastal water at about 40°N.

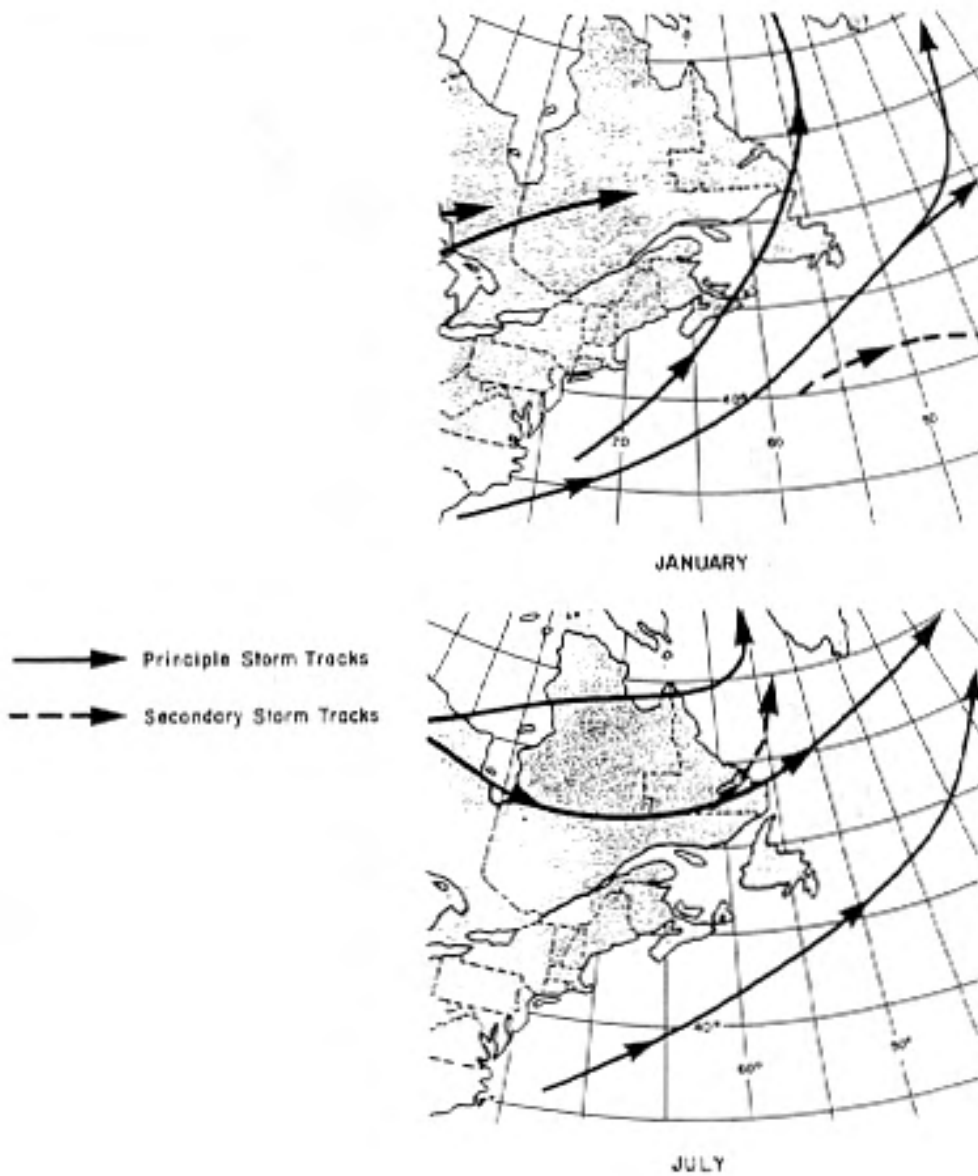


Figure 4.1-7 Extratropical Storm Tracks Affecting the Maritimes

Two factors tend to keep tropical storms away from the Scotian Shelf. First, these storms tend to follow the Gulf Stream whose waters provide the latent heat that sustains them. Second, while still south of Nova Scotia they encounter the strong upper steering pattern of the temperate latitudes, which can accelerate their normal 3 to $7 \text{ m}\cdot\text{s}^{-1}$ (5 to 14 kts) speed of advance to 15 to $21 \text{ m}\cdot\text{s}^{-1}$ (30 to 40 kts) and carry them out to the North Atlantic.

4.1.1.7 Severe Conditions

Extreme Winds

Extreme winds are an important weather hazard affecting the study area, as they usually either cause or accompany other operating hazards. They are associated with severe storms which are generated due to a sudden change in the pressure gradient. The predominant cause of extreme winds at the SOEP offshore sites is extratropical storms. These are the most frequent and also the most persistent. Extreme winds associated with these storms may last for days, compared with hours for those winds associated with a tropical storm or a thunderstorm. Extreme wind statistics are provided in Table 4.1-7 and further discussed in section 4.1.1.9.

Visibility

Table 4.1-8 shows mean days with fog for Sydney, Shearwater and Sable Island. Table 4.1-9 shows the average number of days with visibility for given distance, for Sable Island.

Table 4.1-8 Mean Days with Fog at a Number of Locations in the Study Area

	Ja n	Fe b	Mar	Apr	Ma y	Jun	Jul	Au g	Se p	Oct	No v	De c	Annual
Sydney ¹	4	4	7	9	12	10	10	6	5	4	5	3	78
Shearwater ²	4	4	6	8	12	14	17	13	6	6	5	4	101
Sable Island ³	6	6	9	12	17	20	22	16	8	6	6	4	130
1. Sydney: data from 1941 to 1990 2. Shearwater: data from 1944 to 1990 3. Sable Island: data from 1891 to 1990													
(Source: Atmospheric Environment Service, 1993)													

Table 4.1-9 Average Number of Days with Visibility for Given Distances for Sable Island (1961-1993)

Visibility	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
<1km	1.8	2	3	4	6.5	8.5	9.7	5.5	1.9	1.4	1.5	1	46.8
>1 and <9km	7.6	6.2	6.2	6.1	6.4	6	7.3	7.6	5.3	4.9	5.6	6.1	74.9
>9km	21.8	20	21.8	19.9	18.1	15.5	14	18	22.8	24.7	22.9	23.8	243.5
(Source: Atmospheric Environment Service, 1993)													

Freezing Precipitation

Freezing precipitation presents a potential hazard to aircraft operations and surface transportation systems, as well as to surface-based structures such as towers and transportation lines. Table 4.1-10 shows that, within the study area, frequency of occurrence of freezing precipitation tends to decrease with distance from land, e.g. values of 13 and 19 days for coastal Nova Scotia (Shearwater and Sydney) decrease to 5 days at Sable Island.

Table 4.1-10 Mean Monthly Number of Days with Freezing Rain or Freezing Drizzle

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shearwater ¹	2	3	4	1	<1	---	---	---	---	<1	<1	2	13
Sydney ²	3	5	5	3	<1	---	---	---	---	---	<1	2	19
Sable Island ³	<1	2	2	<1	---	<1	---	---	---	---	---	<1	5
1 Shearwater A weather station 1944 to 1990													
2 Sydney A weather station 1941 to 1990													
3 Sable Island weather station 1891 to 1990													
(Source: Atmospheric Environment Services, 1993)													

Thunderstorms

Thunderstorms (or electrical storms) are local phenomena of varying intensity. Table 4.1-11 provides the mean monthly and annual frequency of thunderstorms in the study area.

Table 4.1-11 Mean Monthly Number of Days with Thunderstorms

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shearwater ¹	<1	<1	<1	<1	1	2	3	2	<1	<1	<1	<1	11
Sydney ²	50.2	40.1	60.2	130.4	361.2	682.2	742.4	682.3	421.4	331.1	250.8	70.2	38112.5
Sable Island ³	<1	<1	<1	<1	1	2	2	2	1	1	<1	<1	12
1 Shearwater A weather station 1944 to 1990													
2 Sydney A weather station 1941 to 1990													
3 Sable Island weather station 1891 to 1990													
(Source: Atmospheric Environment Service, 1993)													

4.1.1.8 Superstructure Icing

The frequency of icing in the marine areas near Sable Island is shown in Figure 4.1-9. It shows saltwater icing is probable from November through April and that moderate icing is possible mainly during January and February. Heavy or very heavy icing is relatively infrequent, but could occur about 3 per cent of the time in January and February.

The meteorological conditions that result in the freezing of sea spray on ships and offshore structures involve air temperatures below the freezing temperature of seawater (about -1.8°C depending on salinity), sea temperatures below $+6^{\circ}\text{C}$, and wind speeds greater than $10 \text{ m}\cdot\text{s}^{-1}$, although at lower wind speeds slight icing is possible. The design of offshore structures will take into consideration the effect of icing (i.e. added weight, stability, etc.).

4.1.1.9 Extreme Criteria

WIND CRITERIA

(a) Offshore (Sable Island Area)

Table 4.1-12 Annual Omni-Directional Extreme Wind Speeds ($\text{m}\cdot\text{s}^{-1}$)

Return Period	Best Fit Mean	90% Upper Limit	95% Upper Limit
	0	—	—
1 year	27.1	31	31.8
10 years	35.8	39.6	40.4
20 years	37.6	42.5	43.5
30 years	38.6	44.2	45.4
50 years	39.9	46.4	47.7
100 years	41.6	49.3	50.9
Wind speeds in $\text{m}\cdot\text{s}^{-1}$ (one hour mean). Reference height: 10 m above mean sea level. 1 kt = $0.51 \text{ m}\cdot\text{s}^{-1}$			
(Source: MacLaren Plansearch, 1989; Shell Project)			

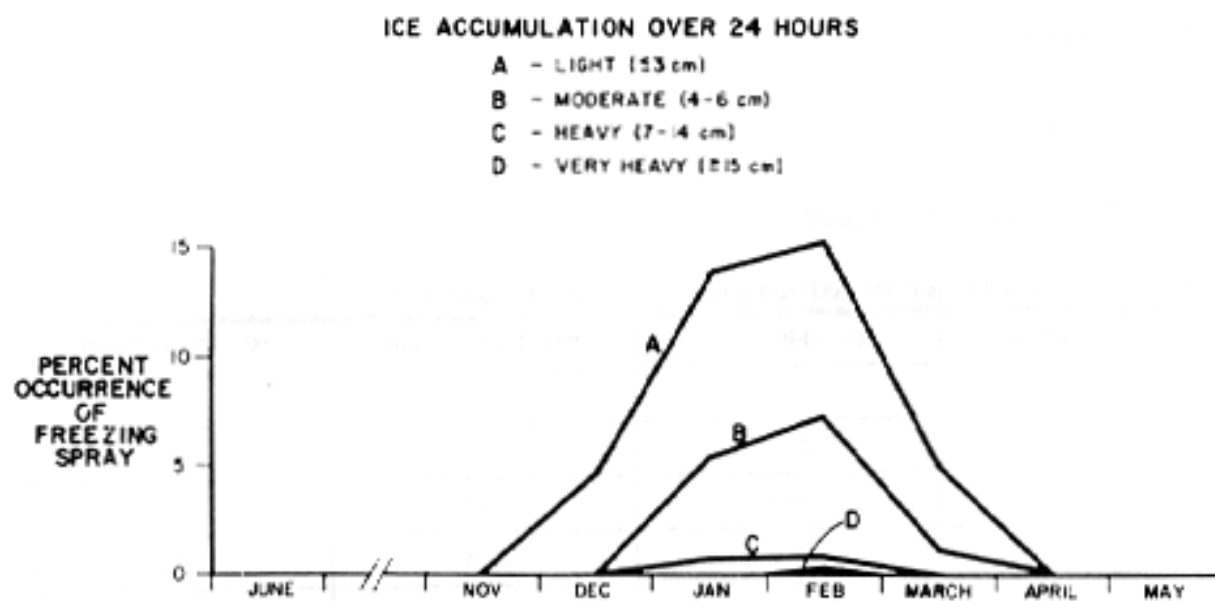


Figure 4.1-9 Monthly Occurrence of Freezing Spray at Sable Island, 1959 to 1978

Table 4.1-13 Annual Extreme Wind Speeds for Different Gust Factors

Wind Speed Averaging Period	Conversion Factors*	Wind Speed (m•s ⁻¹) for Return Period (years)					
		1	10	20	30	50	100
1 hour mean	1.00	27.1	35.8	37.6	38.6	39.9	41.6
10 minute mean	1.05	28.5	37.6	39.5	40.5	41.9	43.7
1 minute mean	1.17	31.7	41.9	44.0	45.2	46.7	48.7
3 second gust	1.34	36.3	48.0	50.4	51.7	54.5	55.7
(*Source: U.K. Department of Energy, 1977)							

The above values represent wind speeds at a standard 10 m height above the mean sea level. To estimate the equivalent values at various heights above sea level, use wind profiles presented previously in Figure 4.1-2.

The following table presents an example of the 100-year, 1-hour mean winds at various heights.

Table 4.1-14(a) Design Wind Profile

Height Above MSL*	Conversion Factor	100 year 1-hr. mean (m/s)
10	1	41.6
20	1.11	46.2
30	1.17	48.7
40	1.22	50.8
50	1.25	52
70	1.31	54.5
100	1.37	57
120	1.4	58.2
150	1.44	60
*Analysis Method: Marine Planetary Boundary Layer of Cardone (1969,1978). 1 kt= 1.95 m/s		
(Source: MacLaren Plansearch, 1989))		

Table 4.1-14(b) Recommended Extreme Wind Speeds for Country Harbour (Wind Speed in knots)

Averaging Time	Return Period (years)				
	1	10	25	50	100
1 hour	44	52	58	62	66
10 minutes	47	55	61	66	70
1 minute	56	66	74	79	84
15 sec. gust	64	75	84	90	96
5 sec. gust	68	81	90	96	102
3 sec. gust	70	83	93	99	106
Data Source: Ecum Secum (Jan. 1953-Mar. 1961) 10.4m above ground, 14 m above MSL Canso (Dec. 1963-Dec.1971) 10.1m above ground, 26m above MSL					
Wind speed 1km/hr = 1.85 knots					
(Source: Seaconsult, 1985)					

AIR TEMPERATURE**(a) Offshore (Sable Island Area)**

- minimum air temperature - 19.7°C
- maximum air temperature +35.0°C
- CSA toughness design temperature - 12.0°C

(b) Coastal (Gas Plant Site)**Table 4.1-15 Extreme Air Temperatures for Country Harbour**

	Return Period (years)				
	1	10	25	50	100
Extreme Highs (°C)	23.2	27.5	28.8	29.8	30.7
Extreme Lows (°C)	-20	-26.5	-28.3	-29.7	-31.1
(Source: Seaconsult Marine Research, 1985)					

STRUCTURAL ICING

Structural icing was estimated using the model described by Brown & Horjen (1989). The model estimates icing rates for sea spray and wave action, and for atmospheric icing caused by freezing rain and snow. In addition to the environmental parameters, the model requires a specification of the configuration. In the present analysis, we have specified a very simple design of one large vertical column, (10 m diameter, 20 m height); one small vertical column, (1 m diameter and 10 m height); one diagonal cylinder, 45° inclination; and a 10 m x 10 m horizontal deck at different heights.

(a) Sea Spray Icing

The results presented in this section are for the 1 m and 10 m diameter vertical columns and the 45° inclined, 1 m diameter cylinder. They include sea spray and wave action icing only.

An extreme value analysis was carried out by fitting the data to a Gumbel distribution using the method of moments. The 100-year return period results are summarized in Table 4.1-16. It should be noted that the following values should be considered conservative estimates of ice thickness, as it was determined based on the most adverse environmental conditions that were issued to persist over a long duration.

Table 4.1-16 Extreme Values (100-year return period) for Structural Icing

	1 m diam. column	10 m diam. column	1 m diam. diagonal
Thickness (cm)	119.6	116	83.2
Growth rate (cm/hr)	1.1	1	0.7
Load (tonnes)	7.5	38.6	12.2
(Source: MacLaren Plansearch Limited (1990), Cohasset-Panuke Design Data)			

The average height of the maximum ice thickness on the columns was:

1 m diameter column: 4.86±0.9 m

10 m diameter column: 4.83±0.9 m

1 m diameter diagonal: 4.77±0.9 m

(b) Atmospheric Icing

The atmospheric icing is independent of height above the sea surface. The results presented here are for a flat plate, 10 m x 10 m, the top surface at 10 m above mean sea level. The 100-year return period values are given below.

Extreme values (100-year return period) for atmospheric structural icing.

Thickness (cm)	2.20
Growth rate (cm•hr ⁻¹)	0.02
Load (tonnes)	1.24

4.1.2 Air Quality

Air quality is determined by the concentrations of contaminants in the atmosphere. Concentration levels of sulphur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), ozone (O₃), and suspended particulate matter (SPM) or total suspended particulate (TSP) are used as indicators of air quality. The atmospheric concentration of these contaminants is affected by daily and seasonal wind patterns, atmospheric stability, atmospheric pressure systems, air temperature and quantity and quality of emission from a single source (such as a refinery) or from a source area (such as a city.)

Air quality in the study area is generally quite good, particularly in the offshore areas. It is affected primarily by shore-based activities, especially near larger commercial or industrial centres. In the offshore area, air quality is difficult to determine because of insufficient reporting sites. However, the only potential sources of air pollutants are marine traffic and exploration rigs, which are, at worst, isolated sources producing small amounts of atmospheric contaminants. Figure 4.1-10 illustrates the principal sources of air pollutants in Nova Scotia.

The main source of information on air quality is the National Air Pollution Surveillance Network (NAPS) of the Environment Protection Service of Environment Canada (EC) and the Air Quality Branch of Nova Scotia Department of Environment (NSDOE). The report prepared by NSDOE (1993) presents the results of the 1992/1993 air quality monitoring program and an assessment of air quality trends in the province over the past decade. Figure 4.1-11 shows the air quality monitoring stations across the province in 1993. There is also a monitoring station for precipitation chemistry on Sable Island. Precipitation chemistry reflects air quality.

4.1.2.1 Factors Affecting Air Quality

Important factors that affect air quality and that need to be considered, especially when directing a response to air pollution problems, include meteorological conditions (i.e. wind patterns, temperature and atmospheric stability and pressure); the sources of pollutants in a given area; the pollutants being measured and their respective background levels; and the location of the air monitoring sites.

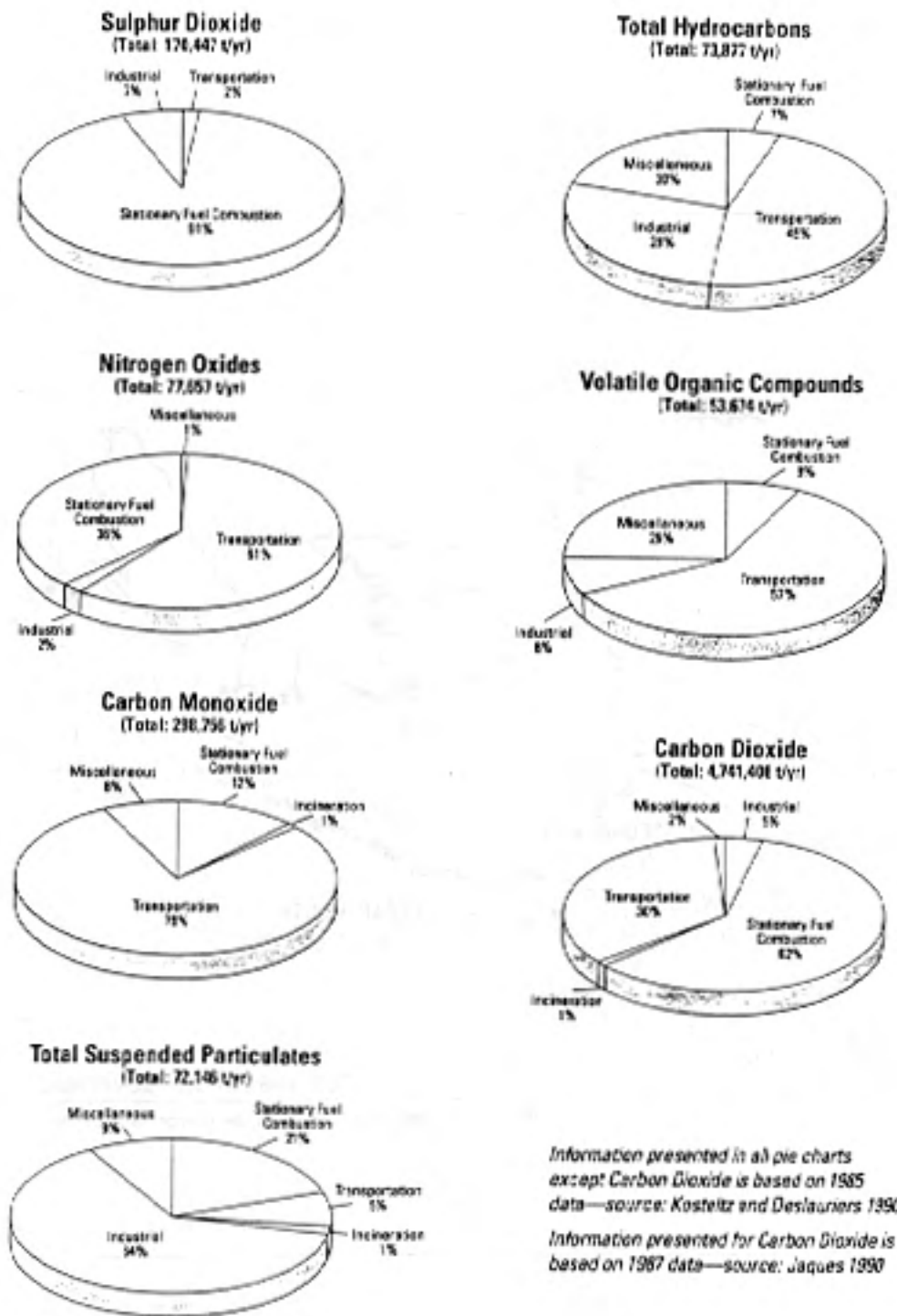


Figure 4.1-10 Sources of Air Emissions in Nova Scotia
(Source: Nova Scotia Department of the Environment, 1992)

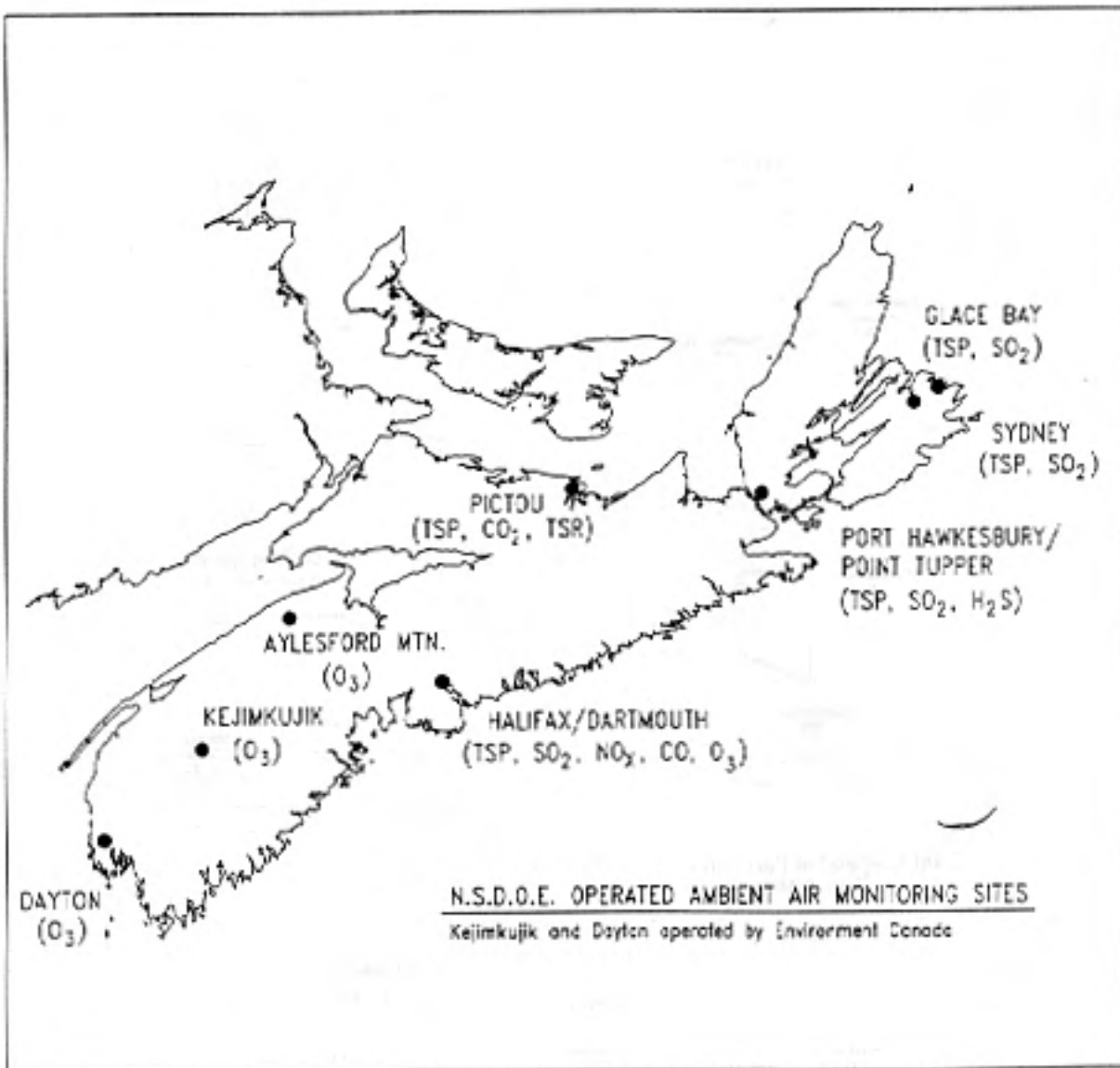


Figure 4.1-11 Nova Scotia Air Quality Monitoring Sites

(Source: Nova Scotia Department of the Environment, 1993)

4.1.2.2 Nova Scotia's Ambient Air Quality Objectives

Table 4.1-17 identifies Nova Scotia's current air quality standards for common air pollutants (as reflected in the Air Quality Regulations passed under the *Environment Act of Nova Scotia*). These pollutants can lead to a variety of health and environmental effects depending upon the nature of the pollutant, its concentration, the exposure period, the presence of other pollutants, and receptor sensitivity. For these reasons, the acceptable level and averaging periods criteria vary according to the pollutant.

The criteria for ambient air quality throughout the province, as described in Table 4.1.17, are expressed as maximum permissible ground level concentrations.

Table 4.1-17 Nova Scotia Provincial Air Quality Objectives

CONTAMINANT	AVERAGING PERIOD	MAXIMUM PERMISSIBLE GROUND LEVEL CONCENTRATION	
		$\mu\text{g}/\text{m}^3$	pphm
Carbon Monoxide (CO)	1 hour	34 600	3000
	8 hours	12 700	1100
Hydrogen Sulphide (H_2S)	1 hour	42	3
	24 hours	8	0.6
Nitrogen Dioxide (NO_2)	1 hour	400	21
	Annual	100	5
Ozone (O_3)	1 hour	160	8.2
Sulphur Dioxide (SO_2)	1 hour	900	34
	24 hours	300	11
	Annual	60	2
Total Suspended Particulate (TSP)	24 hours	120	-
	Annual	70*	-

Source: N.S. Environment Act (1995)

pphm- parts per hundred million

$\mu\text{g}/\text{m}^3$ - micrograms per cubic metre

4.1.2.3 Ambient Air Quality and Long-Term Trend

Sulphur Dioxide (SO_2)

Sources: Nova Scotia relies heavily on imported and local coal supplies, containing sulphur as an impurity, for energy production and space heating. These sources contributed approximately 89% of Nova Scotia's own sulphur dioxide emissions in 1993. Other sources of sulphur dioxide in Nova

Scotia include oil refineries and pulp and paper mills and a minor contribution from the transportation sector.

Levels in 1993 and Long-Term Trends: Figure 4.1-12 presents the one-hour maximum levels and annual means at Halifax-Dartmouth and Port Hawkesbury-Point Tupper areas. As shown, the Point Tupper site reported the highest 1-hour maximum of 53.8 pphm during 1993 and the most number of exceedances of the 1-hour objective of 34 pphm at 10. The 24-hour objective was exceeded briefly (0.2% of the time) at that site with a value of 19.6 pphm recorded as the maximum 24-hour average.

On an annual basis sulphur dioxide levels in the Halifax-Dartmouth region have remained at least within the acceptable level over the last decade. Desirable levels have usually been achieved, except for the Halifax downtown area. In the Port Hawkesbury-Point Tupper region, no results are reported after 1989 at Canso Canal, Landrie Lake and Eddy Point sites; these sites have since been discontinued. While the monitoring record is discontinuous after 1987, the last two years of data indicate that on an annual basis an acceptable level of objectives is achieved at the two current monitoring sites. A thermal generating facility and a pulp and paper plant continue to be significant sulphur dioxide sources in the Strait of Canso area.

Nitrogen Oxides(NO₂)

Nitrogen dioxide contributes to the formation of acid rain and is a primary precursor pollutant in the formation of smog.

Sources: Nitric oxide is released from the exhausts of combustion engines and furnaces. Transportation is the major source of anthropogenic (man-made) nitrogen oxides followed by stationary fuel combustion such as power plants and furnaces.

Effects: Irritation of the eyes and throat may result from nitrogen dioxide levels above 150 pphm. This is well above normal ambient air levels. Asthmatics may exhibit mild symptoms at 50 pphm. Vegetation injury occurs at levels above 200 pphm.

1993 Levels and Long-Term Trends: Ambient levels of nitrogen oxides in Nova Scotia do not pose a risk to human health or the environment. However, controls on nitrogen oxide emissions are being pursued because of the link between these emissions and smog formation. The long-term trend for nitrogen dioxide levels in the Halifax-Dartmouth region is constant and well within the desirable range.

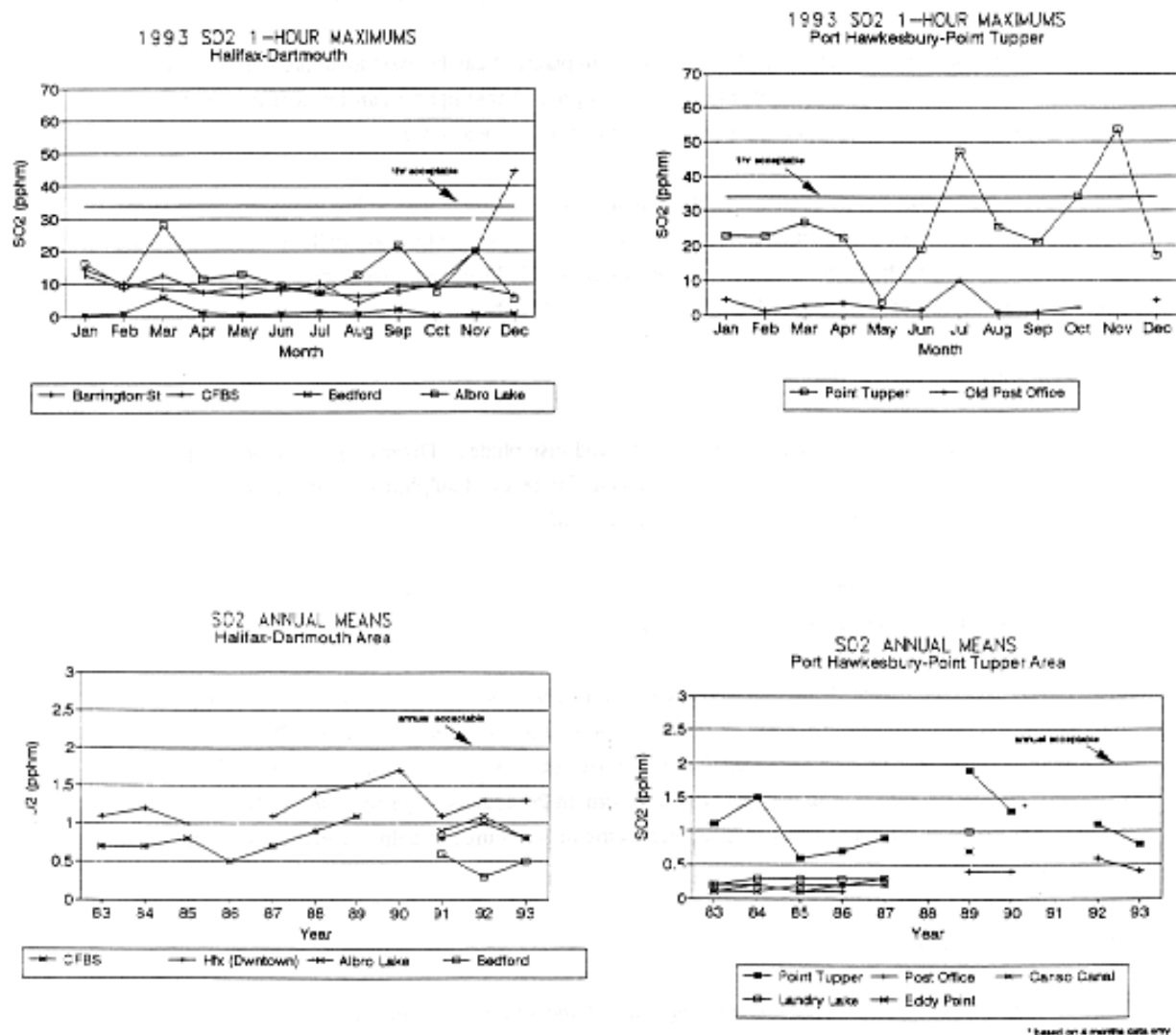


Figure 4.1-12: SO₂ 9-Hour Maximums and Annual Means at Halifax- Dartmouth area and Port Hawkesbury-Point Tupper areas
(Source: NSDOE, 1993)

Carbon Monoxide

Sources: Carbon monoxide is formed from the incomplete combustion of carbon compounds. It is estimated that 236,000 tonnes/year are released by the transportation sector alone in Nova Scotia. Other important sources include stationary fossil fuel and wood fuel combustion plants and furnaces.

Effects: While carbon monoxide is relatively harmless to plants, it can be toxic to humans and animal life. Research has shown that at persistent levels above 30 ppm (3,000 pphm) cardiovascular symptoms in angina patients can occur and central nervous system effects are detectable.

1993 Levels and Long-Term Trends: Carbon monoxide levels remained within desirable levels at the Halifax site in 1993. Annual average carbon monoxide levels appear to be marginally lower between the period 1987-1993 than between 1983-1985. Carbon monoxide levels improved across Canada between 1974-1985 as a result of a general reduction in motor vehicle exhaust emissions.

Reduced Sulphur Compounds

These gases include hydrogen sulphide, mercaptans, and disulphides. Depending upon the composition of the source emissions gases, ambient air monitoring for reduced sulphur compounds would include hydrogen sulphide (H₂S) only or total reduced sulphur (TRS).

Sources: While these gases can be released by the anaerobic decomposition of organic wastes, the major point sources of these gases in Nova Scotia are pulp and paper mills and refineries.

1993 Level: At Point Tupper, hydrogen sulphide monitoring was established in December 1992 and results for 1993 are presented in Figure 4.1-13. A maximum of 61.8 ppb was recorded on July 29, 1993. In total the 1-hour acceptable level was exceeded 9 times on five days out of the year. The 24-hour level was exceeded 0.6% of the time during the year with a maximum 24-hour average recorded of 16.6 ppb. The Stora Forest Products pulp and paper mill represents the major source of sulphide emissions in the Point Tupper area.

Ground Level Ozone

Ground level ozone is a colourless gas, a strong oxidant and a major constituent of smog.

Sources: While Nova Scotia is not a significant source of the emissions which cause ground level ozone to form, it is a receptor of ground level ozone since it lies downwind of major urban and industrialized centres in the United States and Central Canada.

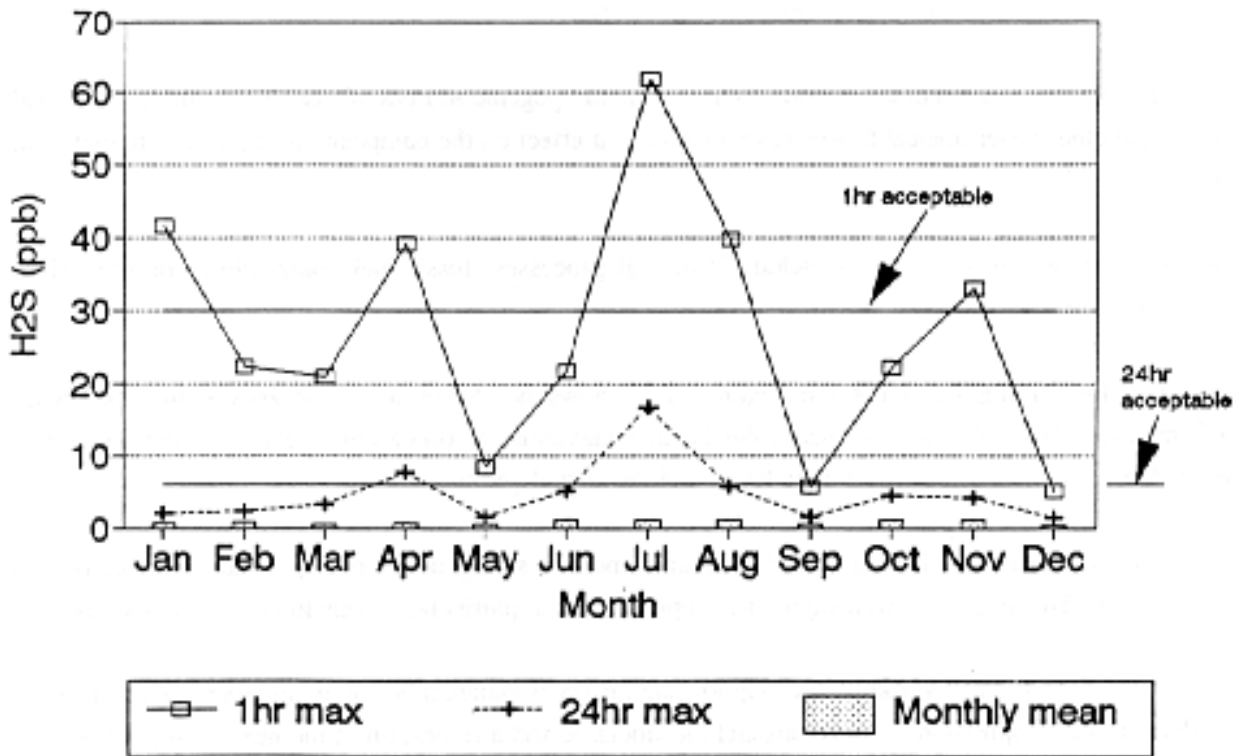


Figure 4.1-13 1993 Hydrogen Sulphide (H₂S) Maximums and Means at Point Tupper

1993 Levels and Long-Term Trends: Figure 4.1-14 shows the 1993 ozone records at Shearwater station. A total of twenty-two 1-hour exceedances of the 8.2 pphm objective were recorded at four sites in Nova Scotia in 1993.

Figure 4.14 also compares data on 1-hour exceedances for five Nova Scotia stations. While not all these stations were operational during each of the last ten years, at least one of the five sites maintained in 1993 was operating during the previous three years.

A recent review of data from 1980-1986 at CFB Shearwater showed no exceedances in 1986 at this site. The 1992 annual report had indicated there were three.

Total Suspended Particulate

Total suspended particulate (TSP) refers to those particles in the air, such as smoke, soot and dust, that remain suspended in the air and do not settle out easily.

Sources: There are a multitude of both natural and anthropogenic sources of suspended particulate. Local winds and other meteorological factors have a significant effect on the composition of particulate matter in the air.

Important anthropogenic sources include industrial processes, fossil fuel combustion, transportation, incineration and mining.

1993 Level and Long-Term Trends: Figure 4.1-15 shows the TSP results at various sites in Cape Breton and mainland Nova Scotia, in terms of the 24-hour maximum recorded during the year, the number of exceedances of the 24-hour acceptable level, and the annual geometric mean.

With the exception of Point Tupper, all TSP sites indicate steady or improving trends over the last 10 years. Point Tupper has showed significant improvement in particulate levels in more recent years.

Activation of the gypsum stockpile and ship loading facility is apparent beginning in 1989 at Point Tupper. Additional dust suppression measures around the stockpile and a relocation of the monitoring instrument within the Point Tupper community have resulted in lower TSP levels being recorded at Point Tupper after 1991.

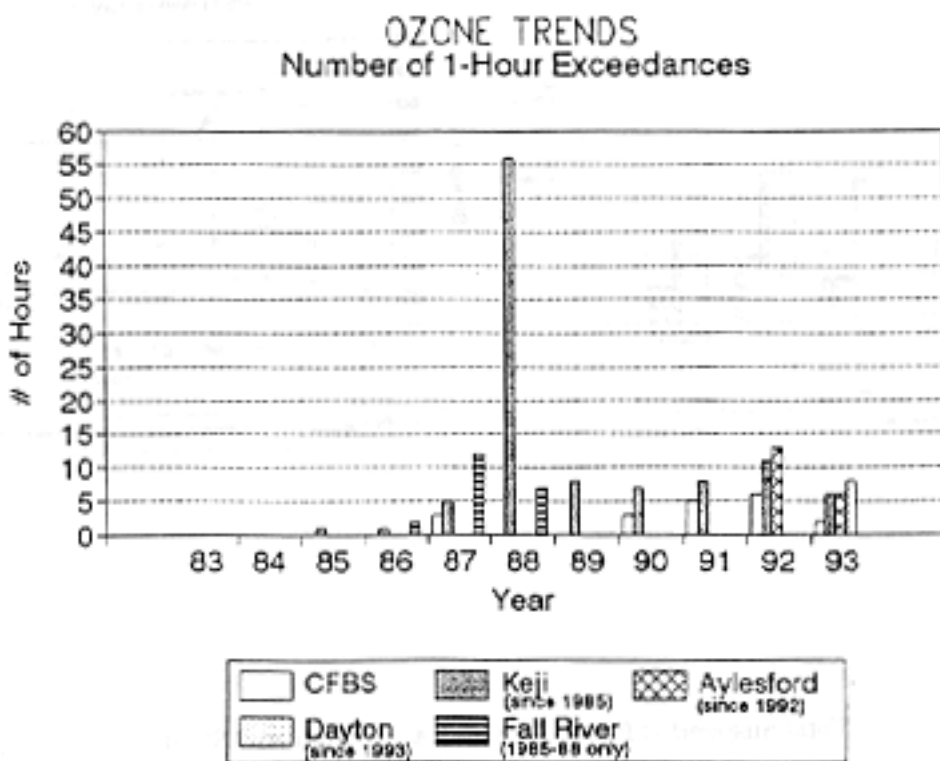
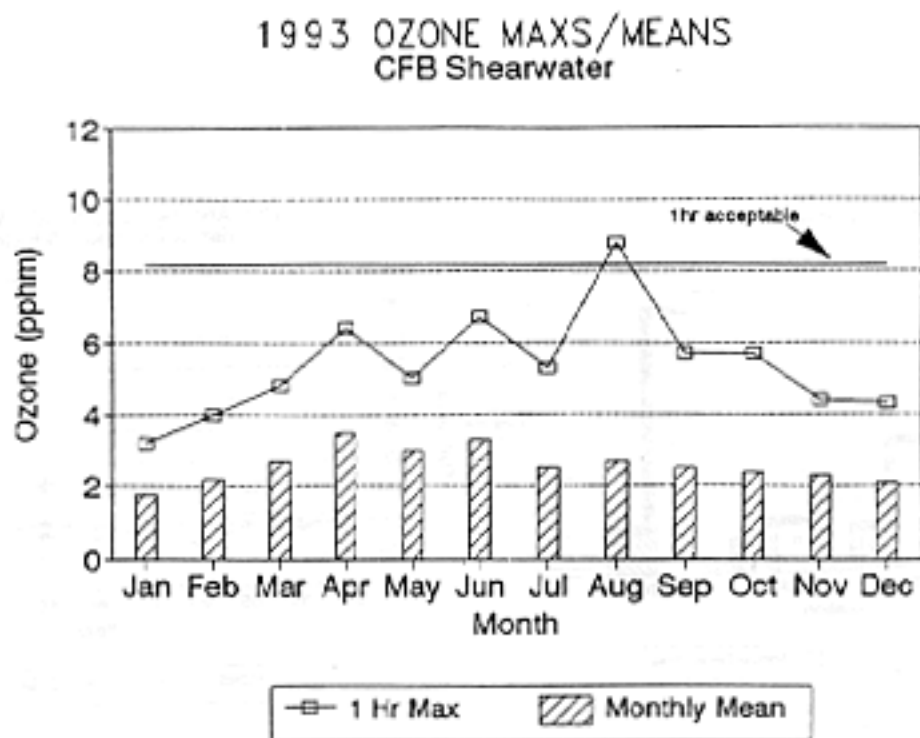


Figure 4.1-14 Ozone Concentrations (1993 Maximums/Means, and Annual Trend)

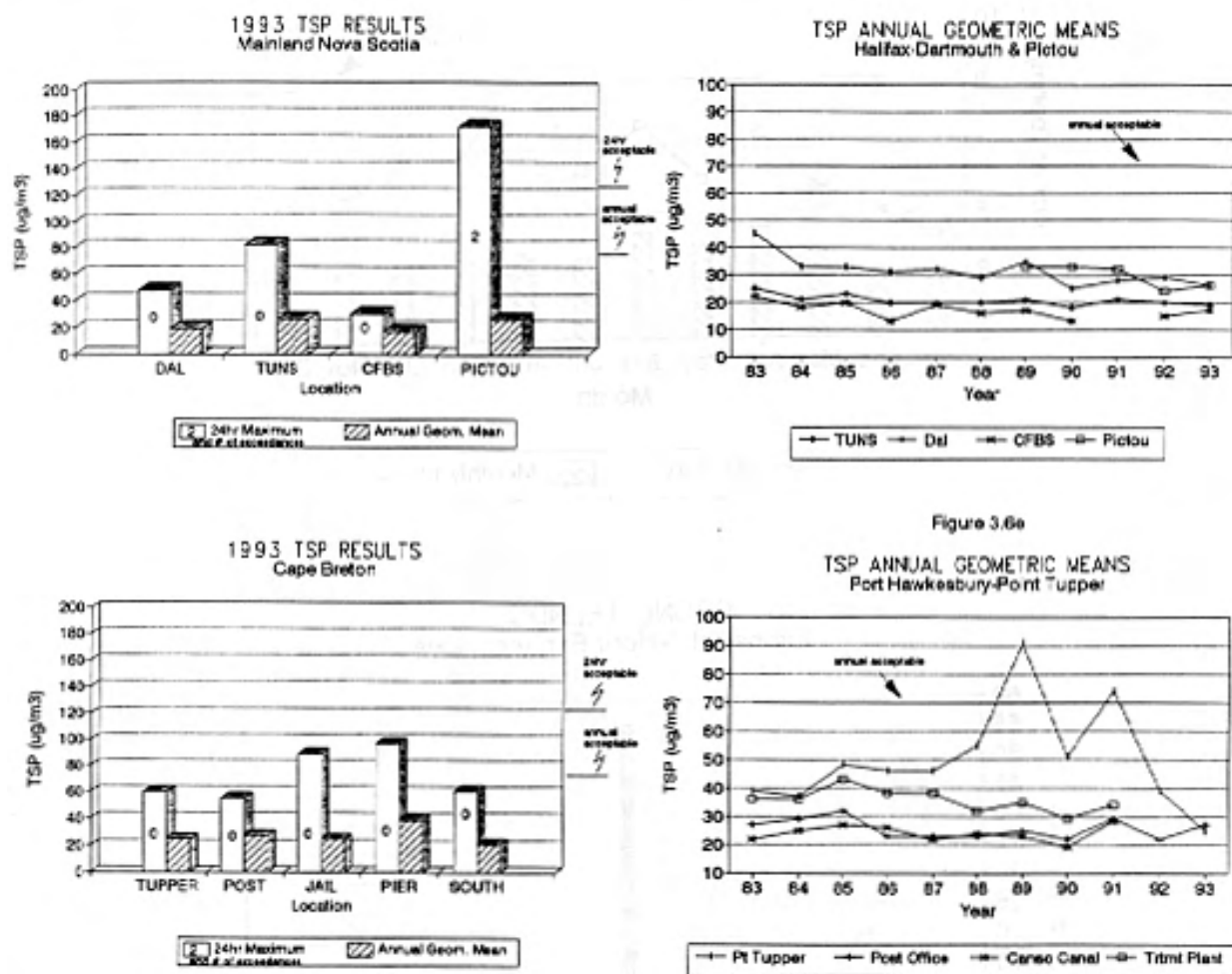


Figure 4.1-15 Total Suspended Particulate and Annual Mean TSP at Various Locations
in Nova Scotia
(Source: NSDOE, 1991)

4.1.2.4 Offshore Ambient Air Quality

No data are available for air quality offshore except for the measurements of precipitation chemistry shown in Table 4.1-18. These data reflect air quality and indicate that offshore pollutant levels are near the background levels measured in remote northern areas. Only episodic long-range transport and local sources (i.e. other offshore activities) would increase these levels.

Table 4.1-18 Measurements of Precipitation Chemistry (Weighed Mean Concentration in $\mu\text{mol}\cdot\text{L}^{-1}$)

Element	1977	1978	1979	1980
pH	4.7	4.7	INS ¹	INS ¹
H ⁺	18	20.2	INS	INS
SO ₄ ⁻²	56	71	INS	INS
SO ₄ ⁻² (corrected for sea salt)	18	22	INS	INS
NO ₃ ⁻	5	5.8	INS	INS
NH ₄ ⁺	INS ¹	3.5	INS	INS
Cl ⁻	714.7	992	INS	INS
Ca ⁺²	14.6	20	INS	INS
Mg ⁺²	65	94.5	INS	INS
K ⁺	15.5	19.9	INS	INS
Na ⁺	619.5	825.7	INS	INS
¹ insufficient (less than 8 months of data)				
(Source: Barrie and Sirous, 1982)				

4.1.3 Physical Oceanography

4.1.3.1 Introduction

This section describes the physical marine environment (physical oceanography) of the study area. Baseline information on various physical oceanographic parameters which will affect the Project planning, design and operation of various components (i.e. offshore facilities, pipeline and coastal structures) is provided. Data for prediction of the effects of project-related activities on the marine environment are also provided.

The physical marine environment provides habitat for the marine biological community and affects every stage of the offshore development. Knowledge of the physical oceanographic conditions (i.e.

water properties, currents, water levels, waves, ice and icebergs) is required for planning, designing and operations of marine and coastal structures. It is also needed to understand the impact of the project on and the interactions with the surrounding biological community (e.g. the behaviour and fate of drilling muds and cuttings, dispersion of discharged effluents, etc.).

Both local (short-scale) oceanographic process and large-scale events that interact on the Scotian Shelf influence the physical marine environment in the study area. The baseline data presented in this section provide a description of the existing environment, both normals and extremes within the study area covering:

1. Offshore: Sable Island Bank including the six offshore natural gas fields and the interfield pipeline corridors;
2. The subsea production gathering pipeline corridors; and
3. The proposed coastal landfall/terminal sites:
 - (a) Country Harbour
 - (b) Strait of Canso

4.1.3.2 Bathymetry and Marine Physiography

The predominant bathymetric feature in the Nova Scotia offshore is the extensive continental shelf known as the Scotian Shelf. Comprising an area of about 120,000 km², the shelf is over 700 km long and extends from the Laurentian Channel southwestward to the Northeast Channel separating the Scotian Shelf from Georges Bank. The shelf is approximately 100 km wide off the southwest coast of Nova Scotia but increases to 250 km wide off Cape Breton Island (Figure 4.1-16).

The Scotian Shelf physiography consists of three physiographic zones on the Scotian Shelf: an inner, central and outer zone (Figure 4.1-16). The inner zone, adjacent to the landmass, is characterized by rough topography, and the coastline of this inner zone in the study area between Cape Canso and Halifax is inundated with islands, rocks and shoals. The central zone exhibits a blocky, dissected relief, where basins (water depth greater than 200 m) alternate with shallow banks (water depth less than 100 m). The region north of the study area is probably the most dissected on the shelf; west of the study area are two large basins, Emerald and LaHave. The outer zone consists of broad, flat banks with relatively little bottom relief. LaHave Bank is separated from Emerald Bank to the west of the study area by a wide

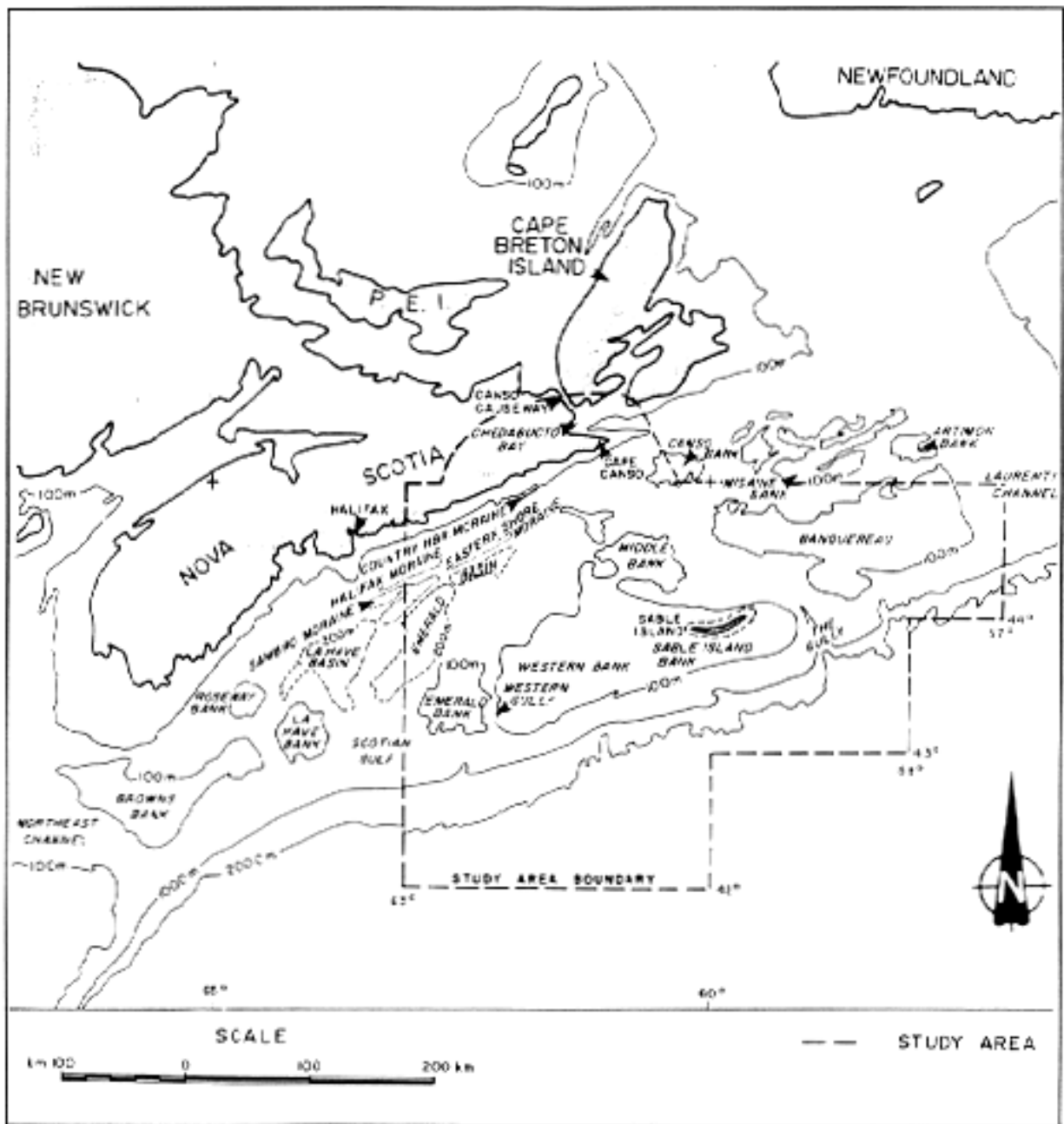


Figure 4.1-16 Scotian Shelf Bathymetry

channel known as the Scotian Gulf. East of Emerald Bank, a depression known as the Western Gully separates it from the most extensive bank on the shelf, Sable Island Bank.

The emerged part of Sable Island Bank, Sable Island, is the only bathymetric feature of its kind off the northeast coast of North America. The island consists of two nearly parallel ridges of sand with underwater extensions to both the west-northwest and east-northeast known respectively as the West and East Bars. The West Bar extends for about 35 km at a depth of less than 5 m. The East Bar extends for about 25 km at a depth of 4 to 18 m. These sand bars are steep on their north sides and are areas of cross seas breaking waves.

Sable Island Bank is defined on its northern side by a narrow depression, the shelf extension of the Gully submarine canyon, which separates it from Banquereau. The trench-like Gully is 11 km wide at its narrowest point and over 914 m deep at its southernmost extremity.

4.1.3.3 Water Column Structure and General Current Regime

Figure 4.1-17 illustrates the water mass types occurring within the study area. These waters are composed of a mixture of the Cape Breton Current and the Labrador Current, two streams which converge over Banquereau. Within the corridor, the upper 50 m of the water column is predominantly Cape Breton Current water mixed across the Shelf with Labrador Current water (Figure 4.1-18).

The volume of flow of the Cape Breton Current varies seasonally, but is greatest in early winter. It is the least saline (30.4 to 31.6 ‰ salinity) of any current in the area. Its temperature is typically 7 to 8°C; inshore, however, surface water temperature can range from -1° to 20°C, depending on the season. A portion of the Cape Breton Current flows southwest along the coast of Nova Scotia where it is known as the Nova Scotia Current.

The basin between Middle Bank and the coastal rise below 50 m is filled with Labrador Current water. This water is cold (-1 to 4°C) with a salinity of 32 to 33 ‰. Offshore, surface water temperatures range from 2 to 20°C, depending on the season and the degree of influence exerted by the warmer upper layers of slope water.

In summer, a homogeneous mixed layer about 10 m thick develops at the water surface. By fall, the layer is 30 m deep, and in winter thickens to more than 60 m. In spring, the rapid warming of the upper water column causes stratification, and a mixed upper layer can no longer be distinguished. At the shallow Venture and Thebaud sites, the water column shows uniform distribution of salinity and temperature year-round, where as at the deeper sites (North Triumph, Glenelg and Alma) temperature stratification occurs in summer and early fall (MacLaren Plansearch, 1989).

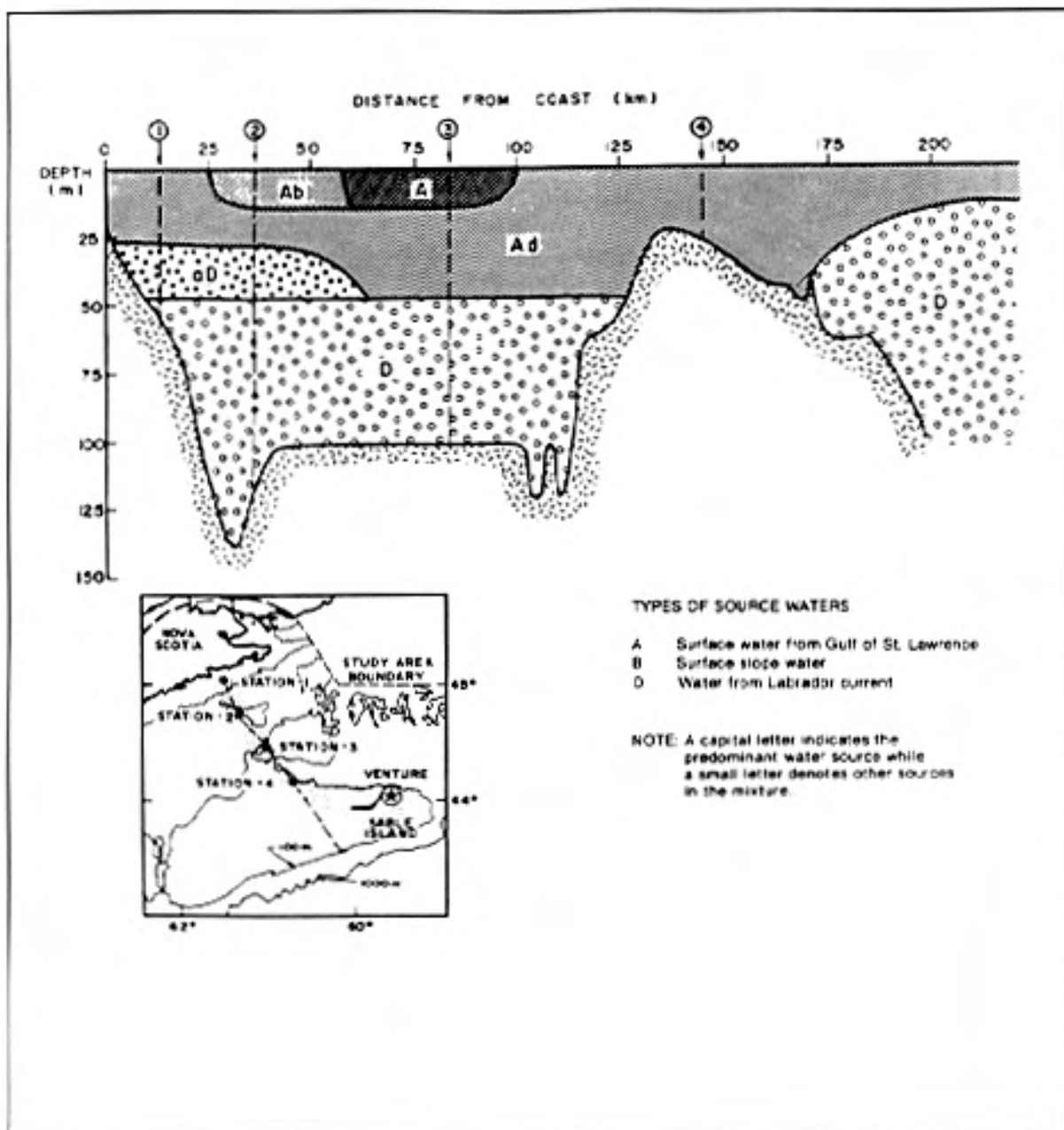


Figure 4.1-17 Water Mass Types Occurring within the Proposed Pipeline Corridor
(Source: after Houghton et al., 1978)

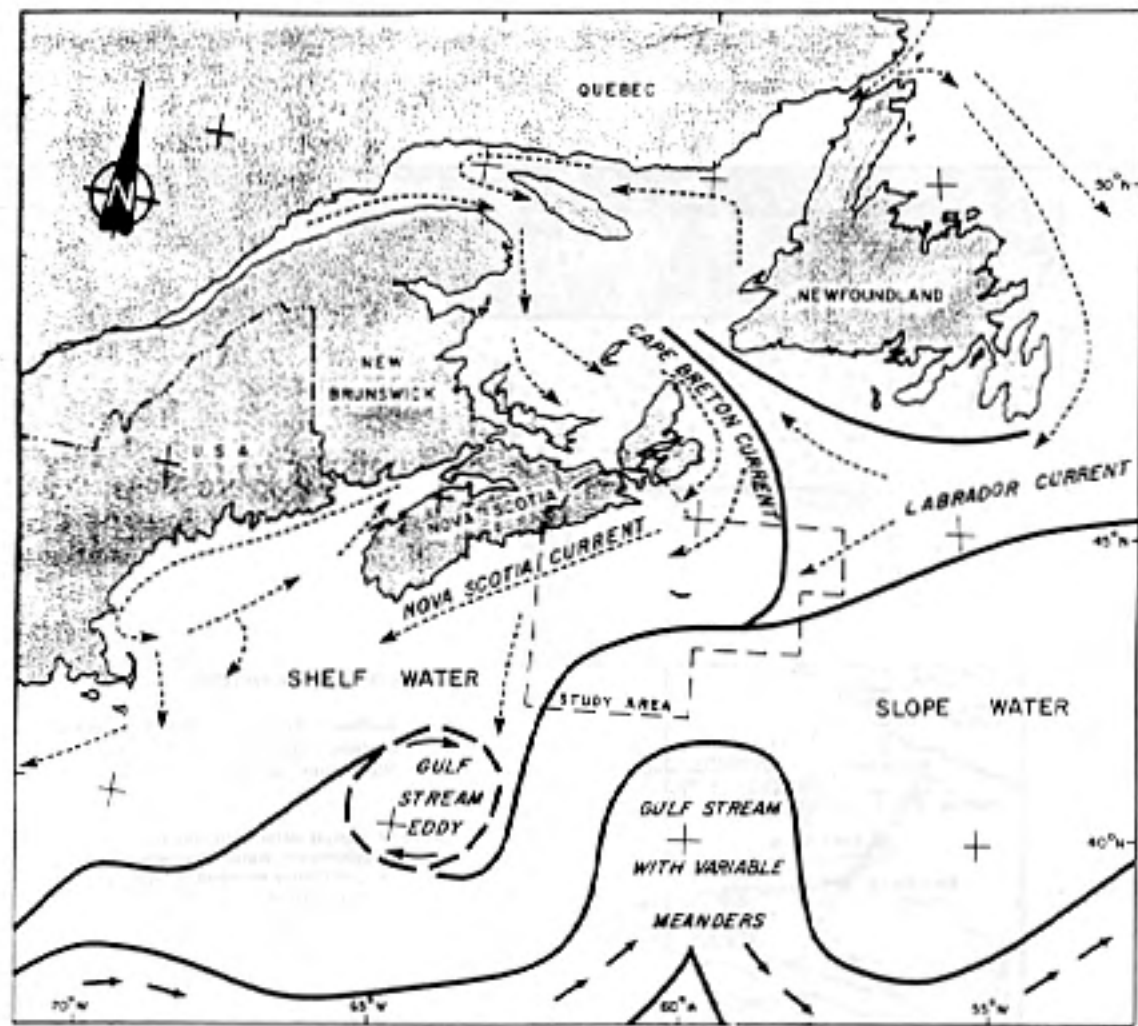


Figure 4.1-18 Major Current Patterns

Short-term variations in currents can result in temporary bursts of high currents. Of these, tidal currents are the most cyclic and predictable. Offshore, the tides describe orbits called tidal ellipses which get larger with increasing distance from shore.

In coastal areas, tidal currents flow back and forth parallel to shore. Near Sable island, the ebb tidal stream sets to the south on and over the bars, at rates up to $100 \text{ cm}\cdot\text{s}^{-1}$, turning east along the south side of the island. The tide floods north at up to $75 \text{ cm}\cdot\text{s}^{-1}$, turning west along the south side of the island, and then north over the West Bar. In the deeper waters over the main part of the corridor, tidal currents are much less. In 100 m of water, for instance, the rate would be $15 \text{ cm}\cdot\text{s}^{-1}$.

Winds associated with storms over the Scotian Shelf also generate short-term currents. Two types occurring on the shelf are inertial motions, which can persist for several days, and forced motions, which have the same frequency (one per two to ten days) as the storms which generate them. At the surface, inertial motion on the shelf has been measured at 30 to $40 \text{ cm}\cdot\text{s}^{-1}$; below 50 m, inertial oscillations rapidly decrease. Direct forcing can cause mean daily surface currents of up to $25 \text{ cm}\cdot\text{s}^{-1}$.

Wind forcing is also responsible for periodic episodes of upwelling of slope water over the shelf. These upwellings can carry nutrient-rich deep water onto the shelf. The Gully is one probable site of regular upwelling. The eastern coast of Cape Breton is also an area of upwelling, and some of the enriched water probably enters the Cape Breton Current, which flows southwest into Chedabucto Bay and then into the pipeline corridor.

Oceanic fronts occurring at the boundaries between water masses may also contribute to nutrient enrichment of surface waters. Near the Scotian Shelf, the only major persistent frontal system is the boundary between the shelf and slope waters, an area which lies outside the proposed pipeline corridor and the offshore well sites. Within the corridor, Sable Island Bank and Middle Bank have some potential for fostering transient fronts.

4.1.3.4 Temperature and Salinity

Temperature and salinity are important properties of sea water. The temperature and salinity of water are major factors in determining its density, and the density distribution is crucial to ocean circulation and mixing. Knowledge of how water properties vary and the rates at which they can change provides important insights into the transport and mixing processes that distribute materials throughout the water column.

A summary of the water temperatures and salinities at seven locations along the pipeline corridor (Figure 4.1-19) are presented in Table 4.1-19 (Seaconsult, 1984). A summary of seawater temperature and salinity for the Country Harbour area is presented in Table 4.1-20 (Seaconsult, 1985).

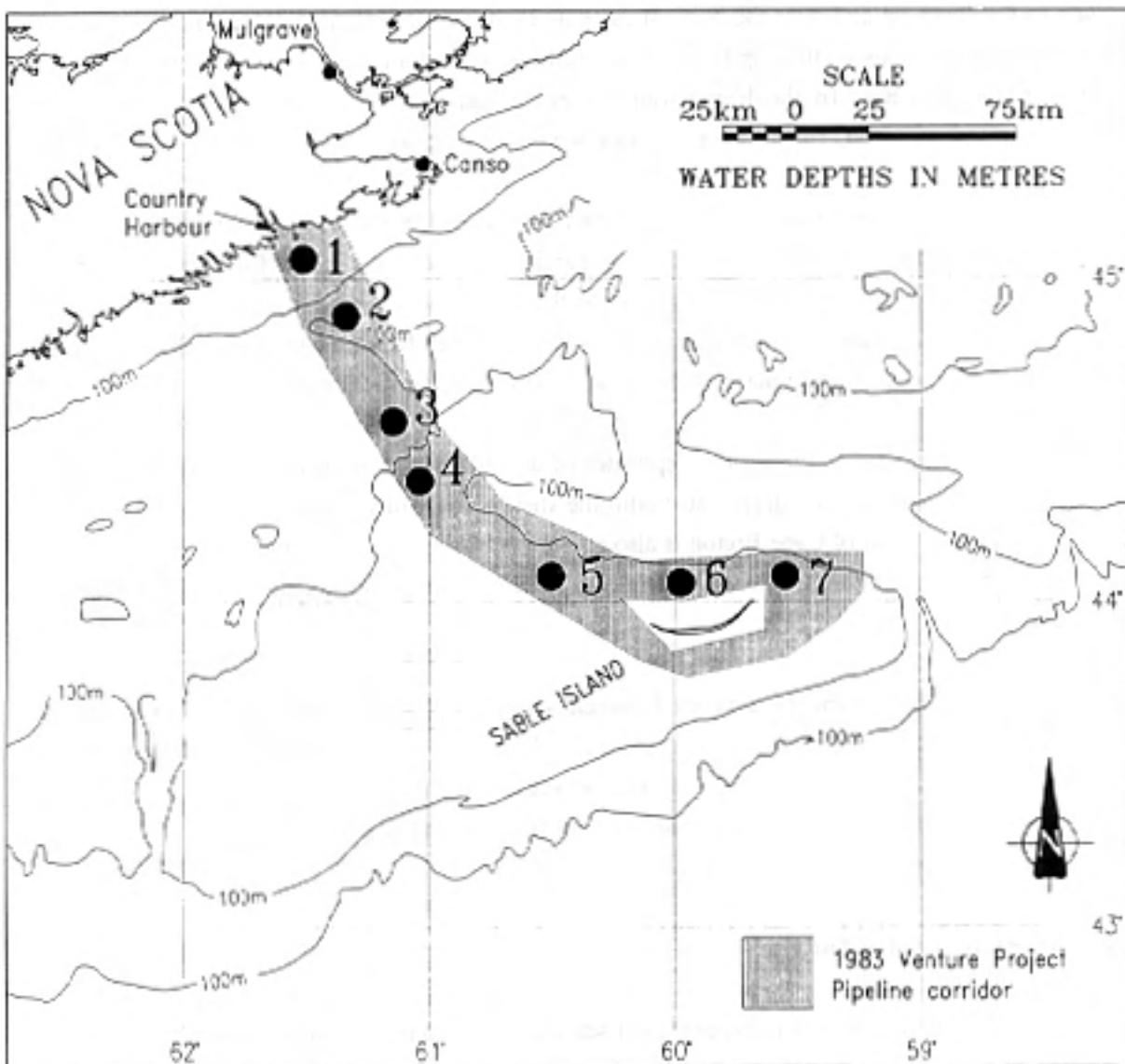


Figure 4.1-19 Water Temperature and Salinity Meter Deployment Sites
Along the Pipeline Corridor
(Source: Seaconsultant, 1984)

Historical temperature-salinity databases have been analyzed recently by Loder et al. (1995) and Gregory (1995) to provide the winter and summer surface and bottom temperature and salinity distributions.

The water column on the Scotian Shelf can be divided into three layers: the upper layer of fresher water (less than 32‰ salinity) with a large seasonal variations in temperature, a cold intermediate layer (temperature less than 5°C and salinity ranging from 32 to 34 ‰) and a deep layer which, along the pipeline corridor, is cold (less than 5°C) with salinities in the range 32 to 33 ‰. Monthly variations of temperature and salinity for four areas (Sable Bank, the Gully, Middle Bank and Canso) for all the dataset collected until 1994 have been analyzed by Gregory (1995) and the results are presented in Figures 4.1-20.

Table 4.1-19 Summary of Water Property Data Along the Pipeline Corridor and Offshore Fields

Site	Property (Near Bottom)	Annual Mean	Range	
			Min.	Max.
1	Temperature(°C)	4.0	-0.4	12.1
	Salinity(ppt)	32.6	27.7	35.2
2	Temperature(°C)	6.8	1.7	11.1
	Salinity(ppt)	34.0	32.4	34.7
3	Temperature(°C)	4.0	0.3	11.4
	Salinity(ppt)	33.2	31.5	34.4
4	Temperature(°C)	4.0	-0.4	12.1
	Salinity(°C)	32.8	31.2	34.3
5	Temperature(°C)	8.3	-0.7	17.7
	Salinity(ppt)	31.6	29.6	32.7
6	Temperature(°C)	5.0	-0.6	16.9
	Salinity(ppt)	32.1	30.9	32.9
7	Temperature(°C)	3.3	-0.5	13.7
	Salinity(ppt)	32.6	31.3	33.6
(Source: Seaconsult, 1984)				

Table 4.1-20 Summary of Country Harbour Sea Water Surface Temperature and Salinity

Temperature					
Parameter	Season				
	January to March	April to June	July to September	October to December	Annual Values
Max. Temp. (°C)	1	12	20.61	18.4	20.61 ⁽¹⁾
Mean Temp. (°C)	-0.09	3.88	14.43	9.32	6.83 ⁽²⁾
Min. Temp. (°C)	-1.6	-0.02	6.57	4.8	-1.60 ⁽³⁾
Std. Dev.	0.49	1.22	1.87	1.52	5.05
No. Obs.	21	120	238	94	473

Salinity					
Maximum Salinity (ppt)	31.09	31.72	31.55	30.72	31.72 ⁽¹⁾
Mean Salinity (ppt)	30.95	31.07	27.88	30.04	29.99 ⁽²⁾
Minimum Salinity (ppt)	30.5	30.9	11.28	16.04	11.28 ⁽³⁾
Std. Dev.	0.18	0.25	3.24	2.75	3.39
No. Obs	6	15	104	29	154
(1) Maximum Value in any Month					
(2) Annual Mean Value					
(3) Minimum Value in any Month					
(Source: Seaconsult, 1985)					

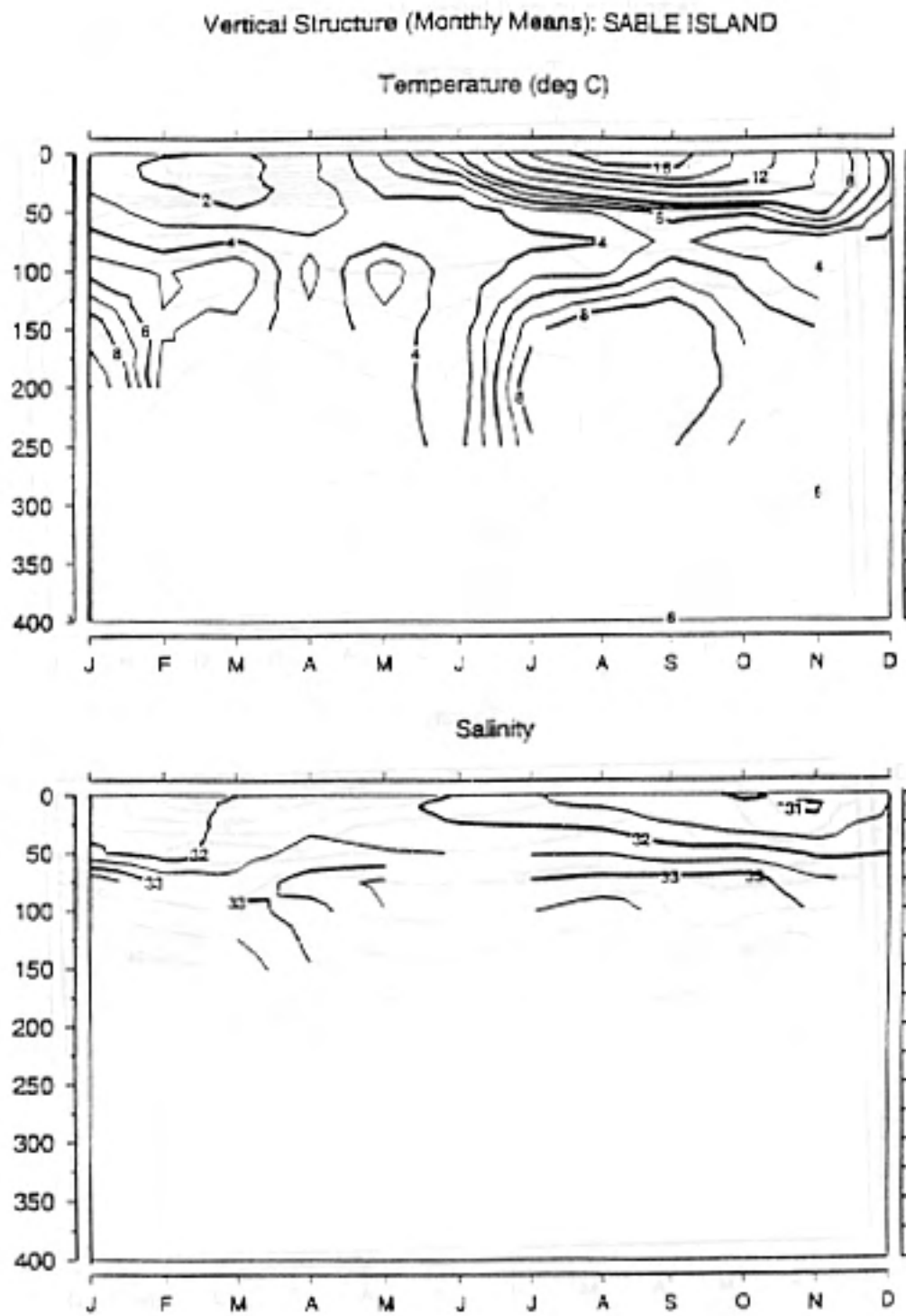


Figure 4.1-20 Monthly Variations of Temperature and Salinity for Sable Island
(Source: Gregory, 1995)

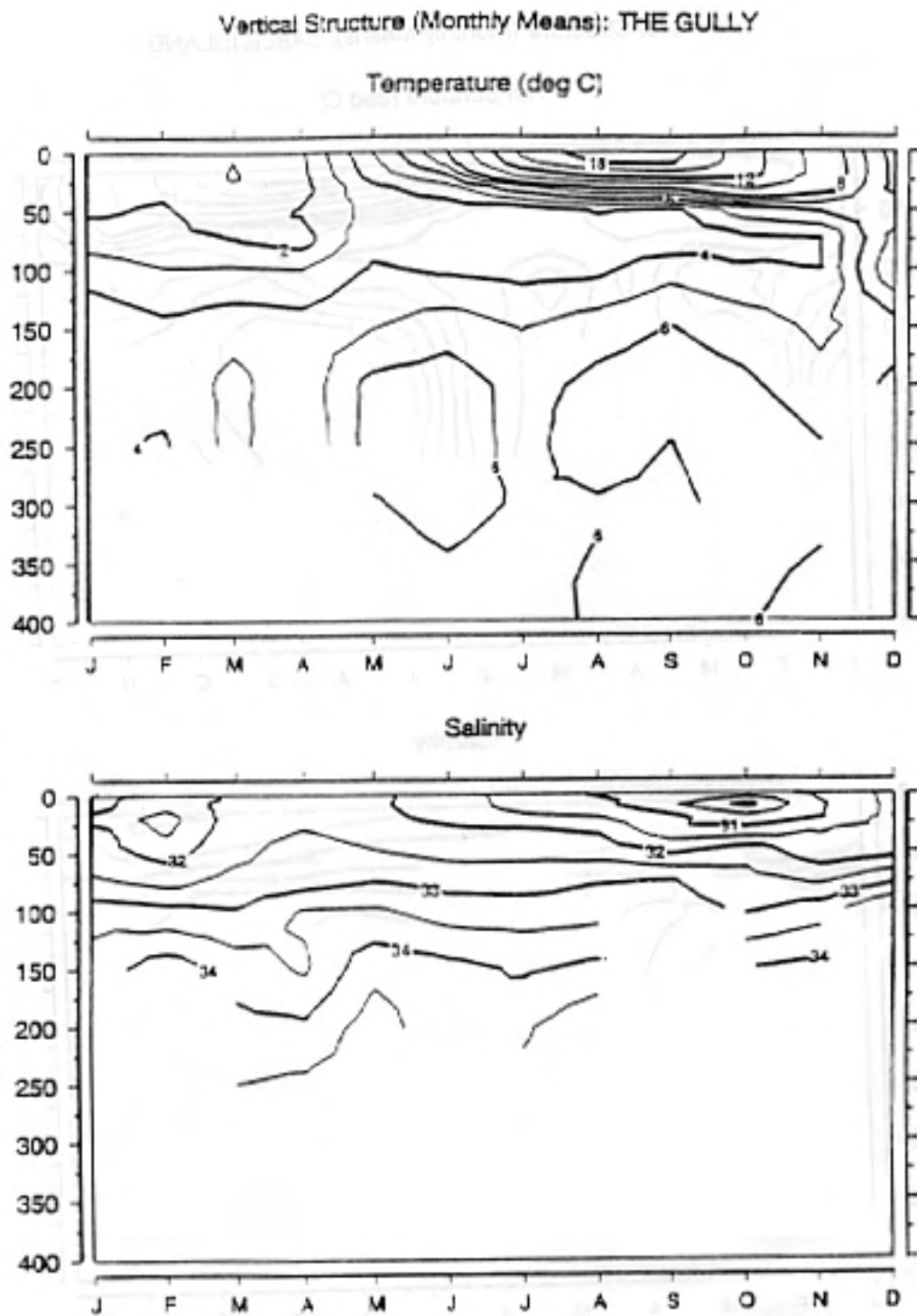


Figure 4.1-20 (cont'd) Monthly Variations of Temperature and Salinity for The Gully
(Source: Gregory, 1995)

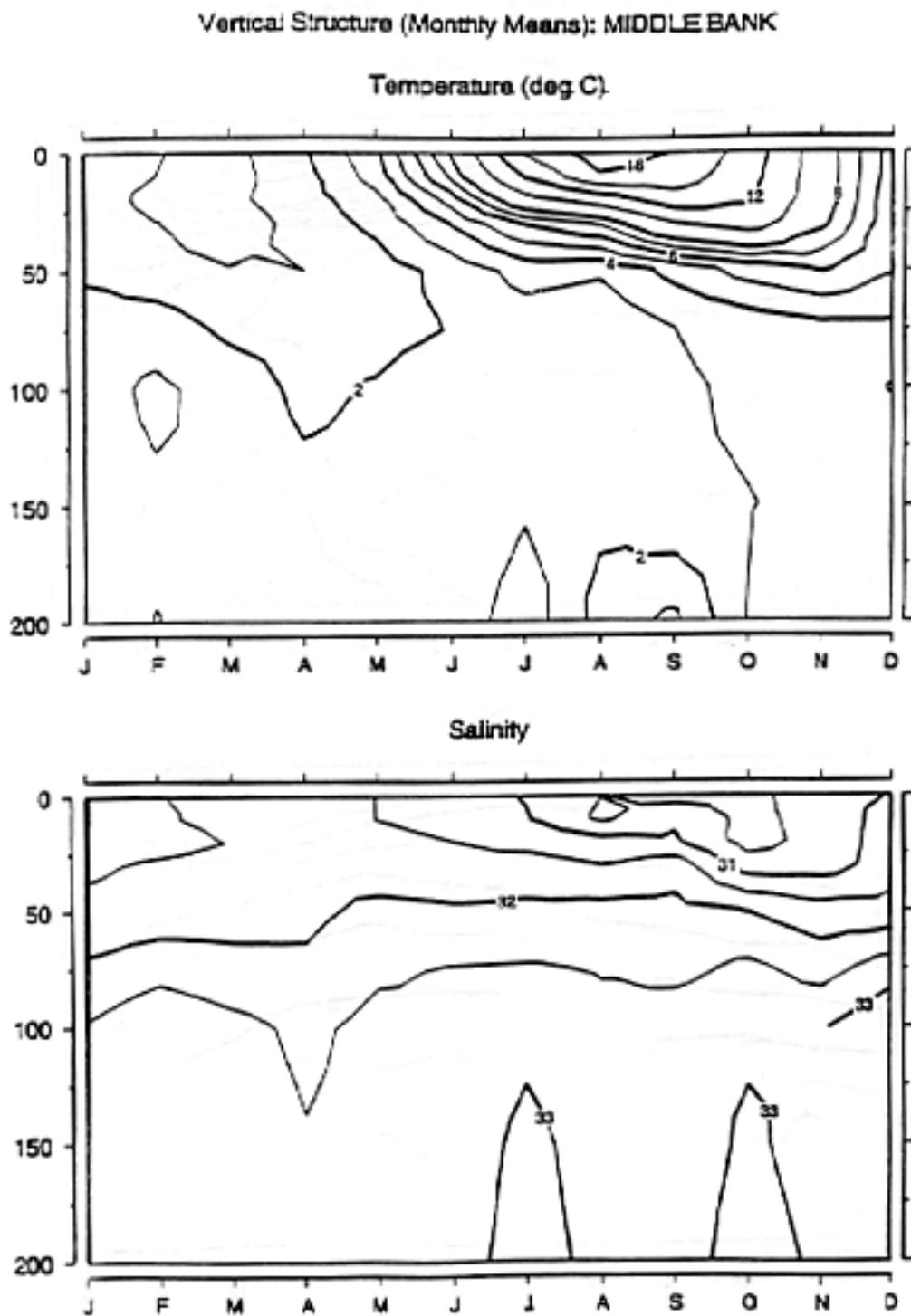


Figure 4.1-20 (cont'd) Monthly Variations of Temperature and Salinity for Middle Bank
(Source: Gregory, 1995)

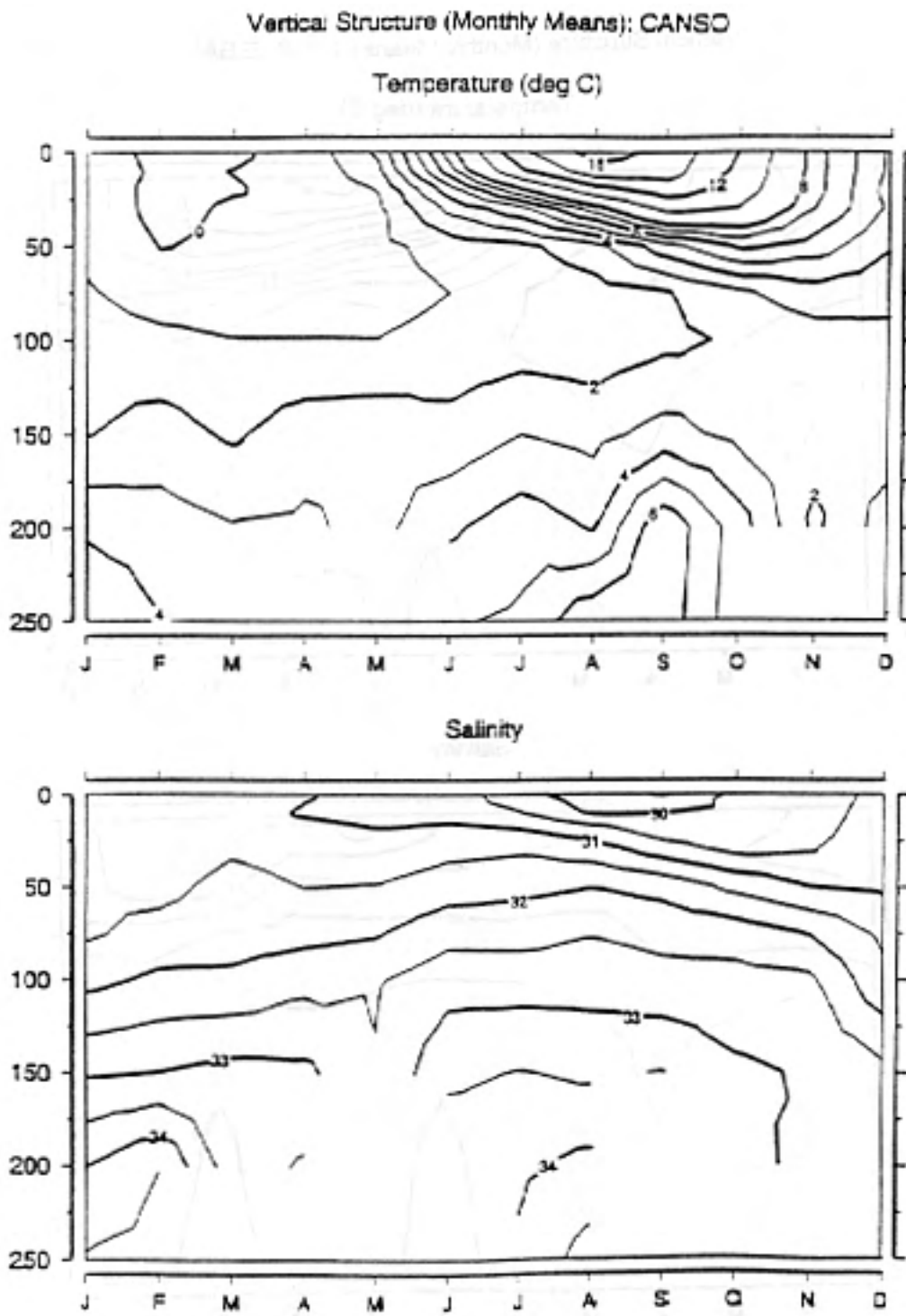


Figure 4.1-20 (cont'd) Monthly Variations of Temperature and Salinity for Canso
(Source: Gregory, 1995)

4.1.3.5 Currents and Circulation

The current variations on the Scotian Shelf are mainly locally generated by various forcing mechanisms, such as winds, tides and density structure. However, the Scotian Shelf cannot be considered to be independent of the North Atlantic; shelf and slope currents do encounter those of the deep ocean. The term "deep ocean forcing" refers to the force arising from such current interaction, such as the effect of large eddies and meanders of the Gulf Stream on the waters of the continental shelf. Eddies, the oceanic equivalent of cyclones, have diameters of about 100 km, move slowly (tens of kilometres per day) and have been observed to persist for more than a year. Velocities inside such eddies can be as high as $100 \text{ cm}\cdot\text{s}^{-1}$ (Richardson, 1980). Current interaction is important in enabling the exchange of water carrying heat, salt and nutrients between the Scotian Shelf as a whole and the open ocean. The primary sources of information on current circulation on the Scotian Shelf are from moored current measurements, tracking of drifters, geostrophic computations and hydrodynamic modelling.

A large current measurements database exists in the study area. Over 800 moored instruments which record the current speed and direction at a desired depth and location were deployed in the Nova Scotia offshore region by BIO, Mobil, Shell, Petro Canada, Dalhousie University and others. Mobil had carried out various current meter measurements at their drilling locations in the vicinity of Sable Island and along the pipeline corridor from 1972 to 1985. The measured current data were analyzed into three main constituents: the tidal currents, the short-term residuals (wind-driven currents) and the long-term residuals (coastal currents). A MacLaren Plansearch (1989) report contains a compilation of current meter data for the period 1983 to 1987 at four well sites (Alma, Glenelg, Thebaud and North Triumph). Seaconsult (1984-1985) compiled large current data at the Venture site and along the proposed pipeline corridor. These measured current data were used in the analysis presented in this report.

Tidal Currents

Tides are generated by the gravitational forces exerted by the sun and moon as they move in relation to the earth. As their motion is cyclic, the currents they generate are also cyclic, and may thus be predicted for any instant in time. Astronomical tides cause water level and current variations at several frequencies. The Scotian Shelf and Slope are dominated by semidiurnal tide, which causes a twice-daily fluctuation in water level and currents. Also important are the diurnal constituents, which cause daily fluctuations. Currents generated by the astronomical tides are uniform in depth except very near the bottom, where friction will diminish their velocity.

In coastal regions, tidal currents are forced to flow back and forth parallel to shore, but farther offshore the tides describe orbits called tidal ellipses. Figure 4.1-21 shows ellipses for the semidiurnal (M2) tide at various locations. In these diagrams, the size of the ellipse is proportional to the tidal-current magnitude, and its orientation indicates the directions of maximum tidal flow.

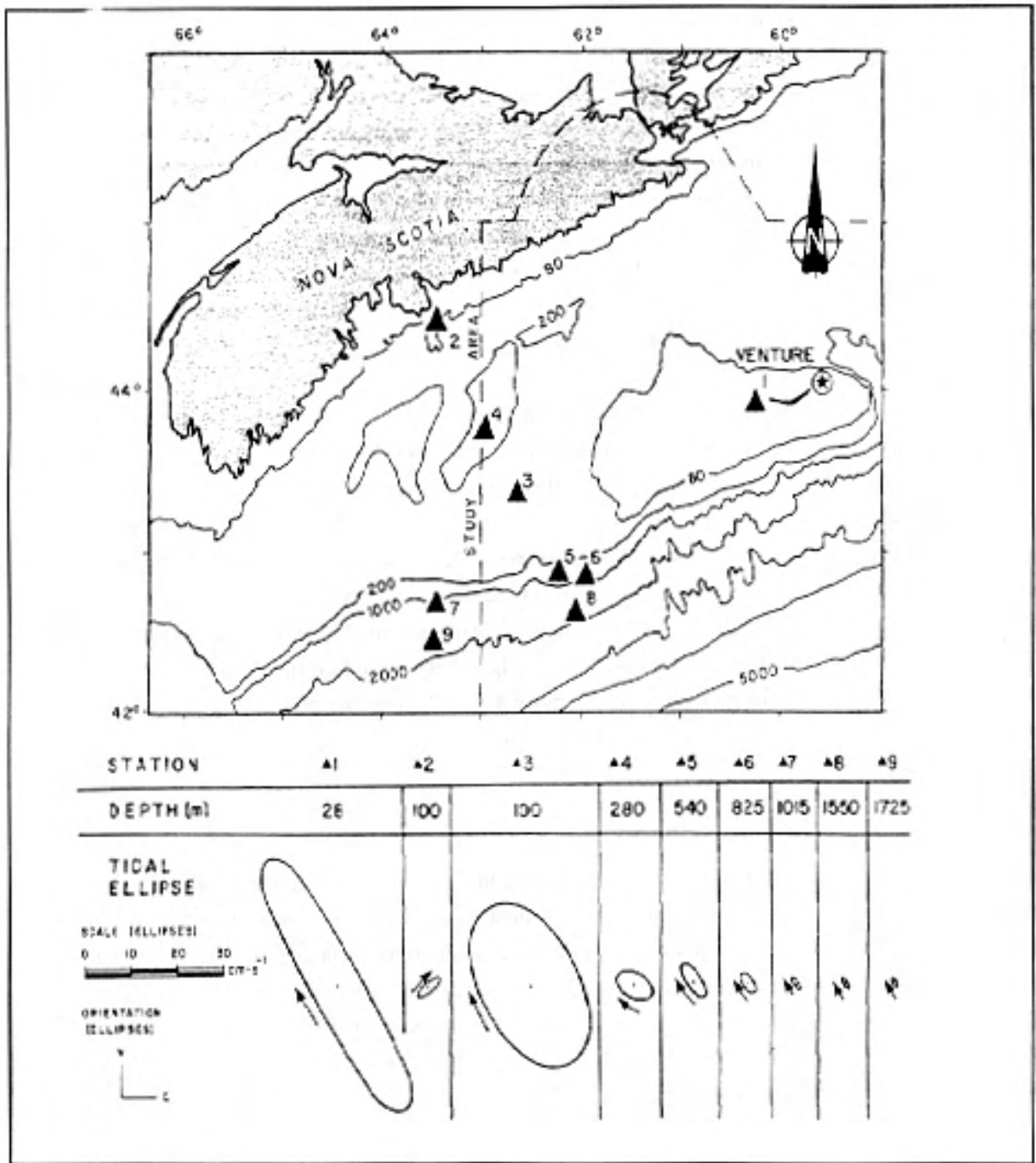


Figure 4.1-21 Tidal Ellipses for the Semi-diurnal Tide
(Source: Ingram et al., 1973; Petrie, 1975)

Near Sable Island, the ebb-tidal stream is considered to set to the south, on and over the bars, often at the rate of 75 to 100 $\text{cm}\cdot\text{s}^{-1}$. The flood stream runs 50 to 75 $\text{cm}\cdot\text{s}^{-1}$ to the north.

Currents Generated by Internal Waves

Internal waves can generate substantial currents in the ocean. As they involve one layer of water moving with respect to another, they always induce vertical shear, with currents flowing in opposite directions at different depths. Compared with surface waves they move slowly, with periods ranging from several minutes to half a day and wavelengths from hundreds of metres to tens of kilometres. Although the troughs and crests of internal waves move slowly, they may cause strong currents because of their large amplitudes.

Most internal waves detected on the Scotian Shelf and Slope are generated by the flow of the astronomical tide in regions of rapidly changing topography, such as at Shelf Break. At each tidal cycle one internal wave is created as the current flows over a sharp bottom feature. These waves therefore have the same periods as the astronomical tides, and are often called internal tides. As their properties depend on stratification, which changes seasonally and with the passage of storms, they cannot be predicted exactly as surface tides can.

There is no stratification at Venture, South Venture and Thebaud, the drill sites where water depths vary from 20 to 30 m. However, at the deeper sites, North Triumph, Glenelg and Alma, where the water depths range from 70 to 80 m, moderate stratification is expected. The pipeline route has some abrupt topographical features where large internal tides and solutions could be generated.

Wind-Driven Currents

Wind blowing over the ocean can cause currents by the drag it exerts on the water surface. During storms such currents can become strong enough to be a concern in offshore structure design. Storms over the Scotian Shelf produce two types of current:

- strong inertial motion with a period of 17.4 h; and
- directly forced motion with the same frequency as the atmospheric disturbances themselves (i.e. one storm per 2 to 10 days).

On the Scotian Shelf, Warner (1970) has studied inertial motions in detail and found amplitudes of 30 to 40 $\text{cm}\cdot\text{s}^{-1}$ to occur frequently. Comparing measurements at 20 and 50 m, in a season when the mixed layer is between the two depths, he found that the oscillatory currents were usually in opposite directions, indicating some complementary flow below the mixed layer as well. Smith et al. (1978) used a mixed-layer model to predict the amplitude of inertial oscillations on the Scotian Shelf, but also found currents below the surface layer the model did not account for. Below 50 m all observations indicate that inertial oscillation decreases rapidly.

Current oscillations at periods of two to ten days are also forced by winds (Petrie and Smith, 1977), and have been found to cause mean daily flows of up to 25 $\text{cm}\cdot\text{s}^{-1}$. Current meter observations (Smith et al., 1978) have confirmed that longshore winds from the southwest are associated with a net

offshore flow near the surface and a compensating return flow of slope water deeper in the water column. Smith and Petrie (1982), in investigating the seasonal dependence of wind-forced currents found, as expected, that the largest currents are generated in winter when storms are most intense, and the smallest in summer.

General Circulation Pattern (large-scale currents)

As discussed earlier, two main sources of water on the Scotian Shelf are the inshore branch of the Labrador Current and the outflow from the Gulf of St. Lawrence (named the Cape Breton Current). These waters are then mixed with the more saline waters from offshore called the "Slope Water". The resulting southwesterly flow over the inner half of the Scotian Shelf parallel to the coast of Nova Scotia is called the Nova Scotia Current (Figure 4.1-22).

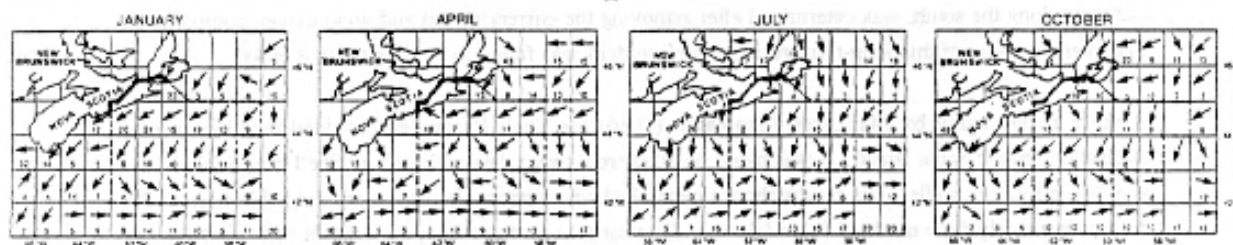
The region between the Nova Scotia current and the Gulf Stream is one of continual variability. The Gulf Stream itself sheds large-scale eddies which move off to the north and into the Slope Water region (Smith, 1978; Louis and Smith, 1982). The Gulf Stream eddies--their formation, movement and decay--are considered vital in the western North Atlantic for redistributing water, biological life, and momentum and energy (Richardson, 1976).

Deep ocean eddies do not penetrate onto the Scotian Shelf, but their effects show in current-meter records as oscillations with periods of 10 to 100 days and amplitudes as large as tens of centimetres per second (Petrie and Smith, 1977). Smith and Petrie (1982), comparing the variabilities due to deep ocean forcing and to wind forcing, found that on the shelf, wind effects dominate, whereas on the slope, ocean forcing prevails. Smith (1978), using satellite imagery and current-meter data, found that a clockwise spinning eddy from the Gulf Stream entrained a significant amount of shelf water into the slope region, and associated at the Shelf Break with currents as strong as $30 \text{ cm}\cdot\text{s}^{-1}$.

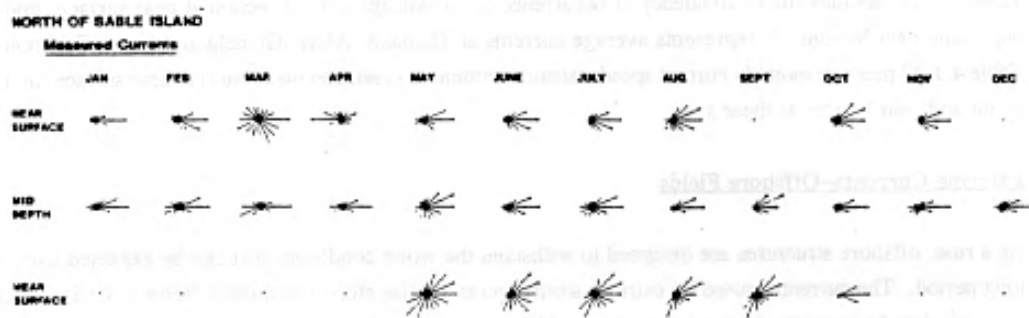
Surface Current Circulation

Surface current circulation over the Scotian Shelf is forced by a variety of oceanographic and meteorological factors interacting over a large range of space and time scales. These forcing parameters include: winds, tides, density gradients and strong flow from adjacent areas. The Labrador Current, the Gulf Stream, outflow from the Gulf of St. Lawrence and influences from the North Atlantic all have some bearing on the long-term circulation in the study area as discussed earlier.

(1) Surface Current Circulation by Season



(2) Monthly Surface, Mid-Depth and Bottom Currents, North of Sable Island



(3) Monthly Surface, Mid-Depth and Bottom Currents, South of Sable Island

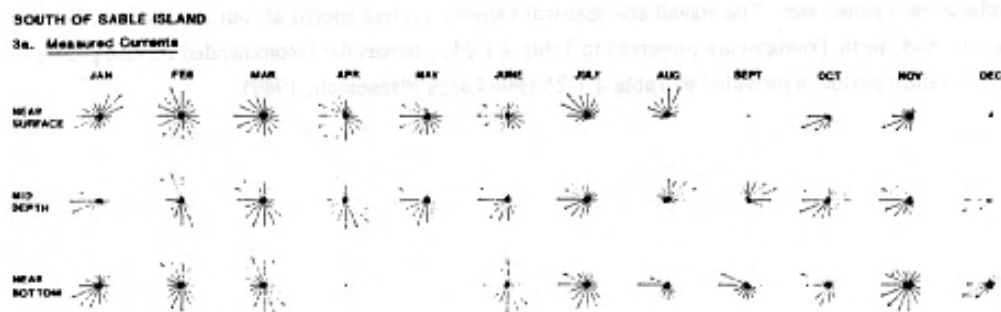


Figure 4.1-22 Monthly Prevailing Current Regime at Various Water Depths
north and south of Sable Island

(Source: MacLaren Plansearch, 1986)

Detailed studies of surface currents, involving current meters and drifter buoys, were undertaken for Mobil around Sable Island by Evans-Hamilton, Inc. (1977, 1978a,b). The results indicate a steady, long-term, residual-current clockwise drift around Sable Island. Residual drift, east along the north shore of the island and west along the south, was determined after removing the current's tidal and wind driven components. The average value of this long-term residual surface drift was found to be about 5 to 8 cm•s⁻¹.

A more recent study by MacLaren Plansearch (1986) for Shell Resources provided detailed current circulation around Sable Island. It was based on all current meter data collected by Shell near Sable Island at their exploratory wells. The results show a clear clockwise current circulation around Sable Island with dominant easterly flow north of Sable Island and westerly to northwesterly flow south of Sable Island as shown in Figure 4.1.3-7 (Kendaris and Eid, 1987).

4.1.3.6 Currents Statistics--Sable Bank

Table 4.1-21 provides annual frequency of occurrence of current speed by direction at near surface, mid-depth and near bottom. It represents average currents at Thebaud, Alma, Glenelg and North Triumph. Table 4.1-22 presents monthly current speed statistics (minimum mean and maximum) at near surface, mid-depth and near bottom at these sites.

Extreme Currents--Offshore Fields

As a rule, offshore structures are designed to withstand the worst conditions that can be expected over a long period. The currents caused by extreme storm events are therefore a dominant factor in design, and are considered separately from tidal currents which recur regularly. Also very important are the severe wave conditions likely to be generated at the same time. The worst combination, from a structural point of view, is when both waves and currents move in the same direction, and this will be taken into account in obtaining design criteria for structures near Sable Island. Table 4.1-23 shows extreme values at different depths at the Venture site. The annual and seasonal extreme current speeds at four sites (Alma, Glenelg, Thebaud and North Triumph) are presented in Table 4.1-24, whereas the recommended current profile for a given return period is provided in Table 4.1-25 (MacLaren Plansearch, 1989).

Tables 4.1-21 Annual Frequency of Occurrence of Current Speed and Direction

Speed Ranges (cm•s ⁻¹)										
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	Sum
Surface Data: 59176 Values (mean depth = 0.25 of water depth)										
N	0.026	0.031	0.025	0.012	0.004	0.001	0	0	0	0.099
NE	0.022	0.027	0.021	0.01	0.005	0.001	0	0	0	0.086
E	0.022	0.023	0.017	0.008	0.003	0	0	0	0	0.075
SE	0.024	0.038	0.035	0.026	0.013	0.004	0.001	0	0	0.142
S	0.027	0.037	0.026	0.009	0.003	0.001	0	0	0	0.102
SW	0.029	0.046	0.035	0.016	0.005	0.001	0	0	0	0.132
W	0.029	0.049	0.047	0.029	0.011	0.002	0.001	0	0	0.169
NW	0.029	0.045	0.045	0.035	0.024	0.012	0.005	0.001	0	0.195
Sum	0.209	0.294	0.25	0.144	0.069	0.023	0.009	0.001	0	1
Mid-depth Data: 46288 Values (mean depth = 0.59 of water depth)										
N	0.019	0.031	0.021	0.005	0	0	0	0	0	0.077
NE	0.017	0.026	0.017	0.004	0.001	0	0	0	0	0.065
E	0.018	0.029	0.02	0.007	0.003	0.001	0	0	0	0.08
SE	0.022	0.044	0.028	0.006	0.001	0	0	0	0	0.101
S	0.028	0.059	0.035	0.005	0.001	0	0	0	0	0.128
SW	0.026	0.064	0.052	0.013	0.004	0.001	0	0	0	0.159
W	0.025	0.071	0.073	0.034	0.013	0.002	0.001	0	0	0.219
NW	0.027	0.065	0.053	0.017	0.005	0.002	0.001	0	0	0.17
Sum	0.182	0.39	0.298	0.092	0.028	0.007	0.002	0	0	1
Bottom Data: 56718 Values (mean depth = 0.87 of water depth)										
N	0.028	0.034	0.014	0.001	0	0	0	0	0	0.077
NE	0.027	0.032	0.012	0.004	0.002	0.001	0	0	0	0.078
E	0.03	0.035	0.013	0.003	0	0	0	0	0	0.081
SE	0.037	0.055	0.03	0.008	0.001	0	0	0	0	0.131
S	0.043	0.052	0.03	0.009	0.002	0	0	0	0	0.137
SW	0.038	0.056	0.032	0.011	0.003	0	0	0	0	0.141
W	0.056	0.081	0.052	0.02	0.003	0	0	0	0	0.212
NW	0.032	0.056	0.037	0.013	0.002	0.001	0	0	0	0.141
Sum	0.291	0.4	0.221	0.069	0.014	0.003	0.001	0	0	1
(Source: MacLaren Plansearch, 1989)										

Table 4.1-22 Monthly Current Speed Statistics

Month	Near Surface (0.25 D)			Mid-Depth (0.59 D)			Near Bottom (0.87 D)		
	Min .	Max .	Mean ± S.D.	Min .	Max .	Mean ± S.D.	Min. .	Max .	Mean ± S.D.
January	0.09	62. 04	19.54±9.40	6.26	72. 76	25.65±9.57	2.06	55. 82	17.98±9.15
February	0.26	62. 68	19.56±9.96	6.96	68	23.07±8.64	2.06	48. 82	15.78±7.25
March	0.26	82. 28	22.83±12.41	4.86	59. 18	19.93±7.47	2.62	38. 74	16.72±6.63
April	0.19	69. 62	19.49±9.94	3.32	40. 42	16.21±6.18	-	-	-
May	0.19	67. 57	17.74±10.14	2.9	41. 68	15.82±6.91	-	-	-
June	0	77. 04	21.78±12.62	2.48	46. 16	17.52±7.73	2.62	39. 86	16.03±6.76
July	0	75. 18	23.90±13.27	0.51	69. 24	20.63±9.98	1.5	49. 38	14.57±7.47
August	0.2	83. 61	22.93±14.72	0	69. 21	17.23±9.52	1.5	64. 64	14.37±9.06
September	0	74. 98	23.26±13.42	0	66. 88	17.87±10.69	1.5	61. 84	15.37±8.48
October	0.19	50. 24	24.62±10.76	4.16	66.6	23.31±10.79	2.2	62. 96	19.78±9.42
November	0.26	58	19.22±10.44	3.74	64. 56	20.39±8.58	1.92	70. 38	18.16±8.58
December	0.38	61. 82	19.97±10.58	8.5	76. 12	28.91±12.20	3.6	62. 54	17.86±9.06
Current speed in $\text{cm}\cdot\text{s}^{-1}$									
Data Sources: Current meter measurements at the four sites									
(Source: MacLaren Plansearch Limited, 1989)									

Table 4.1-23 Extreme Current Velocities for the Venture Site

d/D ¹	Direction (degree toward)	Current in the Direction of Maximum Wave Height (cm•s ⁻¹)			
		Recurrence Interval (years)			
		10	25	50	100
0.1	25	134	140	149	155
0.25	25	119	125	131	134
0.5	25	101	107	110	113
0.75	25	88	94	98	101
0.9	25	70	73	73	76
d/D ¹	Direction (degree toward)	Maximum Current (cm•s ⁻¹)			
0.1	60	143	158	177	186
0.25	60	132	131	143	152
0.5	60	101	107	110	116
0.75	60	88	94	98	101
0.9	60	70	73	73	76
1. d/D is a ratio of depth to total depth at site.					
(Source: Evans-Hamilton, Inc., 1977a)					

Table 4.1-24 Annual and Seasonal Extreme Current Speeds at Thebaud, Glenelg, Alma, North Triumph

Return Period (years)	Residual Current Speed Extreme Plus Peak Tidal Speed (cm•s ⁻¹)				
	Near Surface				
	Winter	Spring	Summer	Autumn	Annual
1	98.8	126.8	121.5	98.7	138.3
10	111.4	142.2	130.7	108	150.3
20	115	146.7	133.3	110.6	153.8
30	117.1	149.3	134.8	112	155.8
50	119.6	152.5	136.6	113.8	158.3
100	123.1	156.8	139.1	116.2	161.6
Mid-Depth					
	Winter	Spring	Summer	Autumn	Annual
1	94.6	74.4	81.8	86.2	96.4
10	104.6	82.3	87.4	94.7	104.6
20	107.3	84.5	89	97	106.9
30	108.9	85.8	89.9	98.4	108.2
50	110.9	87.4	91	100	109.9
100	113.4	89.5	92.4	102.2	112.1
Near Bottom					
	Winter	Spring	Summer	Autumn	Annual
1	86.7	57.5	77.2	87.9	94.4
10	94.8	63.8	83.9	97.1	103.4
20	97	65.5	85.8	99.7	106
30	98.3	66.5	86.9	101.2	107.5
50	99.9	67.7	88.2	103.1	109.3
100	102	69.4	90	105.6	111.8

Return Period (years)	Residual Current Speed Extreme Plus Peak Tidal Speed ($\text{cm}\cdot\text{s}^{-1}$)	
	Near Surface	
	Near Surface = (0.254 ± 0.166) of water depth, below water surface Mid-depth = (0.591 ± 0.125) of water depth, below water surface Near-bottom = (0.872 ± 0.068) of water depth, below water surface Data Sources: Current meter measurements at the 4 sites (Thebaud, Alma, Glenelg, North Triumph)	
(Source: MacLaren Plansearch, 1989)		

Table 4.1-25 Extreme Current Profile for Given Return Periods -- Currents ($\text{cm}\cdot\text{s}^{-1}$)

d/D*	Return Period (years)				
	10	20	30	50	100
0	211	217	220	225	230
0.1	175	180	182	186	190
0.25	150	154	156	158	162
0.5	108	110	112	113	116
0.75	100	102	104	106	109
0.9	98	100	102	104	107
* d/D is ratio of depth to total depth below surface. Table does not include wave generated currents.					
(Source: MacLaren Plansearch, 1989)					

Extreme Currents Along Pipeline Corridor

Mobil undertook a six-week-long current measurement program at seven locations along the proposed pipeline corridor (shown in Figure 4.1-19) during October and November 1983. The current meters were located about 1 meter above the seabed. The meters measured current speed and direction, pressure, temperature and conductivity (Seaconsult, 1985).

The maximum observed current speed ranged 33 to 50 $\text{cm}\cdot\text{s}^{-1}$ and at most of the sites these maximum currents were associated with one of the three storm periods: October 26-27, November 22-23 and November 26-28. These maxima and their date of occurrence are presented in Table 4.1-26.

Extreme current speeds at these sites for various return periods are presented in Table 4.1-27.

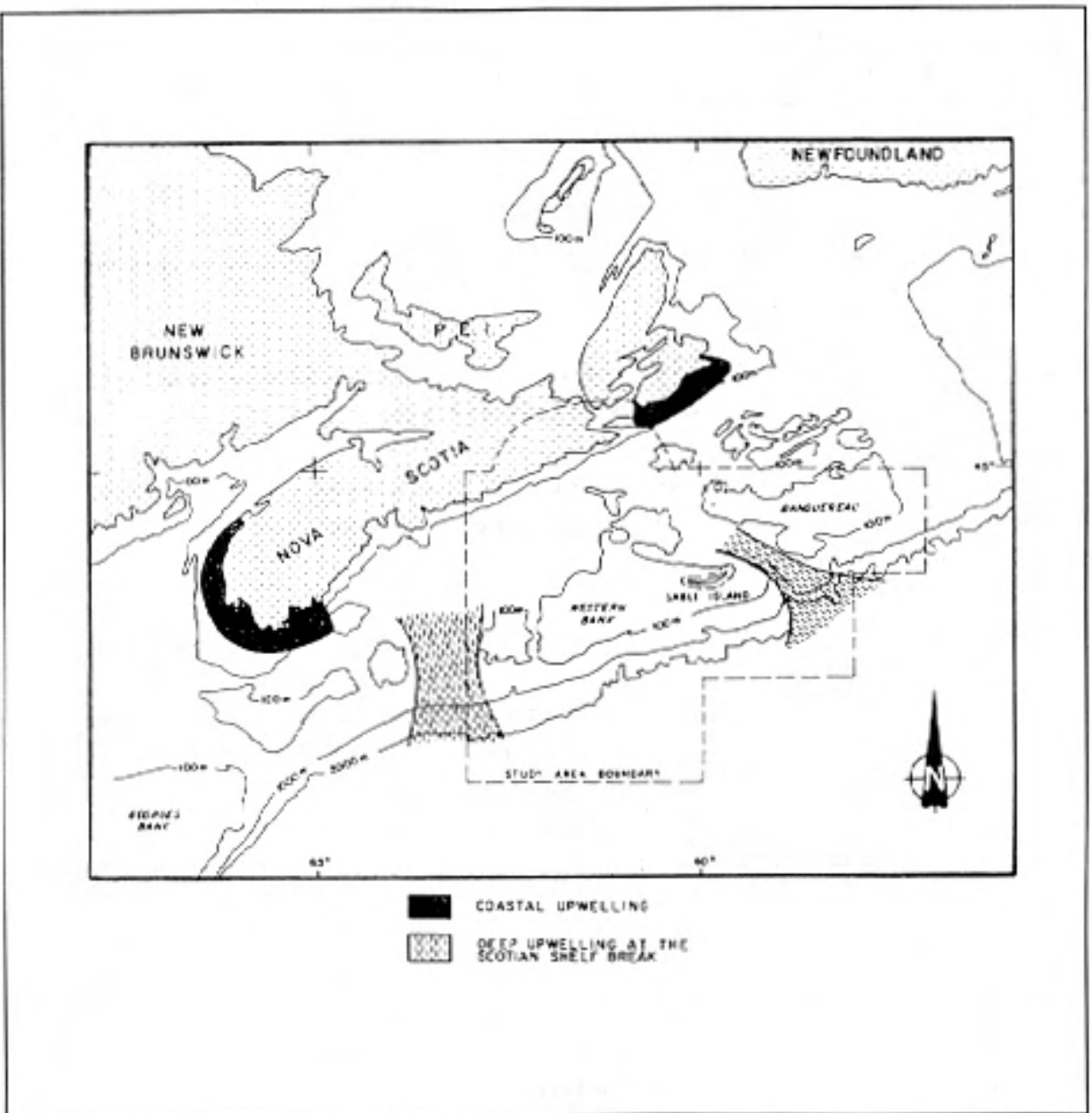


Figure 4.1-23 Upwelling Zones on the Scotian Shelf

Table 4.1-26 Summary of Total and Tidal Current Maxima

Site	Nominal Depth (m)	Maximum Total Current		Maximum Tidal Current	
		Speed ($\text{cm}\cdot\text{s}^{-1}$)	Date	Speed ($\text{cm}\cdot\text{s}^{-1}$)	Direction ($^{\circ}\text{T}$)
1	58	35.9	Nov. 26	14.3	116
2	136	34.8*	Oct. 30*	not available	not available
3	97	42.7	Nov. 23	10.5	244
4	116	33.4	Nov. 23	not available	not available
5	26	49.9*	Nov. 6*	26.7	68
6	59	35.9	Oct. 25	8.6	57
7	49	48.3	Nov. 26	14.9	237
*no concurrent significant storm event					
(Source: Seaconsult, 1984)					

Table 4.1-27 Extreme Current Speeds and Direction -- Pipeline Route Near Seabed (1 m above bottom)

Site	Parameter	Return Period (years)				
		1	10	25	50	100
1	Speed ($\text{cm}\cdot\text{s}^{-1}$)	40.3	44.7	46.3	47.5	48.7
	Direction ($^{\circ}\text{T}$)	250	250	250	250	250
2	Speed ($\text{cm}\cdot\text{s}^{-1}$)	36.6	41.7	43.6	45	46.4
	Direction ($^{\circ}\text{T}$)	235	235	235	235	235
3	Speed ($\text{cm}\cdot\text{s}^{-1}$)	54.7	60.4	62.7	64.1	65.7
	Direction ($^{\circ}\text{T}$)	250	250	250	250	250
4	Speed ($\text{cm}\cdot\text{s}^{-1}$)	47.6	55.2	58.2	60.4	62.6
	Direction ($^{\circ}\text{T}$)	328	328	328	328	328
5	Speed ($\text{cm}\cdot\text{s}^{-1}$)	67.2	79.9	84.8	88.5	92.1
	Direction ($^{\circ}\text{T}$)	250	250	250	250	250
6	Speed ($\text{cm}\cdot\text{s}^{-1}$)	56.5	66.8	70.9	0	0
	Direction ($^{\circ}\text{T}$)	250	250	250	250	250
7	Speed ($\text{cm}\cdot\text{s}^{-1}$)	48.3	52.5	54.1	55.2	56.3
	Direction ($^{\circ}\text{T}$)	250	250	250	250	250
(Source: Seaconsult, 1984)						

4.1.3.7 Upwelling

Upwelling defines processes by which deeper ocean waters are brought up to mix with surface water. These upwelled waters are usually rich in nutrients necessary to support extensive growth of phytoplankton which feed other marine organisms. Upwelling zones, therefore, are usually scenes of intense fishing activity because they are so biologically productive. Upwelling on the Scotian Shelf is of two types: shallow, along the coast; and deep, at the Scotian Break.

Coastal upwelling involves movement of warm surface water offshore by southwesterly winds combined with the effect of the earth's rotation. These surface waters are replaced by cooler subsurface waters moving upward, thus creating upwelling. Sinking or downwelling of coastal surface waters can also occur when winds are northeasterly.

Two persistent areas of coastal upwelling, at the southwestern extremity of the Nova Scotian mainland, and along the east coast of Cape Breton Island are shown in Figure 4.1-23.

Upwelling has also been found at the Scotian Shelf Break, where deep slope water is brought up to flow onto the shelf. Figure 4.1-23 shows the two deep upwelling areas at the Scotian Shelf Break near the study area; the Gully and the Scotian Gulf.

4.1.3.8 Water Level Variations

Sea-level changes in the study area can be described in terms of: astronomical tides; atmospheric pressure change; wind set-up or storm surge; and wave set-up. The contributions of each factor combine to determine the rise or fall in water level, and the timing and extent of these fluctuations. Exceptional circumstances, including the occurrence of tsunamis, which are generated by underwater seismic activity, can also have short-term effects on water elevations. Finally long-term effects of global warming may also affect water levels in the study area, particularly in the shallow coastal areas.

Astronomical Tides

Analyses of sea-level fluctuations in the study area have revealed that the most important component is the lunar semidiurnal (M2) component, which causes the familiar, twice-daily fluctuation in sea level observed on most of Canada's east coast. Because it is linked with the moon's orbit (or a lunar day of about 25 hours) which is a bit slower than the earth's rotation rate, the tide occurs about an hour later on each successive day. Interaction between the forces of the sun and moon causes the semidiurnal tide to vary in amplitude every 14 days.

The tidal heights at various locations in the study area are given in Table 4.1-28. The mean tidal range varies from 1.4 m at Halifax and Point Tupper to 1.1 m at Sable Island, and slightly less on Sable Island Bank. The maximum rise above chart datum (HHW) due to astronomical forcing is 2.4 m for Halifax and Point Tupper, 1.6 m for Sable Island and 1.5 for Sable Island Bank. These maxima occur at the peak of the tidal cycle (two cycles each day) during spring tides (twice each month).

Table 4.1-28 Tidal Heights (M) at Various Locations in the Study Area

Site	Height Above Chart Datum (m)				
	Large Tides		Average Tides		Mean
	HHW	LLW	HHW	LLW	Water Level
Sable Island	1.6	0	1.2	0.2	0.7
Country Harbour	2.0	0.1	1.7	0.3	1
Canso	2.4	0.4	2	0.8	1.4
Point Tupper	2.4	0.4	2.1	0.7	1.3
Port Hawkesbury	2.4	0.3	2	0.7	1.3
Halifax Harbour	2.4	0.3	2	0.6	1.3
All heights are measured above the chart datum.					
(Source: Canadian Hydrographic Service-- Hydrographic Charts)					

Storm Surges

Changes in water level caused by the combined effects of barometric pressure and wind drag on the water surface (i.e. wind set-up) are termed storm surges. The extreme conditions of high water are caused by deep low-pressure weather systems and onshore winds, which tend to pile water up against shore line and Sable Island.

Variation in sea level can also be caused by changes in atmospheric pressure, i.e. a drop in barometric pressure will cause an increase in water level.

A water-level change due to storm winds blowing over the surface is known as a storm surge. This wind-induced effect along with wave action accounts for most of the damage to coastal engineering works and beach areas. Maximum storm surges result from the extratropical storms passing through the study area from November to April.

Extreme values of surge due to wind stress forcing were calculated using a numerical hydrodynamic model and long-term records from tide gauges at coastal stations in the study area (Seaconsult, 1984, 1985). The results of previous studies (i.e. by Ocean Science and Engineering, Inc. (1971a,b), Evans-Hamilton (1977, 1981) and Seaconsult (1984)) which calculated the change in water elevation due to atmospheric pressure forcing and wind forcing are summarized in Table 4.1-29.

Table 4.1-29 Extreme Storm Surge Height at Selected Locations in the Study Area

Site	Return Period (years)			
	10	25	50	100
Halifax	0.49	0.54	0.58	0.62
Point Tupper	0.44	0.48	0.52	0.56
Country Harbour (at entrance)	0.48	0.53	0.57	0.61
Venture	0.49	0.54	0.58	0.62
Above values are the highest surge water level (m) above the mean sea level (MSL)				
(Source: Seaconsult, 1984, 1985)				

Tsunamis

The generation of long, low wave trains known as tsunamis is associated with underwater seismic activity such as slipping fault, submarine landslide or volcanic explosion. Tsunamis are rare on the Scotian Shelf and observed occurrences are of small magnitude. The tsunami effects are assumed to be substantially diminished through dissipation of their energy by sand banks, a common bathymetric feature in the study area. There is no recorded occurrence of a tsunami caused by slumping of surficial sediments on the Scotian Shelf. The Grand Banks earthquake of 1929 centred at 44.5°N, 57.25°W (approximately 200 km east of Sable Island) resulted in tidal-like waves with amplitudes up to 12 m in Burin Inlet, Newfoundland; yet at Halifax, Nova Scotia, where the waves travelled a similar distance, observed amplitudes over the shelf were only 0.5 m.

Seaconsult (1984, 1985) studied in detail the effect of tsunamis on the study area and provided the recommended extreme tsunami wave amplitude and corresponding currents at a number of locations in the study area (i.e. the Venture sites, Sable Island, Country Harbour and Canso area). The results are summarized in Table 4.1-30.

Wave Set-up

Wave set-up is the superelevation of the mean water level caused by wave action. Within the study area it will, during storms, affect the water elevation along the coast of Nova Scotia and the seaward side of Sable Island. For the design of offshore structures (deck free board) the wave crest height is added to the tidal and storm water level as described in later section.

Table 4.1-30 Extreme Tsunami Wave Amplitudes and Current Speeds

Parameter	Return Period (Years)		
	25	50	100
OFFSHORE -- VENTURE SITE			
Water Level (m) above MSL	0.54	0.58	0.62
Depth - Average Current ($\text{cm}\cdot\text{s}^{-1}$)	7	18	43
COUNTRY HARBOUR			
a) the northeast side of harbour			
- water level (m) above MSL	0.26	0.53	1.21
- current ($\text{cm}\cdot\text{s}^{-1}$)	25	54	125
b) at the southwest side			
- water level (m) above MSL	0.42	0.92	2.17
- currents ($\text{cm}\cdot\text{s}^{-1}$)	17	36	93
MELFORD POINT, STRAIT OF CANSO			
- Tsunami Level (m) above MSL	0.23	0.53	1.21
- Current ($\text{cm}\cdot\text{s}^{-1}$)	10	24	56
(Source: Seaconsult, 1984, 1985)			

Maximum Water Levels

Although short-term variations in sea level are due primarily to astronomical tides and storm surges, it does not necessarily follow that the highest levels coincide with the peak tidal potential. It is possible to determine the height of these maximum levels known as the storm still-water levels, by adding the heights of the maximum storm height and the maximum astronomical tide. Maximum wave crest height and tsunami level may be added to the storm still-water level plus an allowance for free-board (or air gap) to determine the design height of the offshore platforms.

Global Warming Sea-Level Rise

Numerous predictions of sea-level rise due to global warming have been made during the past decade (NRC, 1979; Shaw, Taylor and Forbes, 1992). The prediction of IPCC working group (World Meteorological Organization -- WMO, 1990) was that the mean sea-level rise would increase by 16-32 cm (with mean increase of 20 cm) by the year 2030; and by 33-75 cm (mean increase of 45 cm) by the year 2070. There are doubts that these predictions would apply across the globe.

The impact of a global warming sea-level rise may be particularly significant in Nova Scotia. The long-term tide gauge records at a number of locations along the N.S. coast have shown sea level has been rising over the past century. The water level data from the Halifax Harbour tide gauge (since 1851) have shown a rate of sea-level rise of about 3.18 mm/yr, based on records from 1896 to 1990, and of 3.63 mm/yr based on data from 1920 to 1990 (Shaw, Taylor and Forbes, 1992).

The estimated increase in water level due to global warming could vary from 0.20 to 1.4 m by the middle of the next century (Environment Canada, 1988). For the design of coastal and offshore structures, an estimated rise in water level, due to global warming, of 0.5 m to may be assumed for the proposed project life (25 years). However, there was no strong scientific support for such an estimate given in the literature.

4.1.3.9 Wave Climate

Designing structures and planning operations for SOEP must incorporate an understanding of the wave climate in the area. To define the wave climate fully requires a knowledge of both normal and extreme conditions. The main descriptive characteristics of sea state are maximum wave height (the greatest vertical distance between crest and adjacent trough), significant wave height (the average height of the highest one-third of all waves in a given record), and the corresponding maximum wave and significant wave periods. Wave direction and energy spectra are also required for both design and operation purposes.

Waves can be described in two ways. The significant wave method uses a single wave - the significant wave - to represent a sea state at the time of observation, and is used to develop long-term wave statistics. The spectral method gives an energy distribution over different frequency bands developed from instrumental records or model predictions, and provides a detailed short-term description of the sea state.

Wave Data and Wave Studies

Three data sources are considered: visual observation (particularly from ships-of-opportunity), direct measurements and hindcasting techniques. Of the three sources, visual observation is the least reliable or consistent, as it depends on the individual observer's training and skill and is often biased toward fair weather conditions. It is therefore only used in the absence of other data sources.

Direct measurements of sea state at various drilling locations in the study area are used for developing statistics of normal and, with sufficient data, extreme conditions. Analysis of these data provides a general description of the sea state, but these data cannot be used to give accurate extreme values for recurrence intervals longer than five years because each instrument usually is on station near an oil rig for only a few months at a time. MEDS has also maintained a long-term wave recording station offshore Osborne Head, Nova Scotia since 1970. This station provides valuable long-term records suitable for providing wave climate (both normals and extremes) which represents the coastal area of Nova Scotia. It can provide an excellent representation of the wave conditions outside Country Harbour and its approaches.

Hindcast models generate a wave climate based on wind information and are considered better for analysis of extreme events. Hindcast data, when produced by an accurate, reliable model, are considered to be appropriate for design if they cover at least 20 years and have been verified with at least one year of direct wave measurements (Swail, 1982). This can be substituted by hindcasting a sufficient number of most severe storms that occurred over the last 20-30 years and apply a suitable extreme value analysis on the hindcast storm parameters.

A number of wave hindcasting studies were conducted off the east coast of Canada and USA, covering the study area. These include the U.S. Army Corps of Engineers, Waterways Experimental Station (WES) 20-year wind/wave hindcast study covering the entire North Atlantic Ocean; The U.S. Navy Spectral Ocean Wave Model (SOWM) 20-year hindcast study; and most recently, the ODGP (Ocean Data Gathering Program) spectral ocean wave model which was developed by Oceanweather Inc. in the mid-1970s and has been widely used since the mid-1980s for providing reliable wave predictions in the study area.

The WES and SOWM models were evaluated for their use in Canadian waters off the east coast and were found to be deficient in representing wave climate of the area (Resio, 1982; MacLaren Plansearch and Oceanweather Inc., 1985; Eid and Cardone, 1987). The ODGP model was used for storm predictions and design criteria for the Hibernia and Venture projects for Mobil (1985). The ODGP three-year hindcast database (Eid et al., 1989) and the AES-PERD funded extreme hindcast study (Canadian Climate Centre, 1991) together with the buoy measured data (from MEDS and NOAA) provided the basic data set that was used in this report.

The above hindcast models assumed deep water conditions, therefore these wave data must be modified to account for the shallow water effects (i.e. refraction and shoaling) and the sheltering effects of Sable Island and land masses before being applied to specific sites in the study area. Evans Hamilton, Inc. (1981, 1982) and Seaconsult (1984, 1985), under contract to Mobil, have carried out these modifications for a number of locations in the Venture area, along the pipeline route, and at the proposed marine terminals. Recently MacLaren Plansearch Limited (1989) provided wave climate at Thebaud, Glenelg, Alma and North Triumph, for Shell Resources Canada Ltd., and at Cohasset-Panuke sites for LASMO (1990). The results of these studies are presented in the following sections.

Wave Climate Statistics

The wave climate associated with the study area, including Sable Bank, Nova Scotia coast and the sites of the SOEP production platforms and landfall/terminal, is summarized below.

During the winter, the predominant wave direction in the corridor is from the west, southwest and northwest. Late fall and winter storms generate median wave heights greater than 2 m for the months of November through March. From April through October, the wind direction is less consistent with the dominant direction from the southwest, and the median wave height from May through August is slightly over 1 m. Winter and spring are the periods of maximum occurrence and duration of waves with a height of greater than 2.0 m.

A description of the normal wave climate was developed for selected locations in the study area. The wave climate statistics are provided for two areas which are identified as typical of conditions in the corridor around Sable Island and the coastal area: (1) Sable Island Bank, and (2) coastal area. The following statistics represent deep water wave climate.

Normal Conditions -- Deep Water Waves

The results of the wave climate statistics for the Sable Island Bank (outer Scotian Shelf area) and the N.S. coastal area are presented in Tables 4.1-31 and 4.1-32 and in Figures 4.1-24 and 4.1-25 respectively (MacLaren Plansearch Limited, 1991).

Shallow Water Wave Modification

The wave climate information presented in previous sections represent deep water wave conditions. As waves move from a deep-water seaway to a shallow-water area, their height and direction can change. This modification process is apparent when the water depth becomes less than half the length of the deep-water wave. Refraction, or the change in direction of a wave in response to decreasing depth, results in a convergence of waves for convex bottom contours, and a divergence for concave bottom contours. In regions where wave rays converge, wave energy is focused and wave height increases; conversely, when wave rays diverge, wave height is reduced. This wave height amplification (due to focusing) can be quantified if it is assumed that no energy transfer occurs along wave crests. The distance between wave rays can then be used to calculate a refraction coefficient (K_r). The bottom friction is quantified by establishing a shoaling coefficient (K_s) which is a function of wave period and water depth. The refraction coefficient and the shoaling coefficient are then multiplied together to yield an amplification (K) factor. The wave height at any point of interest can now be approximated by multiplying the amplification factor by the initial height of the incident deep water wave.

Wave ray (refraction) analyses were carried out by various groups, contracted by Mobil and Shell (i.e.: Evans-Hamilton, 1977; Seaconsult, 1984/1985; MacLaren Plansearch, 1989) to provide site-specific wave information at various locations in the study area (i.e. at the offshore fields and Country Harbour).

Table 4.1-31 Wave Climate Statistics - Sable Island Bank
Significant Wave Height (m) Monthly Statistics

	Mean	Std Dev	Med	Max	Min	Upper 95% Limit	Lower 5% Limit	Most Freq Dir from	Num Obs
January	3.1	1.6	2.6	8.7	0.1	6.1	1.1	--	1268
February	2.6	1.4	2.3	8.5	0.4	5.2	0.9	--	1538
March	2.6	1.4	2.2	7.8	0.4	5.3	0.9	--	1969
April	2.2	1.1	2.0	7.2	0.3	4.2	0.7	--	1705
May	1.5	0.8	1.3	6.2	0.2	3.1	0.5	--	2063
June	1.4	0.7	1.2	5.1	0.2	2.8	0.5	--	2076
July	1.3	0.6	1.2	8.8	0.3	2.4	0.6	--	2125
August	1.3	0.6	1.1	4.6	0.4	2.3	0.5	--	1815
September	1.6	0.8	1.4	6.0	0.4	3.1	0.7	--	1482
October	2.0	1.1	1.5	8.7	0.0	4.0	0.7	--	1741
November	2.4	1.3	2.1	8.6	0.3	4.9	0.8	--	1575
December	2.7	1.4	2.4	8.4	0.5	5.5	1.0	--	1374
Annual	2.0	1.2	1.6	8.8	0.0	4.4	0.6	--	20731

Source: Waverider Measured Data; MPL (1991)

Annual Percentage Frequency of Occurrence of Wave Height by Direction

Sig. Wave Height(m)	Direction - coming from									
		N	NE	E	SE	S	SW	W	NW	Total
0.0 - <0.5	0	0	0	0	0.1	0.4	0.2	0.1	0.9	41
0.5 - <1.0	0.6	0.7	0.5	0.7	0.7	2.8	2.1	0.7	8.8	285
1.0 - <1.5	1.6	0.9	1.5	1	1.3	4.6	3.6	1.9	16.3	716
1.5 - <2.0	1.4	1	1	0.9	1.6	6.3	3.7	2.2	18.1	795
2.0 - <2.5	1	1.2	1	0.5	1.4	5.2	3.6	2.1	16.2	710
2.5 - <3.0	0.8	0.6	0.7	0.7	0.9	3.8	3.5	1.6	12.6	552
3.0 - <3.5	0.7	0.6	0.8	0.4	0.7	2.3	2.2	1.4	9.1	399
3.5 - <4.0	0.3	0.5	0.4	0.3	0.8	2	1.7	0.8	6.6	289
4.0 - <4.5	0.2	0.5	0.4	0.2	0.5	0.5	1.1	0.5	4	176
4.5 - <5.0	0.1	0.3	0.1	0.1	0.6	0.6	1	0.3	3.1	134
5.0 - <5.5	0.1	0.2	0.1	0	0.2	0.4	0.5	0.1	1.6	68
5.5 - <6.0	0.1	0.1	0.1	0	–	0.2	0.3	0	0.9	40
6.0 - <6.5	0	0.2	0.1	–	–	0.3	0.2	0.1	0.8	36
6.5 - <7.0	0	0.1	0	–	–	0.1	0.2	0.1	0.5	24
7.0 - +	0	0	0	–	–	0.1	0.2	0.1	0.4	19
Total	7	7.1	6.8	4.9	8.5	29.5	24.1	12.1	100	4384

Source: ODGP Model Hindcast, MPL (1991)

Table 4.1-31 (cont'd)
Significant Wave Height Statistics
Annual Occurrence of Significant Wave Height and Wind Speed

Sig. Wave Height (m)	Wind Speed (Knots)												Total	% Occur
	0-<5	5-<10	10-<15	15-<20	20-<25	25-<30	30-<35	35-<40	40-<45	45-<50	50-<55	>50		
0.0 - <0.5	22	19	—	—	—	—	—	—	—	—	—	—	41	0.9
0.5 - <1.0	69	179	125	12	—	—	—	—	—	—	—	—	385	8.8
1.0 - <1.5	59	198	303	133	18	5	—	—	—	—	—	—	716	16.3
1.5 - <2.0	50	127	257	272	65	18	6	—	—	—	—	—	795	18.1
2.0 - <2.5	28	83	170	224	165	29	10	1	—	—	—	—	710	16.2
2.5 - <3.0	8	35	104	153	173	53	21	5	—	—	—	—	552	12.6
3.0 - <3.5	9	20	38	96	121	89	19	7	2	—	—	—	399	9.1
3.5 - <4.0	4	10	22	46	71	97	321	4	3	—	—	—	289	6.6
4.0 - <4.5	2	8	8	22	40	50	29	7	8	2	—	—	176	4
4.5 - <5.0	1	6	6	19	14	31	35	15	4	2	1	—	134	3.1
5.0 - <5.5	—	—	1	4	8	18	19	9	6	2	1	—	68	1.6
5.5 - <6.0	—	—	1	1	5	4	17	7	4	—	—	1	40	0.9
6.0 - <6.5	—	—	—	—	3	5	8	13	6	—	—	1	36	0.8
6.5 - <7.0	—	—	—	—	—	3	3	8	5	4	1	—	24	0.5
7.0 - <7.5	—	—	—	—	—	—	2	4	1	1	1	2	11	0.3
7.5 - <8.0	—	—	—	—	—	—	1	2	1	1	—	—	5	0.1
8.0 - + m	—	—	—	—	—	—	—	—	1	—	1	1	3	0.1
Total	252	685	1033	982	683	402	202	82	41	12	5	5	4384	
% Occurrence	5.7	15.6	23.6	22.4	15.6	9.2	4.6	1.9	0.9	0.3	0.1	0.1		100

Source: ODGP Wave Hindcast, MPL (1991)

Annual Occurrence of Significant Wave Height (m) and Peak Period

Sig Wave Height (m)	Peak Period (seconds)																			Total	% Occur
	<4	4>5	5>6	6->7	7>8	8>9	9>10	10	11	12	13>14	14>15	15>16	16>17	17>18	18>19	19>20	>20			
0.0-<0.5	27	15	21	29	46	62	23	6	5	5	12	--	9	--	2	--	2	--	264	1.3	
0.5-<1.0	199	272	453	587	600	642	347	112	70	54	66	2	36	2	10	--	--	--	3452	16.7	
1.0>1.5	39	380	799	941	970	111	633	170	79	49	46	3	38	4	5	1	--	--	5266	25.4	
1.5>2.0	--	73	497	540	634	857	757	223	106	36	30	1	12	--	2	--	--	--	3668	18.7	
2.0>2.5	1	2	158	439	405	551	649	230	138	40	19	-	--	--	1	--	--	--	2633	12.7	
2.5>3.0	--	1	24	166	257	364	478	249	150	55	10	--	1	--	--	--	--	--	1755	8.5	
3.0>3.5	--	--	1	46	149	237	344	204	132	51	16	--	4	--	1	--	--	--	1185	5.7	
3.5>4.0	--	--	--	8	43	113	227	165	124	66	14	--	2	--	--	--	--	--	762	3.7	
4.0>4.5	--	--	--	1	17	70	141	108	95	63	19	--	--	--	--	--	--	--	514	2.5	
4.5>5.0	--	--	--	--	5	39	95	64	86	52	12	2	--	--	--	--	--	--	355	1.7	
5.0>5.5	--	--	--	--	2	13	43	42	56	47	22	--	2	--	--	--	--	--	224	1.1	
5.5>6.0	--	--	--	--	1	4	28	32	44	26	22	1	4	--	--	--	--	--	162	0.8	
6.0>6.5	--	--	--	--	--	--	25	27	20	35	13	--	2	--	--	--	--	--	131	0.6	
6.5>7.0	--	--	--	--	--	--	12	14	17	9	15	--	6	--	--	--	--	--	71	0.3	
7.0>7.5	--	--	--	--	--	--	5	6	9	10	7	--	1	--	--	--	--	--	46	0.2	
7.5>8.0	--	--	--	--	--	--	--	4	2	8	3	--	1	--	--	--	--	--	22	0.1	
8.0+ m	--	--	--	--	--	--	--	--	7	9		--	--	--	--	--	--	--	19	0.1	
Total	266	743	1953	2857	3129	4063	3807	1656	1140	615	345	9	118	6	21	1	2	0	20731		
% Occurrence	1.3	3.6	9.4	13.8	15.1	19.6	18.4	8	5.5	3	1.7	0	0.6	0	0.1	0	0	0		100.0	

Source: Waverider Measured Data; MPL (1991)

**Table 4.1-32 Wave Climate Statistics- Nova Scotia Coastal Area
Significant Wave Height Monthly Statistics - Waverider**

	Mean	Std Dev	Med	Max	Min	Upper 95% Limit	Lower 95% Limit	Most Freq Dir from	Num
January	1.6	1.1	1.3	7.6	0.0	3.8	0.4	--	3974
February	1.6	1.1	1.3	7.9	0.0	3.7	0.4	--	3281
March	1.6	0.9	1.3	5.9	0.1	3.4	0.4	--	3658
April	1.5	0.9	1.2	6.2	0.0	3.2	0.4	--	3913
May	1.2	0.6	1.0	4.9	0.0	2.2	0.4	--	4366
June	1.1	0.6	0.9	4.4	0.1	2.1	0.3	--	4095
July	1.0	0.4	0.9	4.3	0.1	1.8	0.4	--	4483
August	0.9	0.5	0.8	4.1	0.0	1.7	0.3	--	4526
September	1.0	0.6	0.9	4.5	0.1	2.1	0.4	--	4244
October	1.3	0.8	1.0	5.9	0.1	2.8	0.4	--	4415
November	1.5	0.9	1.2	7.2	0.1	3.3	0.4	--	4005
December	1.6	1.0	1.3	7.7	0.0	3.7	0.4	--	4407
Annual	1.3	0.8	1.1	7.9	0.0	3.0	0.4	--	49367

Source: Waverider Measured Data; MPL (1991)

**Percentage Frequency of Occurrence by Direction
Annual- ODGP**

Sig Wave Height (m)	Direction - coming from									Num Obs
	N	NE	E	SE	S	SW	W	NW	Total	
0.0 - <0.5	--	0.0	0.1	0.1	0.0	0.6	0.6	0.1	1.6	70
0.5 - <1.0	1.0	0.8	1.0	1.0	1.0	3.6	3.9	1.6	13.8	606
1.0 - <1.5	1.4	0.9	1.8	1.2	1.7	6.6	5.4	2.2	21.2	931
1.5 - <2.0	1.1	1.0	1.5	1.3	1.6	5.9	5.0	2.4	19.8	869
2.0 - <2.5	0.6	0.8	1.2	0.5	1.3	5.0	4.2	1.9	15.6	682
2.5 - <3.0	0.4	0.8	1.0	0.9	0.8	2.7	2.4	1.4	10.3	450
3.0 - <3.5	0.3	0.5	0.5	0.5	0.7	1.8	1.9	0.7	6.8	299
3.5 - <4.0	0.1	0.6	0.5	0.5	0.7	0.7	1.1	0.3	4.6	202
4.0 - <4.5	0.1	0.3	0.4	0.3	0.4	0.5	0.6	0.1	2.7	117
4.5 - <5.0	0.1	0.1	0.2	0.1	0.2	0.4	0.4	0.1	1.5	67
5.0 - <5.5	--	0.2	0.1	--	0.3	0.3	0.2	0.0	1.1	47
5.5 - <6.0	0.0	0.1	0.1	--	--	0.1	0.1	0.0	0.4	17
6.0 - <6.5	0.0	--	0.1	0.0	--	0.1	0.1	--	0.3	14
6.5 - <7.0	--	0.0	0.1	--	--	--	--	--	0.1	4
7.0 - +	--	0.1	--	--	--	0.1	0.0	--	0.2	9
Total	5.0	6.3	8.6	6.3	8.7	28.3	25.9	10.8	100.0	4384

Source: ODGP Model Hindcast, MPL (1991)

Table 4.1-32 (cont'd)
Significant Wave Height Statistics
Annual Occurrence of Significant Wave Height and Wind Speed

Sig. Wave Height (m)	Wind Spdd (kts)													
	0-<5	5-<10	10	15	20	25	30	35	40	45	50	>5	Total	% Occur
0.0 - <0.5	35	35	—	—	—	—	—	—	—	—	—	—	70	1.6
0.5 - <1.0	86	278	227	14	1	—	—	—	—	—	—	—	606	13.8
1.0 - <1.5	67	203	403	217	36	5	—	—	—	—	—	—	931	21.2
1.5 - <2.0	33	101	220	32	132	21	10	—	—	—	—	—	869	19.8
2.0 - <2.5	20	38	109	224	218	47	24	2	—	—	—	—	682	15.6
2.5 - <3.0	12	24	49	74	154	100	21	11	5	—	—	—	450	10.3
3.0 - <3.5	2	16	19	39	80	88	37	15	2	1	—	—	299	6.8
3.5 - <4.0	4	6	12	21	34	53	46	17	6	3	—	—	202	4.6
4.0 - <4.5	3	4	3	21	7	28	24	14	10	3	—	—	117	2.7
4.5 - <5.0	—	3	—	6	4	14	19	8	7	3	3	—	67	1.5
5.0 - <5.5	—	2	—	3	8	7	13	5	6	2	1	—	47	1.1
5.5 - <6.0	—	—	—	1	—	2	2	6	1	—	3	2	17	0.4
6.0 - <6.5	1	—	—	—	—	1	2	5	2	—	2	1	14	0.3
6.5 - <7.0	—	—	—	—	—	—	—	2	1	1	—	—	4	0.1
7.0 - <7.5	—	—	—	—	—	—	1	—	2	—	1	—	4	0.1
7.5 - <8.0	—	—	—	—	—	—	—	1	1	—	—	1	3	0.1
8.0 - + m	—	—	—	—	—	—	—	—	1	—	—	1	2	0
Total	263	710	1042	972	674	366	199	86	44	13	10	5	4384	100
% Occur	6	16.2	23.8	22.2	15.4	8.3	4.5	2	1	0.3	0.2	0.1		

Annual Occurrence of Significant Wave Height and Peak Period
Waverider

Sig. Wave Height (m)	Peak Period (seconds)																			Total	% Occur
	<4	4->5	5->6	6->7	7->8	8->9	9->10	10->11	11->12	12->13	13->14	14->15	15->16	16->17	17->18	18->19	19->20	>20			
0.0-<0.5	550	173	213	283	469	725	667	223	224	145	147	-	117	-	18	-	18	4	3976	8.1	
0.5-<1.0	1253	1067	1450	1777	2528	3647	3112	1019	600	320	240	8	153	-	47	-	12	-	17233	34.9	
1.0->1.5	199	833	1608	1222	1559	2910	2955	1114	618	262	92	1	45	1	10	-	-	-	13429	27.2	
1.5->2.0	5	89	690	755	657	1171	1741	806	540	257	61	5	19	-	1	-	-	-	6797	13.8	
2.0->2.5	3	5	148	440	413	526	889	525	419	169	54	-	3	3	2	-	1	-	3605	7.3	
2.5->3.0	1	-	11	165	213	250	423	317	251	144	34	1	9	-	-	-	-	-	1829	3.7	
3.0->3.5	-	-	-	23	98	149	234	203	209	128	42	-	1	-	-	-	-	-	1087	2.2	
3.5->4.0	-	1	-	3	37	94	133	95	119	87	39	-	6	-	2	-	-	-	616	1.2	
4.0->4.5	-	1	-	-	9	46	84	50	72	64	31	-	3	-	-	-	-	-	365	0.7	
4.5->5.0	-	-	-	-	1	16	47	26	38	46	22	-	7	-	-	-	-	-	203	0.4	
5.0->5.5	-	-	-	-	-	2	20	14	16	37	25	-	3	-	-	-	-	-	117	0.2	
5.5->6.0	-	-	-	-	-	-	10	13	14	17	9	1	2	-	-	-	-	-	66	0.1	
6.0->6.5	-	-	-	-	-	-	5	6	5	10	4	-	-	-	-	-	-	-	30	0.1	
6.5->7.0	-	-	-	-	-	-	-	1	2	-	-	-	1	-	-	-	-	-	4	0.0	
7.0->7.5	-	-	-	-	-	-	-	1	2	1	1	-	-	-	-	-	-	-	5	0.0	
7.5->8.0	-	-	-	-	-	-	-	-	4	-	1	-	-	-	-	-	-	-	5	0.0	
8.0-+m	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0	
Total	2011	2169	4120	4668	5984	9536	10320	4413	3143	1687	802	16	379	4	80	0	31	4	49367		
% Occur	4.1	4.4	8.3	9.5	12.1	19.3		8.9	6.4	3.4	1.6	0.0	0.8	0.0	0.2	0.0	0.1	0.0		100.0	

Source: Waverider Measured Data; MPL (1991)

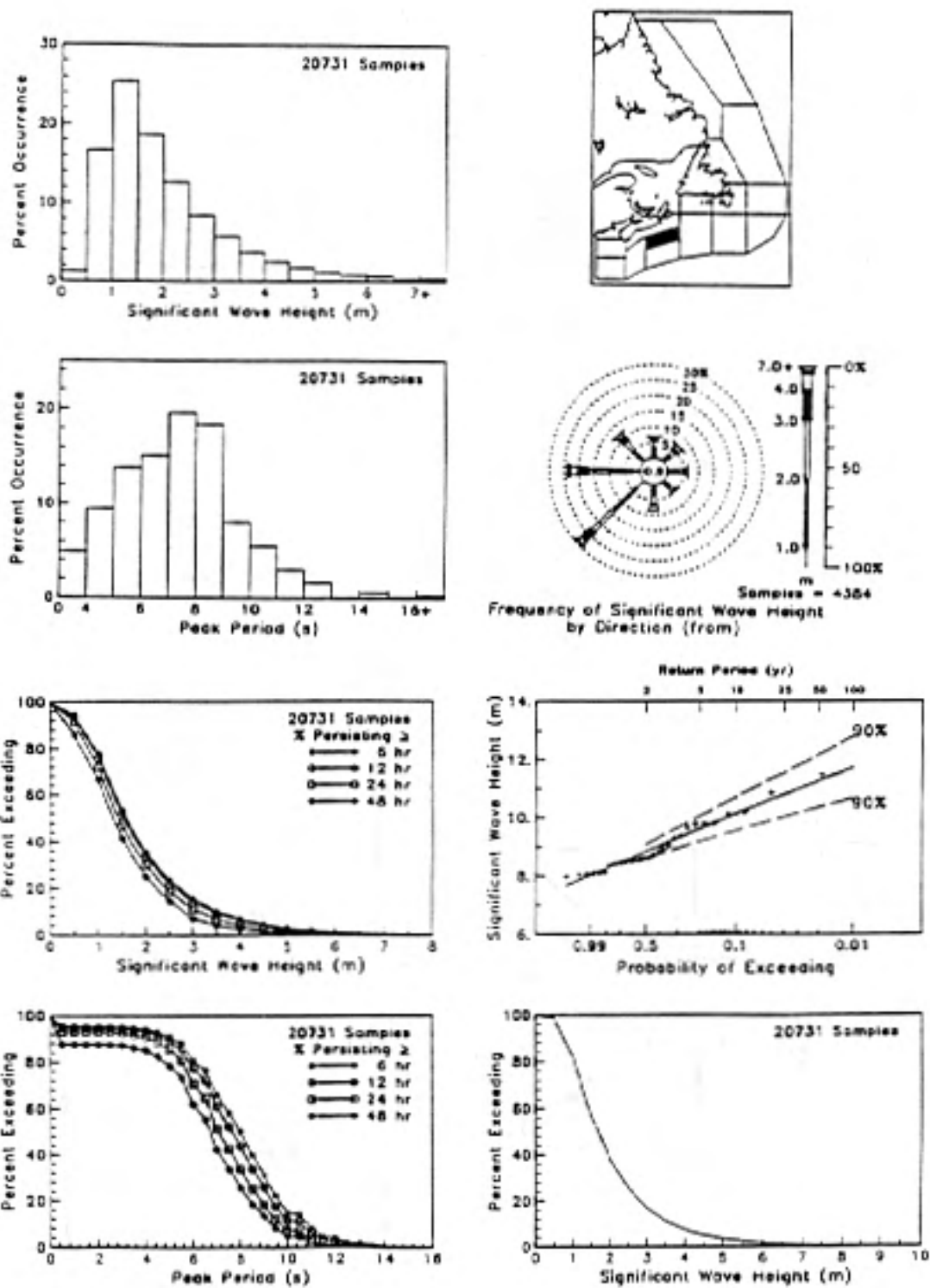


Figure 4.1-24 Annual and Monthly Wave Climate Statistics - Sable Island
(Source: MacLaren Plansearch, 1991)

MONTHLY WAVE STATISTICS
 EAST COAST AREA — SABLE
 FREQUENCY OF SIGNIFICANT WAVE HEIGHT BY DIRECTION (FROM)

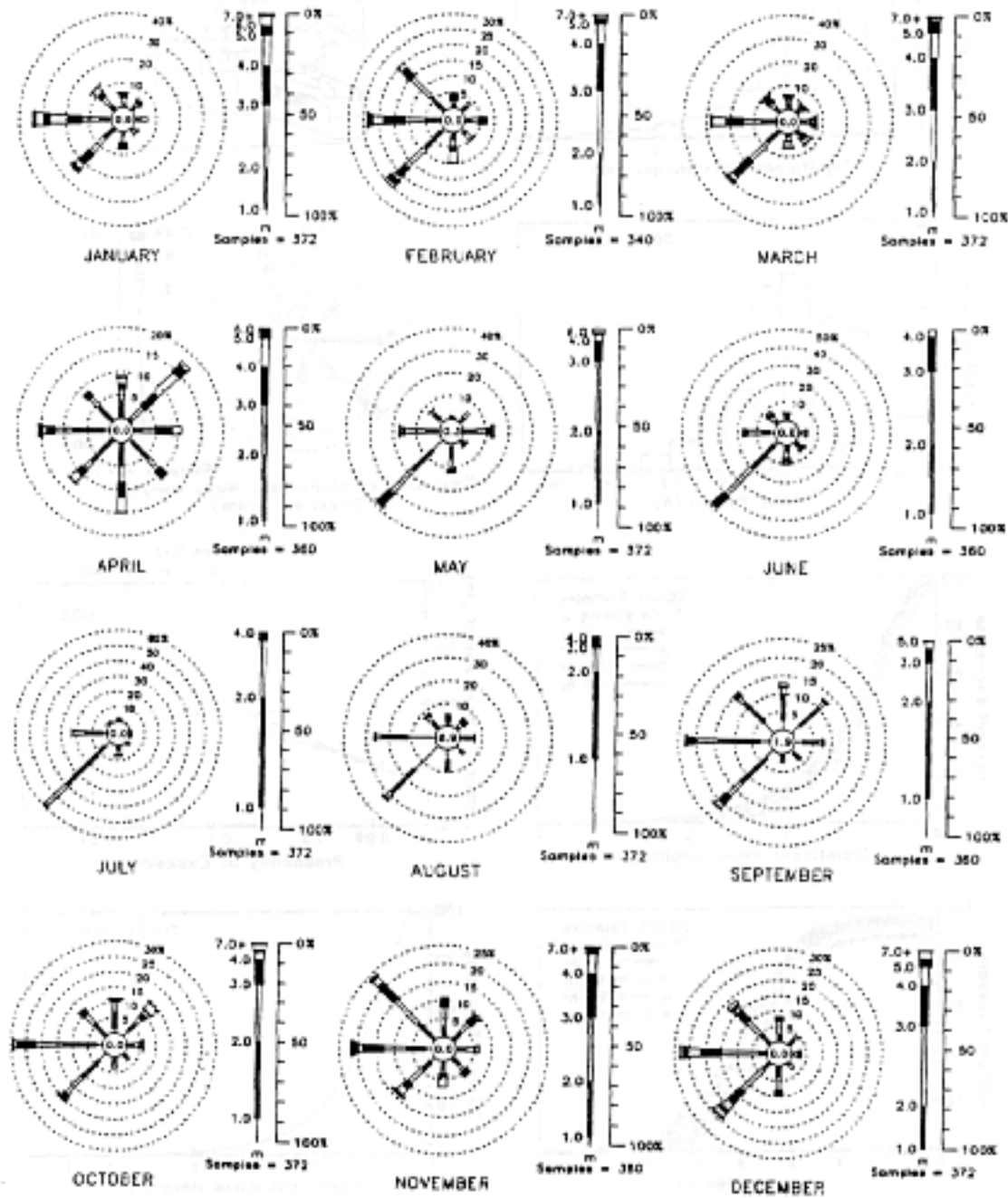


Figure 4.1-24 (cont'd)

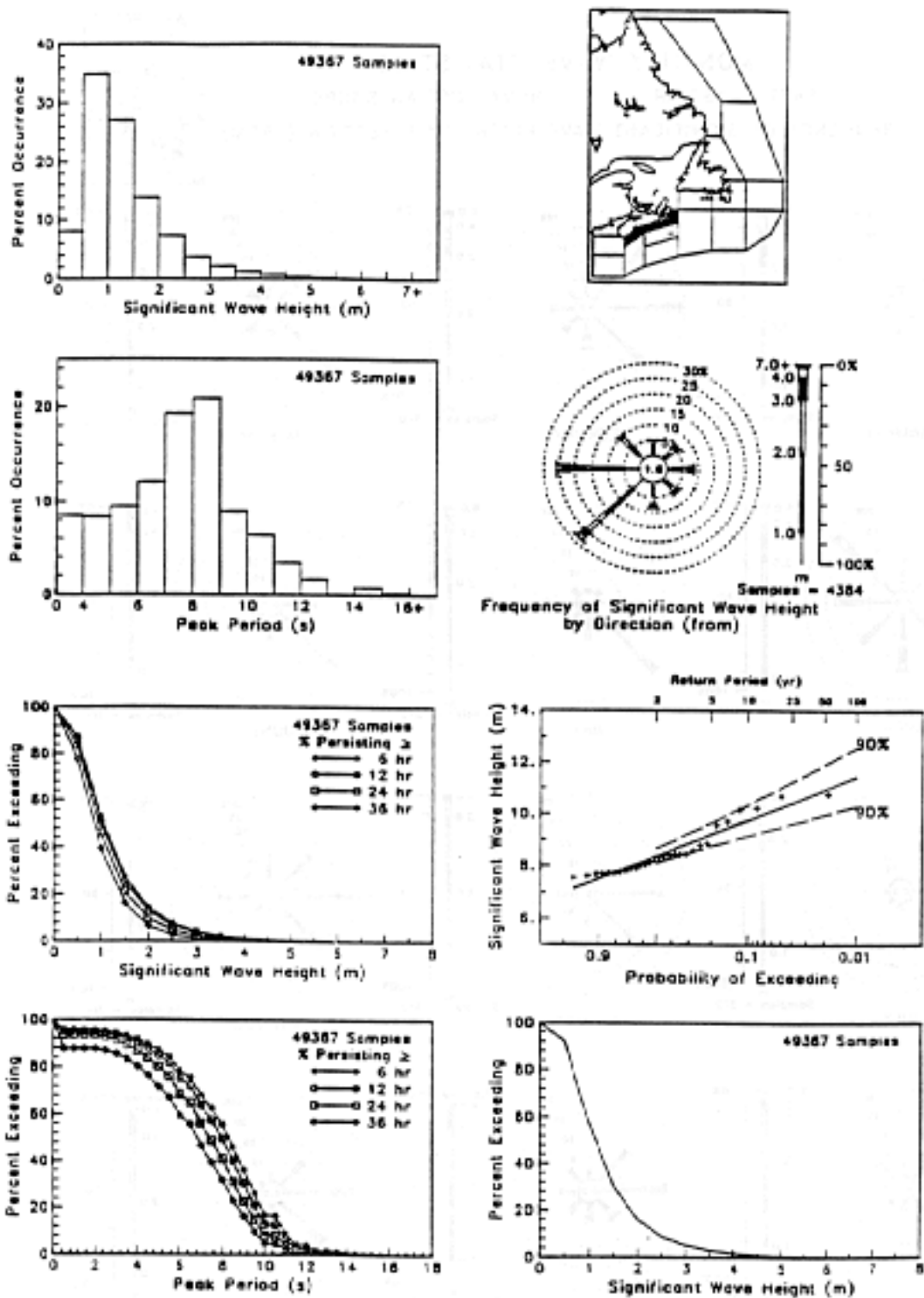
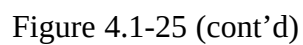


Figure 4.1-25 Annual and Monthly Wave Climate Statistics - N.S. Coast
(Source: MacLaren Plansearch, 1991)



A summary of recommended amplification factors for various sites in the study area is provided in Tables 4.1-33 for Venture sites; Table 4.1-34 for Alma, Glenelg, North Triumph and Thebaud; and in Table 4.1-35 for Country Harbour.

Table 4.1-33 Shallow Water Amplification Factor (K) for Venture Site

Site	Depth (m)	K_s	K_r	$K_s K_r$	$(K_s K_r)$ eff
Wave Period T = 7.7 s					
B-13	23	0.93	1.00	0.93	0.93
B-43	55	1.00	1.00	1.00	
Waver Period T = 12.8 s					
B-13	23	0.94	0.96	0.90	0.98
B-43	55	0.92	1.00	0.92	
(Source: Seaconsult, 1989)					

K_s = shoaling coefficient

K_r = refraction coefficient

$K = K_s K_r$ = Amplification factor

$(K_s K_r)_{\text{eff}}$ = effective average factor

Table 4.1-34 Shallow Water Amplification Factors for Alma, Glenelg, North Triumph, and Thebaud. (Weighted Average K Factors)

Incident Wave Direction	Alma	Glenelg	North Triumph	Thebaud
N (0°)	0.35	0.25	0.25	0.65
NE (45°)	0.15	0.25	0.36	0.30
E (90°)	0.98	0.99	0.99	0.65
SE (135°)	0.99	1.00	1.00	0.88
S (180°)	1.00	1.00	1.00	0.91
SW (225°)	0.98	1.00	1.00	0.92
W (270°)	0.89	0.75	0.60	1.20
NW (315°)	0.85	0.20	0.15	0.25
(Source: MacLaren Plansearch, 1989)				

Table 4.1-35 Shallow Amplification Factor (K) for Country Harbour

Site	d (m)	T (s)	k _r	k _s
Harbour Entrance	28.3	5	4.56	1
		7	2.37	0.97
		9	1.54	0.92
		11	1.15	0.91
		13	0.93	0.93
		15	0.78	0.95
		17	0.67	0.99
(Source: Seaconsult, 1985)				

With deepwater wave data corrected for sheltering, shoaling, refraction and breaking, the extreme values of the wave heights for given recurrence intervals (e.g. 50 and 100 years) or probability of being exceeded (e.g. 0.02 and 0.01) can be determined for specific locations as shown in the following section.

Extreme Wave Criteria

Values of extreme wave height, the associated wave period, and the elevation of the wave crests above mean water level are necessary criteria for the design and operation of the marine structures. These wave parameters are expressed in terms of a return period (or probability of being exceeded). For instance, the 100-year return value is expressed as the height which has a 1 per cent probability of being exceeded in any given year. Directional information on extreme waves is useful in calculating the extreme loading forces on the structure. Spectral wave energy values are also required for the design of offshore structures.

Both historical observations and hindcast techniques have been used to determine extreme wave height values for the project area.

A number of wind and wave hindcast studies were carried out to provide an estimate of extreme wave climate in the study area as part of Mobil Venture Development project (e.g. Evans-Hamilton Inc., 1981, 1982; Seaconsult, 1984, 1985). The U.S. Army Waterways Experimental Station (WES) hindcast study and the U.S. Navy's spectral ocean wave model (SOWM) study, both of which provided 20 years wave climate data for the North Atlantic Ocean, were also considered by various groups to provide long-term wave climate data.

Recent studies, which were carried out by MacLaren Plansearch and Oceanweather for AES, ESRF and Transport Canada (Canadian Climate Centre, 1991; Eid and Cardone, 1987; MacLaren Plansearch, 1991), have indicated that the previously estimated extreme values appear to be overestimated. However, without a detailed shallow-water wave hindcasting study using appropriate shallow water models, and incorporating the most recent extreme storm events (e.g. the Halloween storm, October 31, 1991; the storm of the century, March 13, 1993; and the most recent hurricanes Felix and Luis, Sept. 1995) these discrepancies cannot be easily resolved. However for the purpose of this assessment, the results from various sources are presented for comparison.

Tables 4.1-36 to 4.1-39 provide summaries of the estimated extreme wave parameters for various return periods (i.e. 1, 10, 25, 50 and 100 year) for Venture sites; Thebaud, North Triumph, Glenelg and Alma; along the pipeline corridor; and Country Harbour and Canso areas.

In a most recent PERD-funded study, which was carried out by MacLaren Plansearch and Oceanweather Inc. (1995), a number of most recent severe storms were hindcast, including the Halloween storm (Oct. 31, 1991) in which the highest ever recorded wave height occurred off the east coast (Laurentian fan area). However, the results of these studies have not been included in updating the above design parameters.

In the Sable Offshore Energy Project Development Plan Application (Volume 2, Section 5.6.2), plans to complete a new comprehensive wind and wave hindcast are presented.

Table 4.1-36 Extreme Wave Criteria for Venture Site

East Venture	Return Period (Years)				
	1	10	25	50	100
Sig. Wave Height H_s (m)	8.9	11	12.6	14.1	14.7
Sig. Wave Period T_s (m)	14	14.2	14.7	15.3	15.8
Max. Wave Height H_m (m)	26.3	26.3	26.3	26.3	26.3 ⁽¹⁾
Max. Wave Period H_m (m)	19.6	19.9	19.9	20.1	20.2
Period Range $T_{z,m}$ (s)	12.7 to	13.0 to	13.4 to	13.8 to	14.5 to
Direction of Maximum Waves (°T from)	180	180	180	180	180
West Venture					
Sig. Wave Height H_s (m)	8.9	10.3	11.5	12.7	13.2
Sig. Wave Period T_s (m)	14	14.2	14.7	15.3	15.8
Max. Wave Height H_m (m)	24.8	24.9	24.9	25.4	25.7
Max. Wave Period H_m (m)	18.2	18.2	18.5	19.3	19.7
Period Range $T_{z,m}$ (s)	12.7 to	13.0 to	13.4 to	13.8 to	14.5 to
Direction of Maximum Waves (°T from)	180	180	180	180	180
(Source: Seaconsult, 1984)					

¹ The maximum wave heights are equal for all return periods because of the influence of changes in wave refraction coefficient (K_r) and spectral peak period (T_p) as a function of return period in the combined wave method. The maximum crest heights are not, however, equal because of the way in which the primary and secondary wave crests are calculated and added to give H_c .

Table 4.1-37 Extreme Wave Criteria for Thebaud, North Triumph, Glenelg and Alma

	Return Period (Years)					
	1 year	10 years	20 years	30 years	50 years	100 years
Thebaud						
Significant Wave Height H_s (m)	8.1	9.6	10.3	10.7	11.1	11.8
Maximum Wave Height H_{max} (m)	14.9	16.9	17.7	18.1	18.6	19.3
Ratio: H_s/H_{max}	1.84	1.76	1.72	1.69	1.67	1.63
Maximum Crest Height H_c (m)	8.7	10	10.5	10.8	11.1	11.5
Peak Wave Period T_p (s)	13.0	14.8	15.6	16.1	16.5	17.3
Mean Zero-Crossing Period T_z (s)	9.4	10.6	11.2	11.6	11.9	12.5
North Triumph, Glenelg and Alma						
Significant Wave Height (H_s (m))	8.1	9.6	10.3	10.9	11.1	11.8
Maximum Wave Height H_{max} (m)	15.0	17.8	19.1	19.9	20.6	21.9
Maximum Crest Height H_c (m)	8.3	9.8	10.6	11	11.5	12.2
Peak Wave Period T_p (s)	13.0	14.8	15.6	16.1	16.5	17.3
Mean Zero-Crossing Period T_z (s)	9.4	10.6	11.2	11.6	11.9	12.5
For North Triumph, Glenelg and Alma sites: T_p , T_z , and H_{max} were calculated using: $T_p = 2.7595 H_s^{0.743}$ $T_z = 0.72 T_p$ $H_{max} = 1.857 H_s$ (Using Forrestal, 1978)						
For Thebaud site: based on Gluhovski Distribution for shallow water waves, water depth = 28 m						
(Source: MacLaren Plansearch, 1989)						

Table 4.1-38 Extreme Wave Criteria for Pipeline Corridor Sites (Figure 4.1.19)

	Return Period (Years)				
	1	10	25	50	100
Site 1					
Significant Wave Height H_s (m)	8.2	8.4**	8.5	9.1	9.6
Mean Zero-Upcrossing Wave Period T_z (s)	9	9.1	9.2	9.6	9.8
Maximum Wave Height H_m (m)	15.4	15.7	16	17.1	18
Peak Wave Period T_p (s)	10	12.1	12.6	13.2	13.4
Site 2					
Significant Wave Height H_s (m)	8.2	9	10.2	11.1	11.9
Mean Zero-Upcrossing Wave Period T_z (s)	9	9.5	10.1	10.6	10.9
Maximum Wave Height H_m (m)	15.4	16.9	19.1	20.8	22.3
Peak Wave Period T_p (s)	10	13	13.8	14.5	15
Site 3					
Significant Wave Height H_s (m)	8.2	9.5	10.6	11.3	12
Mean Zero-Upcrossing Wave Period T_z (s)	9	9.8	10.3	10.7	11
Maximum Wave Height H_m (m)	15.4	17.8	19.8	21	22.3
Peak Wave Period T_p (s)	10	13.4	14.1	14.7	15
Site 4					
Significant Wave Height H_s (m)	8.9	10	11	11.8	12.5
Mean Zero-Upcrossing Wave Period T_z (s)	9.5	10	10.5	10.9	11.2
Maximum Wave Height H_m (m)	16.7	18.7	20.6	21.9	23.2
Peak Wave Period T_p (s)	12.9	13.7	14.4	14.9	15.3
Site 5					
Significant Wave Height H_s (m)	8.9	11.4	12.7	13.5	14.4
Mean Zero-Upcrossing Wave Period T_z (s)	9.5	10.7	11.3	11.6	12
Maximum Wave Height H_m (m)*	16.7	21.3	22.6	22.6	22.6
Peak Wave Period T_p (s)	12.9	14.7	15.5	16	16.5
Site 6					
Significant Wave Height H_s (m)	8.9	11.4	12.7	13.5	14.4
Mean Zero-Upcrossing Wave Period T_z (s)	9.5	10.7	11.3	11.6	12
Maximum Wave Height H_m (m)	16.7	21.3	23.6	25.1	26.6
Peak Wave Period T_p (s)	12.9	14.7	15.5	16	16.5
Site 7					
Significant Wave Height H_s (m)	8.9	12.2	13.5	14.7	15.7
Mean Zero-Upcrossing Wave Period T_z (s)	9.5	11.1	11.6	12.2	12.6
Maximum Wave Height H_m (m)	16.7	22.7	25	27.1	28.9
Peak Wave Period T_p (s)	12.9	15.2	16	16.7	17.2
* $H_m = 0.78 D$, $D = 27$ (chart depth) + 1.4 (tide) + 0.55 (surge)					
** smoothed to give an even transition from one-year return to 10-year return period values					
(Source: Seaconsult, 1984)					

Table 4.1-39 Extreme Wave Criteria for Country Harbour and Melford Point

	Return Period (Years)				
	1	10	25	50	100
Country Harbour Entrance					
Significant Wave Height H_s (m)	5.3	6.8	7.5	8	8.5
Maximum Wave Height H_{max} (m)	9.3	12	13.2	14	14.9
Peak Wave Period T_p (s)	10	10	10	11	11
Average Angle of Incidence ($^\circ T$)	140	140	140	140	140
Melford Point ($^\circ T=90$)					
Significant Wave Height H_s (m)	1.68	1.98	2.16	2.29	2.38
Significant Wave Period T_s (s)	5	5.5	5.6	5.7	5.8
(Source: Seaconsult, 1984, 1985)]					

4.1.3.10 Sea Ice and Icebergs**SEA ICE**

Sea ice forms along Nova Scotia's Atlantic coast during January, February and March. It is confined to inlets and bays, seldom reaching thicknesses greater than 30 cm. If carried out to sea by winds and currents, this ice cover melts; it has not been a hindrance to navigation. Sea ice formed in the Gulf of St. Lawrence can affect the study area by drifting through Cabot Strait onto the Scotian Shelf under the influence of winds and surface currents.

Under the influence of north winds and Cape Breton currents, the Gulf of St. Lawrence ice pack may drift into the Scotian Shelf coastal areas. The ice stream departs the Gulf of St. Lawrence past the northern tip of Cape Breton Island, carrying heavy, tightly packed, rafted ice up to 75 cm thick. When winds are from the north and east, the Gulf ice piles up along the Nova Scotia coast, and tugs or icebreakers may be needed to keep the harbours open. Along the coastline pipeline corridor, such ice has occurred mainly between the second week of February and the second week in May.

Figure 4.1-26 shows the monthly percentage of occurrence of any ice affecting the study area, whereas Figure 4.1-27 presents the maximum ice concentration between the months of December and April (AES digital database, 1962-1983). The ice edge has not been observed to reach Sable Island, although it has approached within 40 km on several occasions.

PERCENTAGE OCCURRENCE OF ANY ICE
APRIL 1962-1983

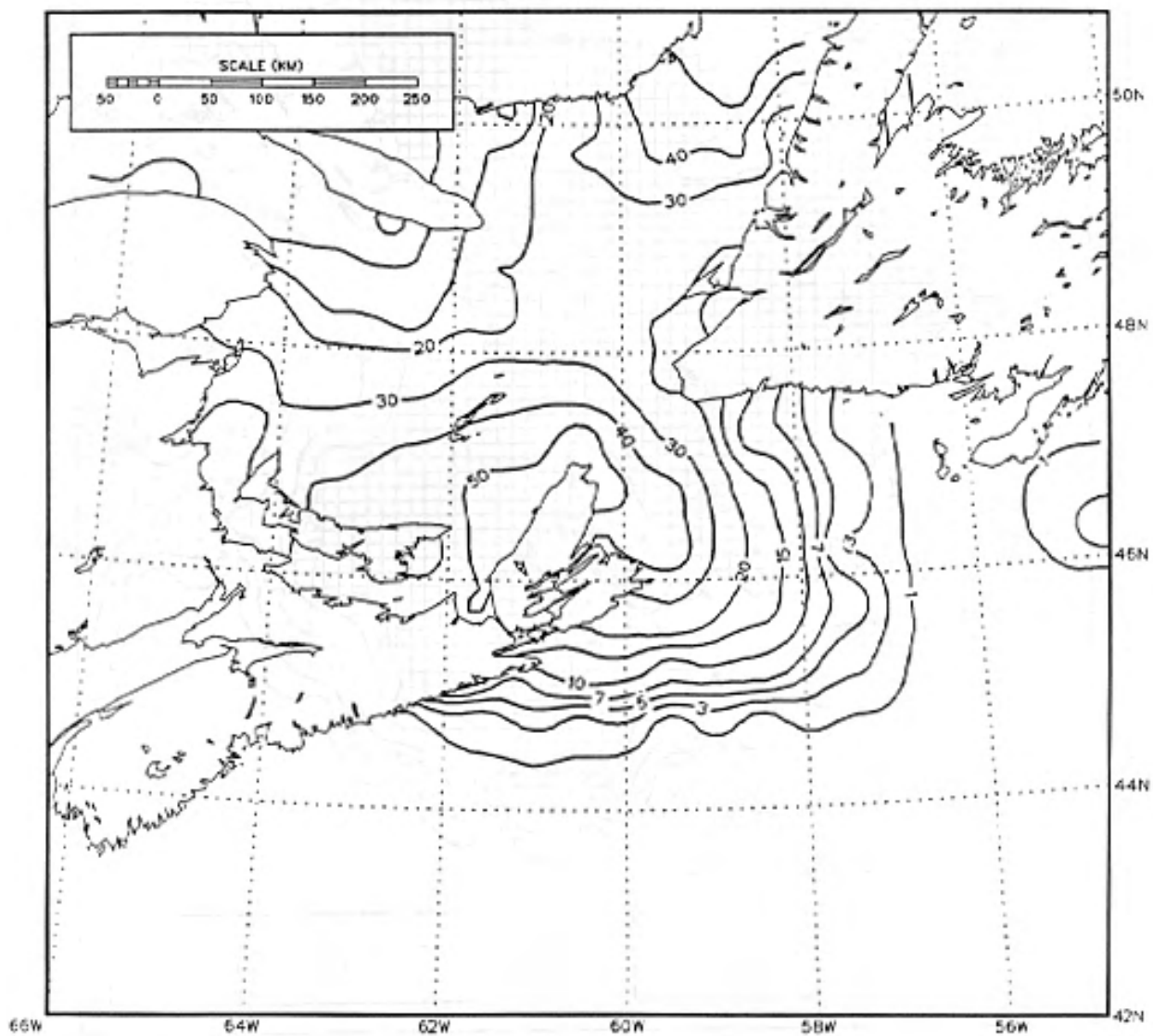


Figure 4.1-26 Percentage of Occurrence of Any Ice (maximum extent)
(Source: AES, Canadian Climate Center, Digital Database)

MAXIMUM ICE CONCENTRATION FEBRUARY 1962-1983

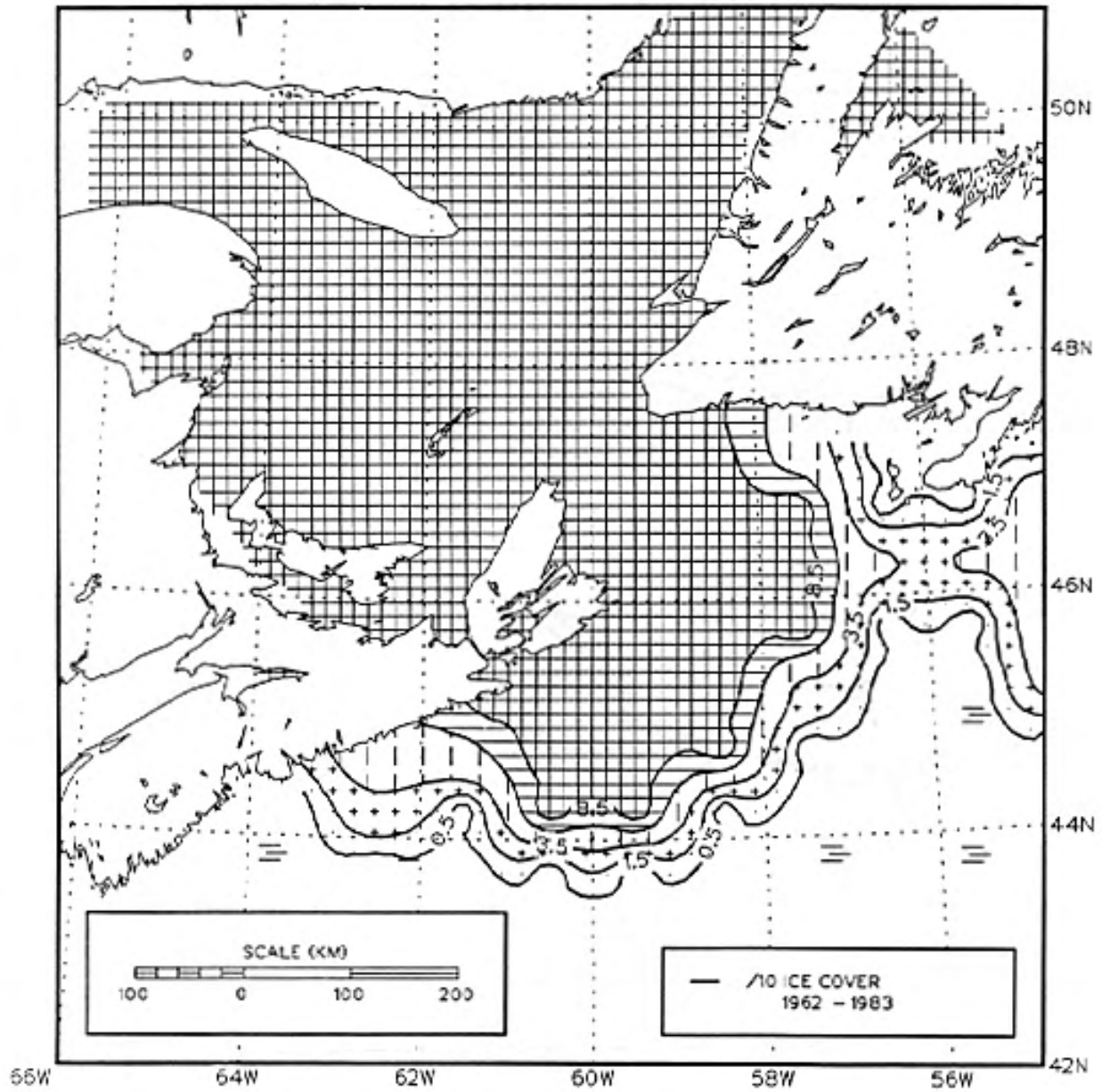


Figure 4.1-27 Maximum Ice Concentration by Month
(Source: AES, Canadian Climate Center, Digital Database)

MAXIMUM ICE CONCENTRATION MARCH 1962-1983

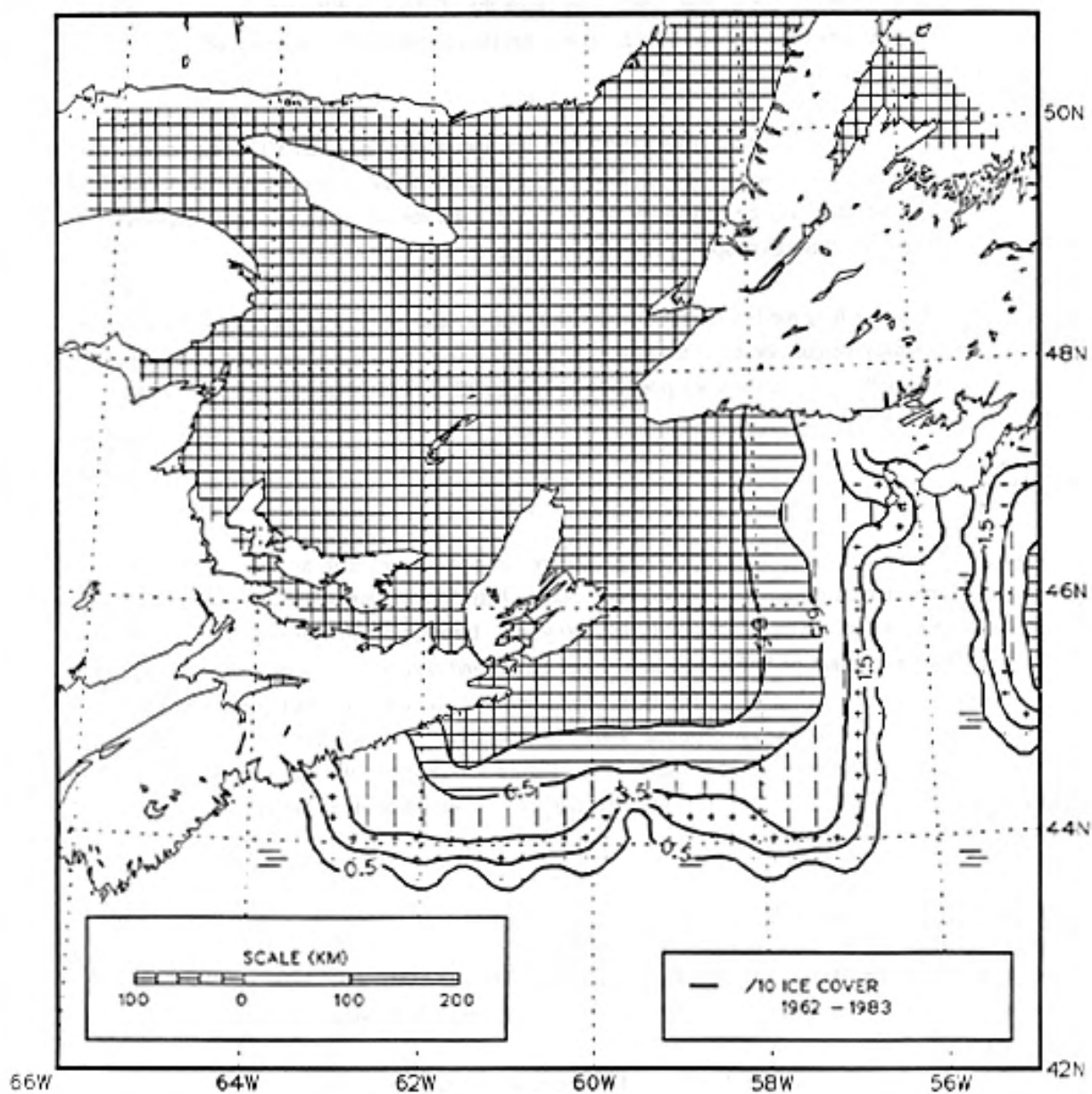


Figure 4.1-27 Maximum Ice Concentration by Month cont'd

Sea Ice Design Criteria

As shown in Figures 4.1-26 and 4.1-27, the maximum southern extent of the sea ice (approaching from the Gulf of St. Lawrence into the Scotian Shelf) may reach the offshore SOEP sites. The maximum sea ice conditions occur in late February and March. However, the percentage of occurrence of any ice at the development sites is very low (less than 1%).

The maximum ice concentration at the development sites was found to be less than 3/10th ice cover. The probability of occurrence of a compact sea ice field approaching the offshore development sites is almost nil. Therefore sea ice need not be considered as a design criteria for offshore structures. However, it should be accounted for through proper operational procedures.

For the pipeline approaching the landfall (at Country Harbour or Strait of Canso) particularly close to the coastline, sea ice must be considered in the design of coastal defence structures and the shallow pipeline approaching the coastline. Most shore ice piles develop within 20 m of the shoreline and are less than 15 m high (Taylor, in Lewis and Keen, 1990).

ICEBERGS

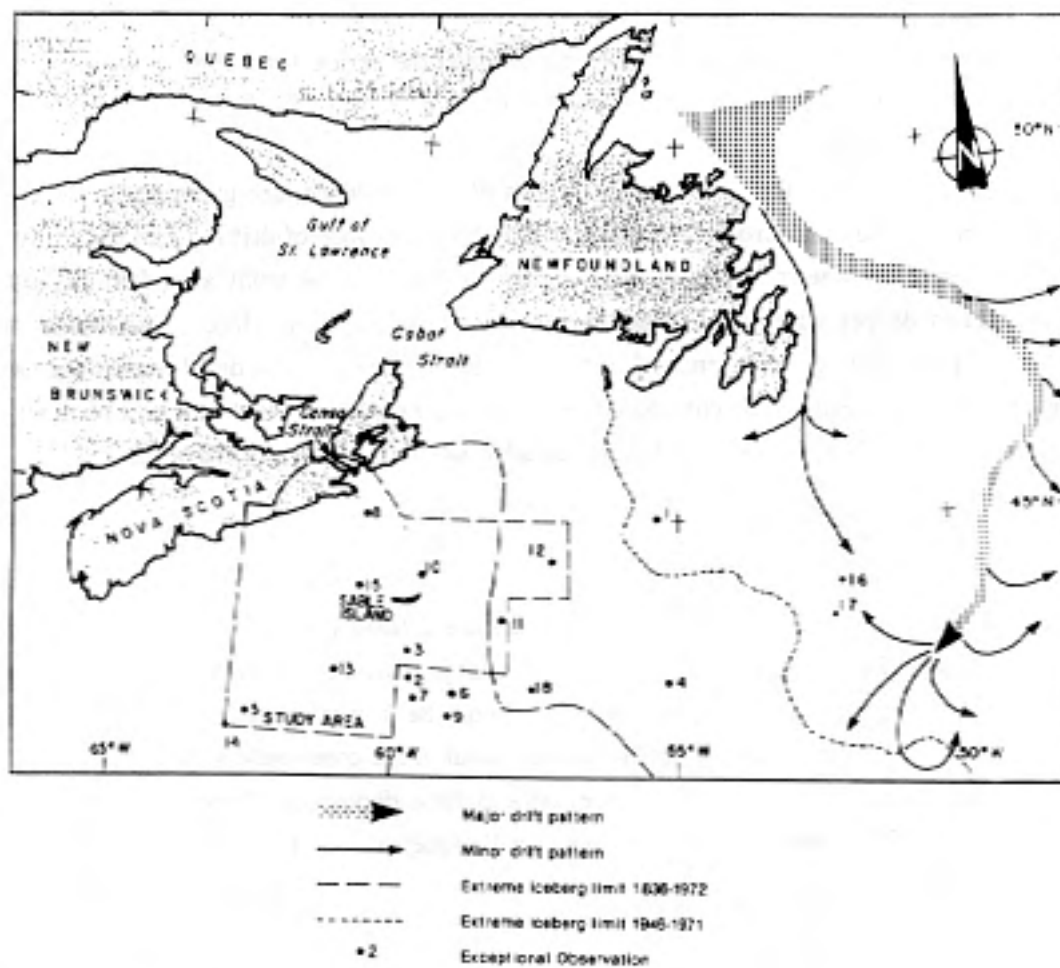
The SOEP offshore study area is not within the extreme limit of iceberg drift as defined by Markham (1980), using information gathered by the International Ice Patrol from 1946 to 1972. Only one iceberg has been reported within the study area in the past 60 years. Icebergs on the Canadian east coast come from the tidewater glaciers of Baffin Bay and Davis Strait, and their drift is governed by winds and currents. Most follow the Labrador Current down the Labrador coast and may reach the Grand Banks of Newfoundland before decaying. Exceptional sightings (Meserve, 1974; MacLaren Plansearch, 1984) historically occur from April to July in the study area. Figure 4.1-28 shows the major and minor iceberg drift patterns, and the maximum extent of iceberg drift on the Scotian Shelf as determined by Meserve (1974) and Markham (1980).

Iceberg Exceptional Sighting Statistics

More recent studies by MacLaren Plansearch Limited (1984 and 1990) that have provided detailed statistics on probability of occurrence of icebergs in the study area are discussed below.

Data Source: International Ice Patrol (IIP) database covering the period 1960-1989. The IIP has maintained records of the unusual iceberg sightings over the past thirty years.

Study Area: Two areas were considered (a) a large area which extends from 41° to 48°N and 55° to 65°W, and (b) a smaller area from 43° to 46°N and 57° to 63°W.



- | | |
|---|------------------------------------|
| 1 Iceberg - January 1920 | 10 Iceberg - July 1913 |
| 2 Iceberg - April 1892 | 11 Iceberg - July 1844 |
| 3 Iceberg - April 1918 | 12 Iceberg - July 1921 |
| 4 Icebergs - April 1851 | 13 Growlers 60 cm high - July 1836 |
| 5 Growlers and large slabs of sea ice
30-45 m long and 1.5 m high - May 1914 | 14 Iceberg 18 m long - July 1916 |
| 6 Iceberg - May 1919 | 15 Iceberg - September 1919 |
| 7 Several Icebergs - May 1843 | 16 Iceberg - October 1920 |
| 8 Iceberg - May 1962 | 17 Iceberg - October 1923 |
| 9 Iceberg - June 1921 | 18 Iceberg - December 1915 |

Figure 4.1-28 Unusual Iceberg Sightings on Scotian Shelf

Source: Meserve, 1974; Markham, 1980

All iceberg sightings found in the above areas were identified and iceberg types (or sizes) were also identified (MacLaren Plansearch, 1984 and 1990). Figure 4.1-29 shows the IIP iceberg sightings on the Scotian Shelf for the period 1960 to 1989.

The monthly average number of icebergs observed by the IIP over the period 1960-1989 in the area defined by 43° to 46°N and 57° to 63°W is shown in Figure 4.1-30.

Most of the icebergs that arrive on the Grand Banks or Gulf of St. Lawrence, are generally in some stage of deterioration. Only medium and small-sized icebergs may have a chance of drifting into the study area due to the relatively shallow waters. Most of the icebergs that arrive at the study area drift through the Laurentian Channel or deeper water west of the SOEP offshore fields. Therefore, as shown from the existing data set, the probability of occurrence of icebergs on Sable Bank near the development site (within 50-100 km) is very low and need not be considered as a design criterion. However, it will be dealt with through proper operational procedures (e.g. through an adequate monitoring program, etc.).

Iceberg Scour

The eastern Scotian Shelf shows evidence of the presence of iceberg furrows, the scoured seafloor resulting from grounded icebergs. The dimensions of these furrows vary, but on average they are approximately 2 m deep, 30 to 40 m wide, and possibly many kilometres long. Such furrows, however, are considered relict because of the relative absence of icebergs since withdrawal of the continental ice sheet (King, 1970). The furrows are also found in deeper water where there is little deposition (Fader, 1992). Features resembling iceberg scour have been recently observed on Banquereau (G. Fader, pers. comm., 1995), although the age of these features is not known.

4.1.4 Marine Chemistry

4.1.4.1 Introduction

Ocean productivity and the value of harvestable marine bio-resources are highly dependent on the quality of seawater and sediments comprising the habitat for marine organisms. An understanding of the chemistry of the existing marine environment and its assimilative capacity in the vicinity of the proposed Sable Offshore Energy Project (SOEP) provides the basis for an assessment of the Project's potential impacts on the area's marine biological resources.

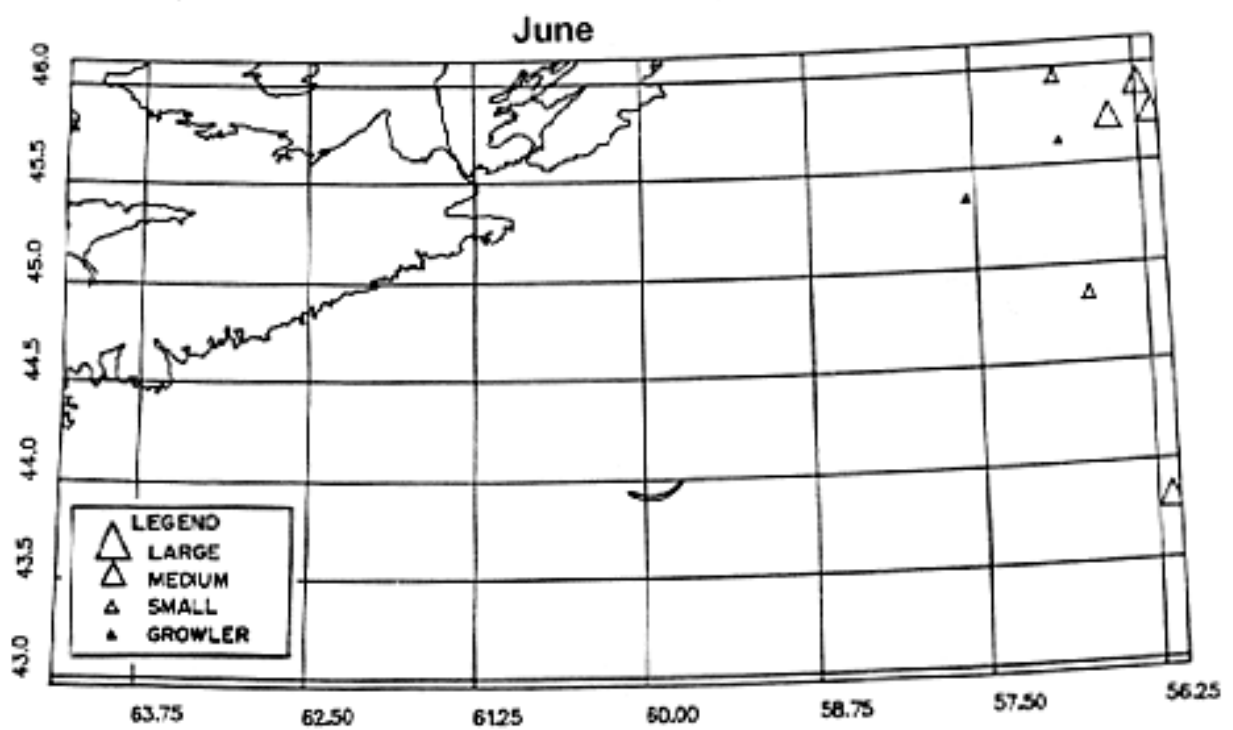
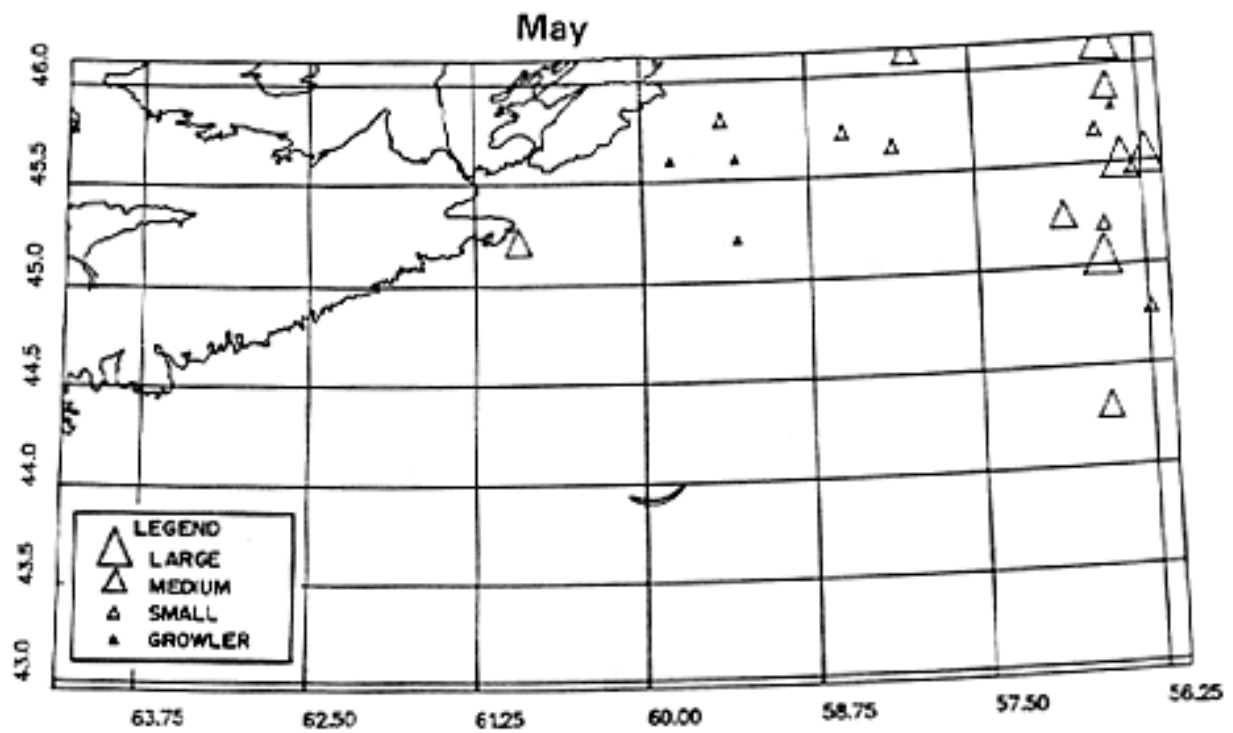


Figure 4.1-29 Iceberg Sightings on the Scotian Shelf Period 1960 to 1989 (cont'd)

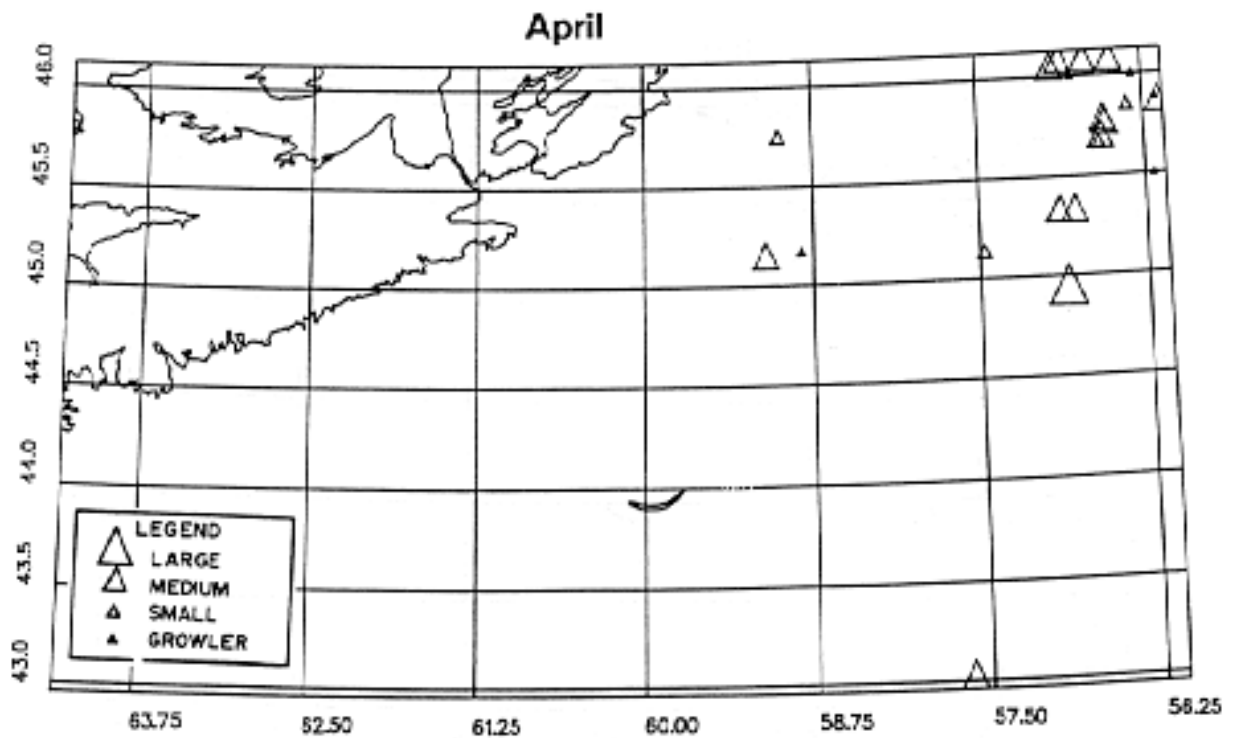
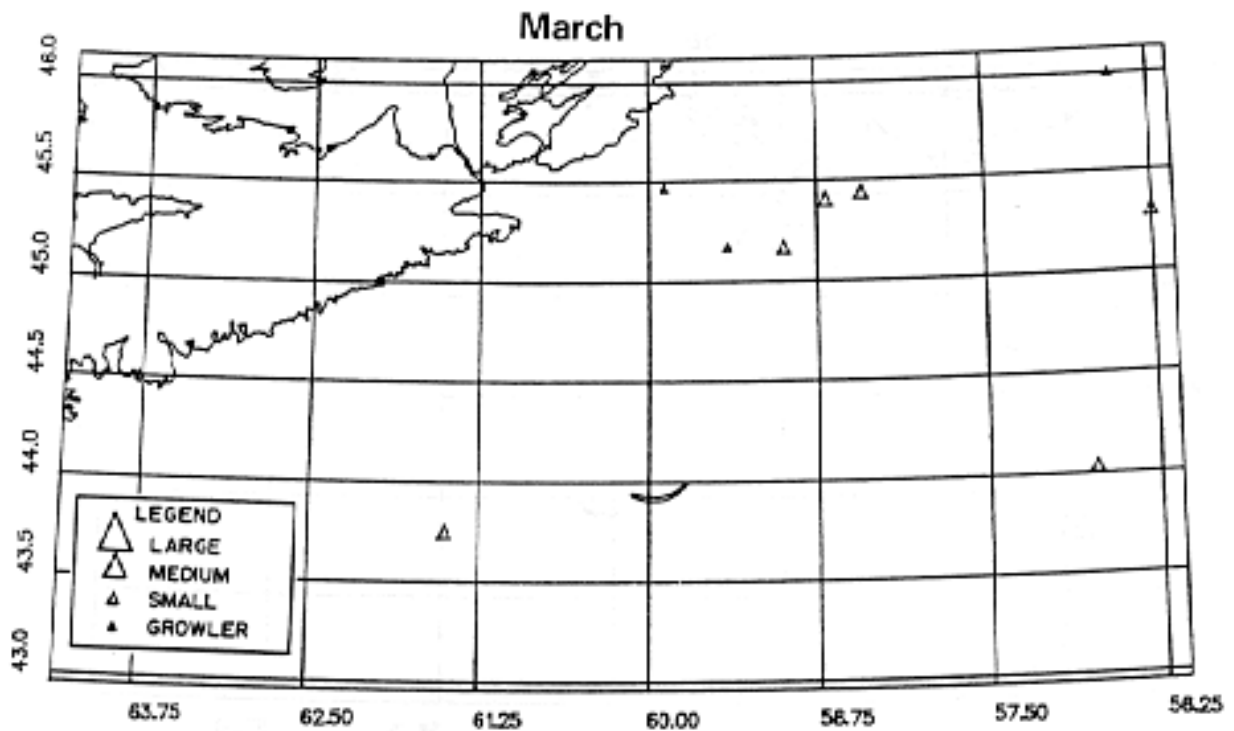


Figure 4.1-29 Iceberg Sightings on the Scotian Shelf for Period 1960 to 1989
 (Source: International Ice Patrol (IIP) Database)

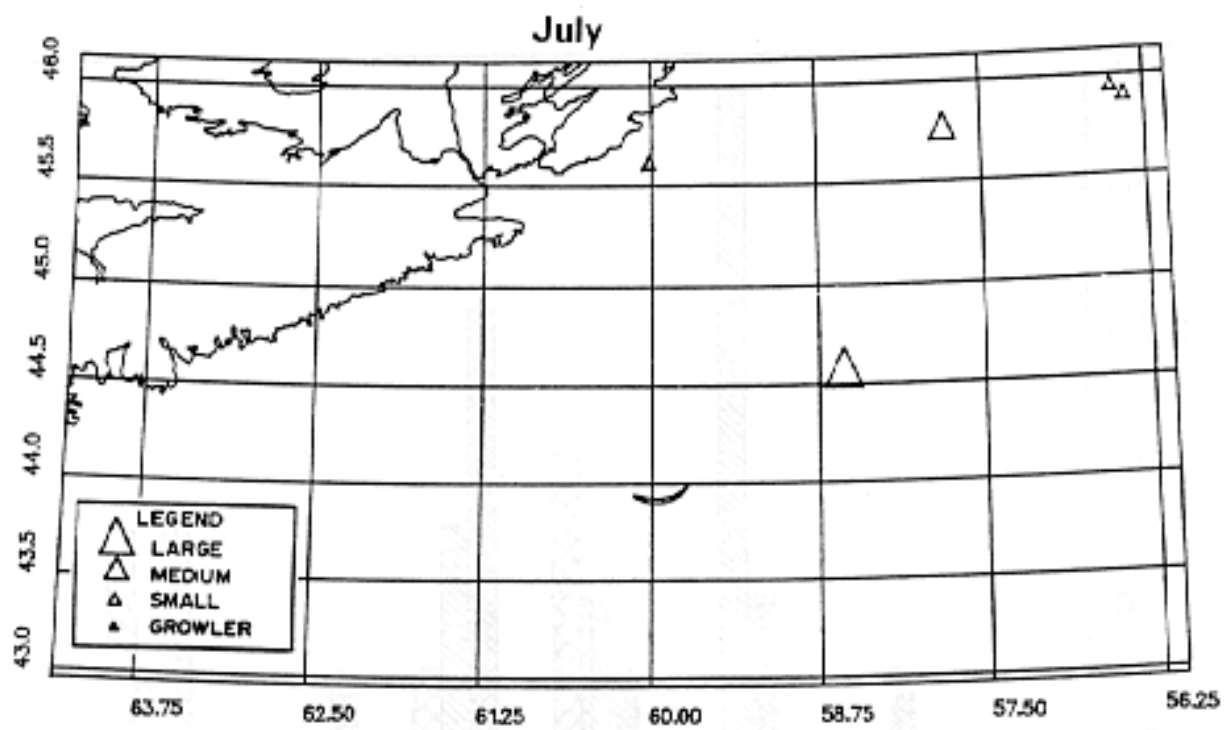


Figure 4.1-29 Iceberg Sightings on the Scotian Shelf for Period 1960 to 1989 (cont'd)

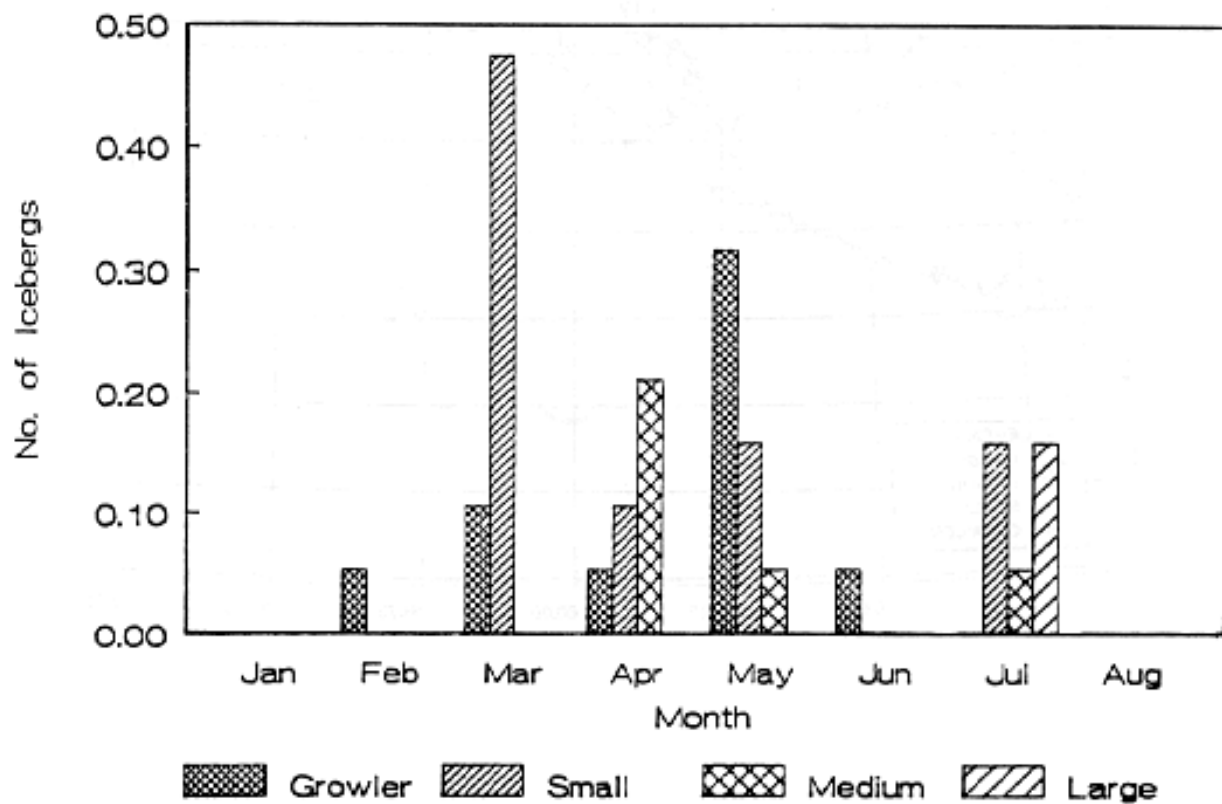


Figure 4.1-30 Monthly Average Number of Icebergs Observed by the IIP over the period 1960-1989 in the Area defined by 43° to 46°N and 57° to 63°W (Source: MacLaren Plansearch, 1990)

Monthly Average Iceberg Sightings

Month	Growler	Small	Medium	Large
February	0.053	0	0	0
March	0.105	0.474	0	0
April	0.053	0.105	0.211	0
May	0.316	0.158	0.053	0
June	0.053	0	0	0
July	0	0.158	0.053	0.158
August	0	0	0	0
(Source: MacLaren Plansearch, 1990)				

The proposed development area lies to the outer reaches of the Scotian Shelf. This places the development near the outer limit of measurable effects of land-based sources (both natural and anthropogenic), but also near the Continental Shelf-Break, often the site of significant biological productivity in offshore coastal waters. Thus the chemical composition of water and surficial sediments in the study area can be expected to reflect limited terrestrial input and predominant biogenic input.

4.1.4.2 Database

While the Scotian Shelf has been the site of numerous oceanographic studies, the database suffers from two major deficiencies: (a) focused studies, often not including all parameters or substances of interest to this review; and (b) studies conducted in areas well south of the project site (e.g. along the Halifax Section, a series of standard oceanographic stations along a transect extending southeastward from the mouth of Halifax Harbour across the Emerald Bank to the Continental Slope). Further, the number and scope of studies undertaken since the 1982 review has been considerably diminished. As a result, data often have to be extrapolated for the study area.

4.1.4.3 Water Quality**(1) Major Ions and pH**

While the chemical composition of seawater is complex, the relative concentrations of the major ions are generally constant throughout the oceans. Subtle but significant differences in the ratios can be attributed to differences between surface and deep waters (particularly near submarine vents and other geological features) and between coastal and open ocean waters, with the former affected by land-based drainage and anthropogenic inputs.

The pH of seawater is relatively constant throughout the oceans, ranging from 7.5 to 8.4, with a mean of 7.8. Minor deviations may occur in the pH of surface waters or near effluent outfalls. Within

seawater, a large proportion of the carbonate and bicarbonate ions is associated with cations; this association is responsible for the high buffering capacity of seawater.

(2) Dissolved Oxygen

The major sources of dissolved oxygen are exchange with the atmosphere and production by marine plants; the major pathways of consumption are oxidation of chemical compounds (expressed as chemical oxygen demand) and aerobic biological processes (expressed as biological oxygen demand). Numerous physical, chemical and biological factors determine the horizontal and vertical distribution of dissolved oxygen in the water column.

The waters in the SOEP area are well-mixed and shallow. Thus dissolved oxygen concentrations are likely to be near or at saturation, with concentrations to be expected in the 8-10 mg/L range. There is no indication that concentrations of substances or biological processes in any area of the Scotian Shelf are high enough to result in zones of low oxygen concentration (semi-anoxia) or depletion (anoxia).

(3) Suspended Particulate Matter

The concentration, size range and distribution of suspended particulate matter (SPM) can alter (reduce the spectral range) or attenuate (reduce the intensity and depth of penetration) light entering the water column. As photosynthetic activity depends on light, the concentration of SPM and associated turbidity influences primary production.

There is little published information on either the concentrations of SPM, or turbidity measurements in the study area. 1979 data from the Emerald Bank indicated a variation of 5.5 mg/L at the surface, increasing to 10.1 mg/L at 20 m and then decreasing to 4.0 mg/L below this depth. The data reflected the strong influence of biological activity during and after the spring plankton bloom (B. Hargrave, Fisheries and Oceans, 1995; personal communication). However, observations by Heffler and Bennett (Fisheries and Oceans Canada, pers. comm. 1982) suggest that concentrations of suspended particulate matter on Sable Bank are much lower than those measured on Emerald Bank.

(4) Nutrients

Considerable nutrient data for surface waters of the study area are available as a result of the Scotian Shelf Ichthyoplankton Program (SSIP) and other studies. Even in the nearshore area, the offshore seasonal cycle dominates the nutrient distributions in embayments of drastically different morphologies and degrees of neighbouring industrial development (Platt et al., 1972). A strong seasonal pattern has been observed for nitrate and phosphate in the euphotic zone. Concentrations of nitrate were elevated (5.0 to 10.0 μg at $\text{NO}_2\text{-N/L}$) in early spring, dropped dramatically in late spring in correlation with the plankton bloom, remained low (approximately 0.5 to 1.5 μg at $\text{NO}_2\text{-N/L}$) through the summer, and generally rose (0.5 to 10 μg at $\text{NO}_2\text{-N/L}$) in autumn. Phosphate concentrations were high (0.6 to 0.9 μg at $\text{PO}_4\text{-P/L}$) in early spring, changed little on average in late

spring (0.4 to 1.3 μg at $\text{PO}_4\text{-P/L}$), dropped through the summer (0.1 to 0.2 μg at $\text{PO}_4\text{-P/L}$) and remained low through to autumn (0.1 to 0.3 μg at $\text{PO}_4\text{-P/L}$).

(5) Trace Metals

Trace metal inputs to the study area are a function of natural and anthropogenic inputs from Nova Scotia and the Gulf of St. Lawrence (as a drainage basin for central North America) and, to a limited extent, atmospheric transport from central and eastern North America. The distributions of these metals within the waters of the Scotian Shelf are the result of natural processes within the water column and circulation of water masses across the Shelf. The latter are the major controlling function regulating daily or seasonal variations in concentrations.

Using data for trace metals reported from other areas of the Scotian Shelf or adjacent waters and worldwide oceanic average values, concentrations for trace metals of interest can be predicted for the SOEP area. These are listed in Table 4.1-40.

(6) Hydrocarbons

Hydrocarbons are ubiquitous in the marine environment, arising from both recent biogenic processes and petrogenic sources. There are numerous pathways for petrogenic hydrocarbons' entry into the marine environment, but only submarine and coastal oil seeps can be considered as natural processes.

As to be expected, concentrations of petroleum and biogenic hydrocarbons in nearshore waters are generally greater than offshore. Gordon et al. (1978) reported annual mean concentrations in Halifax Harbour water of 2.5 mg/m^3 (surface) compared to 1.8 mg/m^3 for near bottom. Much lower concentrations were observed in more pristine coastal inlets: e.g. 0.1 mg/m^3 in St. Georges Bay, Nova Scotia and 0.5 mg/m^3 in St. Margaret's Bay, Nova Scotia.

One of the major difficulties in interpreting quantitative data is the differences in methods of measurement and problems of contamination during sampling. Earlier estimates of oil in the waters of the Scotian Shelf are suspect because of contamination problems associated with the sampling procedures.

**Table 4.1-40 Predicted Trace Metal Seawater Concentrations in the Study Area
(concentrations in µg/L)**

Arsenic	2
Barium	25
Cadmium	0.04
Chromium	0.4
Copper	0.3
Iron (total)	1.5
Lead	0.02
Manganese	0.3
Mercury	0.002
Molybdenum	1.1
Nickel	0.2
Vanadium	2
Zinc	1

While there is considerable interest in the occurrence of polycyclic aromatic hydrocarbons (PAH) in the environment because of the biological effects induced by many of the compounds within this group, there are no data for the study area. It is reasonable to assume that concentrations in the water column will be very low to undetectable because of the distance from high population and heavily industrialized centres (i.e. anthropogenic sources). An occasional detectable amount could occur due to bilge water discharges from passing ships.

(7) Other Contaminants

While now considered to be relatively ubiquitous in the North Atlantic due to long-term land-based discharges, the concentrations of polychlorinated biphenyls (PCB) and various organohalogen pesticides (particularly the DDT group) are not expected to be significant in the project area. No data are available for the study area.

4.1.4.4 Sediment Quality

(1) Nutrients

Biological activity in surface sediments, both sublittoral and intertidal, is a pathway for the remineralization of nutrients in the marine environment. This process is important in intertidal and shallow areas for maintaining growth in marine plants. Concentrations of nutrients, particularly ammonia, phosphate and silicate, can be orders of magnitude greater in interstitial waters than in the overlying water.

Interstitial water data from Fitzgerald et al. (1988) taken from sediment cores in the Emerald Basin to the south and west of the study area are the nearest and most recent data; there are no data of nutrient concentrations for the interstitial waters in

the study area. Ammonia results for Core 88-2 indicated a range of 0.2 to 2.1 mm with steadily increasing concentrations over a depth of 600 cm.

(2) Trace Metals

Trace metals in marine sediments are derived from a variety of natural sources and human activities. Drilling and production operations can contribute to the trace metal concentrations in sediments around wells as a result of the disposal of drilling muds, well cuttings and suspended solids associated with formation waters. The composition, concentrations and chemical forms of the metals in these discharges are variable. Within any sediment sample, the sum of the concentrations of a metal in all possible geochemical associations or combinations is referred to as the "total" metal concentration. The bioavailability of a metal can vary, depending on whether the compound is loosely associated with a particular component (e.g. absorbed onto the surface of a suspended sediment) or more tightly bound within a mineral matrix (e.g. barium in the barite of a drilling mud).

Available data for Scotian Shelf sediments are limited and mostly from areas well away from the study area. Table 4.1-41 provides comparative data from other eastern Canadian sites and pre-drilling survey data from Carter et al. (1985). As "total" metal does not accurately represent the potential impact on associated biota, attempts have been made to determine the "bioavailable" fraction of the metals and relate the concentration to observed effects. Fitzgerald et al. (1989) reported leachable metal concentrations for Emerald Basin sediments were typically on the order of 10% of "total" metal; Loring (1981) suggested that typically less than 25% of "total" metal could be considered as "bioavailable"; Carter et al. (1985) suggested concentrations of less than 25%, but the leachable fraction varied from up to 85% for zinc to a low of 0.5% for barium.

(3) Hydrocarbons

Hydrocarbons in marine sediments are derived from a number of sources, including biogenic and petrogenic. Biogenic hydrocarbons are produced in-situ in shallow areas by the decomposition of surface algae and by the sedimentation of detrital material. In nearshore areas input from terrestrial sources, including organic debris from terrestrial plants and decomposed organic material from soils contribute -- sometimes quite substantially--to the organic content of marine surficial sediments; e.g. materials from pulp and paper operations, such as in the Strait of Canso. Keizer et al. (1978a) analyzing sediments collected along the Halifax transect and around Sable Island, found concentrations of oil ranging from less than 1 to 94 µg/g with concentrations highest in the nearshore stations, suggesting a terrestrial source.

Table 4.1-41: Comparative "Total" Trace Metal Concentrations in Marine Sediments (concentrations in mg/kg)

Metal	Grand Banks (1985, EIA)	Bay of Fundy (Loring, 1980)	Gulf of St. Lawrence (Loring, 1988)	Sable Bank, (Carter et al., 1985)
Arsenic	-	4-15	2-11	-
Barium	1-690	310	-	57-211
Cadmium	0.02-0.43	0.03-0.52	0.04-0.45	0.03-0.1
Chromium	1.48-3.9	15-352	8-158	0.03-0.1
Copper	3.0-25.6	5-32	3-76	0.4-1.5
Lead	0.7-15.3	8-42	8-40	1.5-6.5
Mercury	0.01-0.02	0.02-0.07	0.03-0.6	0.01-0.14
Nickel	-	3-46	2-160	-
Vanadium	-	27-136	4-168	-
Zinc	-	18-104	18-116	1.4-14.6

Subtidal sediments collected from an unpolluted coastal area of Newfoundland had concentrations ranging from approximately 1 to 25 µg/g (Keizer, 1974), whereas Hargrave and Philips (1975) found concentrations ranging from 5 to 405 µg/g in samples collected from a variety of "clean" and polluted areas.

In recent years, concentrations of many aromatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) have been determined in marine sediments from different areas, especially the northeastern United States, the North Sea and the Canadian Arctic. There are usually only a few nanograms of individual PAHs per gram of sediment. Yunker and Drinnan (1987) reported elevated concentrations of PAH and other aromatic hydrocarbon residues near Sable Bank drilling operations (West Venture and South Des Barres) which they attributed to drilling wastes and oil-based drilling muds associated with cuttings disposal. There are no other PAH data for the Scotian Shelf. It can be predicted that PAH concentrations are likely to range from very low to non-detectable except in those areas that have been directly affected by waste discharges.

(4) Other Contaminants

There are no data for the Sable Island area, but concentrations of PCB, DDT pesticides and PAH have been reported for a number of harbours and embayment inlets along the Nova Scotia coast within the land side of the study area. PCB and DDT typically occur at concentrations of less than 10 ng/g, except in select harbours where various anthropogenic inputs result in much higher concentrations (200-3000 ng/g) (e.g. Ernst et al., 1984). It is expected that on Sable Island Bank, concentrations of

organohalogens and other similar lipophilic contaminants in surficial sediments will be very low, reflecting the relatively low organic content of these sandy sediments.

4.1.4.5 Marine Organisms

(1) Trace Metals

The best-detailed tissue trace-metal concentrations for the project area are for inshore species. There are specialized data sets for the Sable Bank area derived from well discharge monitoring programs. Away from the actual Bank area, project area benthos may be characterized as relatively uncontaminated, except for select harbours significantly impacted by anthropogenic inputs or the Arrow and Kurdistan tanker spills.

Tissue cadmium concentrations are generally less than 1 µg/g wet or dry weight, except for blue mussels (*Mytilus edulis*) around Cape Breton, where maximum cadmium concentrations of 2.35 µg/g dry weight have been recorded. This concentration is lower than those in mussels from industrialized estuaries on the Baltic, or the northeast coast of the United States. Cadmium and many other contaminants are concentrated within the digestive gland (hepatopancreas) of crustaceans such as the American lobster (*Homarus americanus*) and the common rock crab (*Cancer irroratus*). Concentrations may reach 50 µg/g wet weight, but usually average around 20 µg/g. Mercury levels in marine fish in Canadian Atlantic waters are generally low, except in some of the larger predators. Zitko (1981) also noted that high levels of arsenic (greater than 190 µg/g wet weight) occur in some fish in Atlantic Canada. Lead concentrations in fish are generally low (less than 0.5 µg/g wet weight).

Monitoring data from Carter et al. (1985) and LASMO (1994) indicate detectable increases in contaminant body burdens of trace metals and petroleum hydrocarbons in scallops (naturally-occurring and in place) and mussels (deployed in water column enclosures) at considerable distances from the rig discharges. While uptake concentrations were still low, the incidents indicate that such filter feeders will readily accumulate contaminants associated with the drilling discharges. Any monitoring will have to take this process into account.

(2) Petroleum Hydrocarbons

Data for Nova Scotia centre on Chedabucto Bay, site of the Arrow spill. Lobsters were found to have appreciable petroleum hydrocarbon concentrations (up to 130 µg/g wet weight) in their hepatopancreas. Predatory starfish such as the purple starfish (*Astelias vulgaris*) had up to 100 µg/g wet weight. This high concentration as compared with levels (2.4 to 18.3 µg/g wet weight) for the same species in deeper waters on Georges Bank (Boehm et al., 1979) suggests that the starfish were still contaminated with oil, presumably from the Arrow spill. Periwinkles were also susceptible to petroleum hydrocarbon contamination in Chedabucto Bay.

(3) Other Contaminants

PCB, because of its chemical stability and general ubiquity, is often used as a "signature" compound to indicate contamination by a range of other synthetic chemical compounds. Higher concentrations

of PCB are associated with fish with higher fat contents, such as alewives, herring and mackerel, reflecting the general tendency of PCB and other organochlorine compounds to preferentially accumulate in lipids and fats. The muscle of most demersal fish species on the Nova Scotian banks generally contains less than about 0.1 µg/g wet weight, although halibut have been reported to contain up to 0.6 µg/g. The highest concentrations for demersal fish species other than silver hake on Georges Bank range from 0.006 to 0.035 µg/g dry weight (0.001 to 0.007 µg/g wet weight, assuming 80 per cent water content) (Boehm and Hirtzer, 1982).

Review of long-term trends for mussels throughout estuarine/near-shore sites in the United States suggests a noticeable decrease over the past two decades. This is consistent with increased regulation of the discharge of such contaminants as PCB and lead.

4.1.5 Geology, Geomorphology and Sediments

4.1.5.1 Bedrock Geology

The bedrock geology of the Scotian Shelf consists of two main components: rifted Palaeozoic continental crust (Acoustic Basement) and the accretionary wedge of Mesozoic and Cenozoic sediments which form the Scotian Basin (see Figure 4.1-31).

The acoustic basement offshore Nova Scotia is made up of rifted Palaeozoic rocks similar to those found onshore Nova Scotia. This crust underwent extension and thinning during the Mesozoic breakup of Pangaea prior to the initiation of seafloor spreading in the North Atlantic Ocean. Resulting subsidence and erosion of continental crust onshore created the thick accumulation of Mesozoic and Cenozoic sediments which make up the Scotian Basin.

The rocks of the acoustic basement in the study area are separated by a large fault system called the Minas Geofracture. Onshore, this is represented by the Cobequid-Chebucto fault. Offshore, it defines the southern boundary of the Orpheus Basin east of Chedabucto Bay and continues eastward onto the tail of the Grand Banks (Bell and Howie, 1990). South of this fault lie the rocks of the Meguma Group. North of the fault lie undifferentiated upper Palaeozoic rocks.

South of mainland Nova Scotia the acoustic basement is composed of rocks of the Cambro-Ordovician Meguma Group that were folded and metamorphosed and subsequently intruded by Devonian-Carboniferous granitoid rocks. The Meguma Group consists of thick greywacke, quartzite and slate. These rocks are believed to range in age from Cambrian to Ordovician.

The acoustic basement along the southeast coast of Cape Breton Island is not well differentiated and is mapped only as a pre-Pennsylvanian unit. This unit is probably composed of Precambrian metasediments and volcanics, Cambrian-to-Devonian sediments and granitoids, and some overlying Mississippian sediments. Mississippian strata underlie much of Chedabucto Bay and the nearshore around Isle Madame (Mobil, 1983) and make up part of the Orpheus Basin. This basin is a graben structure containing deformed low-density sediments (Loncarevic and Ewing, 1967) and is less than 50 km wide, extending for over 200 km offshore.

The present Atlantic Ocean began to develop in the late Triassic with rifting accompanied by non-marine sedimentation and volcanism followed by evaporite deposition. Breakup and seafloor spreading at approximately 180 Ma was initially associated with the development of carbonate banks, then with thermal subsidence, while clastic sedimentation continued through to Late Tertiary time. Thick sedimentary deposits accumulated along the basin's subsiding western margin forming the Scotian Basin (Wade and MacLean, 1990). This sedimentary sequence contains the source rocks responsible for the accumulation of hydrocarbons in the area. These Mesozoic-Cenozoic sediments thicken seaward, forming a wedge which, in some places, may be up to 18 km thick (Keen and Potter, 1995). The strata dip seaward, except where locally disturbed by folding, faulting or salt domes.

4.1.5.2 Surficial Geology

Offshore unconsolidated Quaternary deposits in the study area have been described by King (1970), MacLean and King (1971), MacLean et al. (1977), King and Fader (1986) and Piper et al. (1990).

The five main Quaternary formations within the study area overlay the acoustic basement and consist of Scotian Shelf Drift, Emerald Silt, Sambro Sand, Lahave Clay, and Sable Island Sand & Gravel (see Figures 4.1-32 and 4.1-33). A sixth deposit, the Laurentian Formation, has recently been identified below the Scotian Shelf Drift. The Laurentian Formation is the lowest Quaternary unit and is overlain by the Scotian Shelf Drift which is a sequence of glacial till. The Scotian Shelf Drift is continuous with and the same age as the glacial drift onshore. Within the study area this unit is exposed on the central portion of the shelf and is overlain by younger sediment on the inner and outer shelf (King, 1970). The extent and location of glacial till ridges and tongues are shown in Figure 4.1-34.

The Scotian Shelf Drift is a cohesive, poorly sorted sediment generally containing angular fragments in the pebble, cobble and boulder range. It is dominantly sandy, but always contains abundant silt and clay. The top surface of the till is rough and undulating, and appears to parallel the underlying bedrock surface. It occurs in relatively uniform thicknesses (10-15 m) except in areas of morainic ridges where thicknesses can reach 100 m (King and Fader, 1986). Its surface has also been heavily scoured by icebergs.

The Emerald Silt overlies and interfingers with the Scotian Shelf Drift. The contact with the Scotian Shelf Drift is marked by lift off moraines on basin floors and interfingers with till tongues (see Figure 4.1-34) at basin margins. These features are interpreted to correlate with the transition from grounded ice shelf to floating ice shelf conditions. It appears that most of the Emerald Silt was deposited from floating ice carrying a wide range of particle sizes, and many factors have contributed to the wide variations in texture.

The Emerald Silt is a fine-grained muddy sediment which is generally silty and locally sandy. Angular gravel-sized particles are present, but are more common in the northeast margin of the basin complex. The Emerald Silt has a smooth surface that is generally horizontal and has a variable thickness reaching a maximum of 240 m.

The LaHave Clay overlies the Emerald Silt and is a bioturbated, olive grey mud derived from the winnowing of glacial sediments during the Holocene transgression. This unit is found ponded in the basins and depressions of the shelf. The LaHave Clay is a loosely compacted silty clay which locally grades to a clayey silt at the basin margins. The formation is remarkably homogeneous and varies little from place to place.

A 110-120 m lowering of sea level on the shelf in the late Quaternary would have subaerially exposed the banks on the outer shelf (Figure 4.1-33). This has been interpreted from widespread erosion of the Scotian Shelf Drift and Emerald Silt at basin margins, in water depths of 100 to 120 m. These units are overlain, in deeper water, by a muddy sand unit called the Sambro Sand, and in shallower water depths by well-sorted sand and gravel of the Sable Island Sand and Gravel Formation. These formations are interpreted to be derived from the reworking of older glacial sediment during the Holocene sea level rise, with the Sable Island Sand and Gravel representing beach sediments and the Sambro Sand resulting from sub-littoral reworking or deposition. Both are time equivalents of LaHave Clay in the basins.

The Sambro Sand Formation is medium to fine grained, and moderately to well sorted. It generally contains about 15% of silt and clay, and locally grades to a sandy gravel. These finer fractions help to distinguish the Sambro Sand from the Sable Island Sand and Gravel. The Sambro Sand generally forms a thin veneer a few metres thick, although pockets of the unit up to 80 m thick have been identified. Its surface ranges from flat and smooth, to undulating and hummocky.

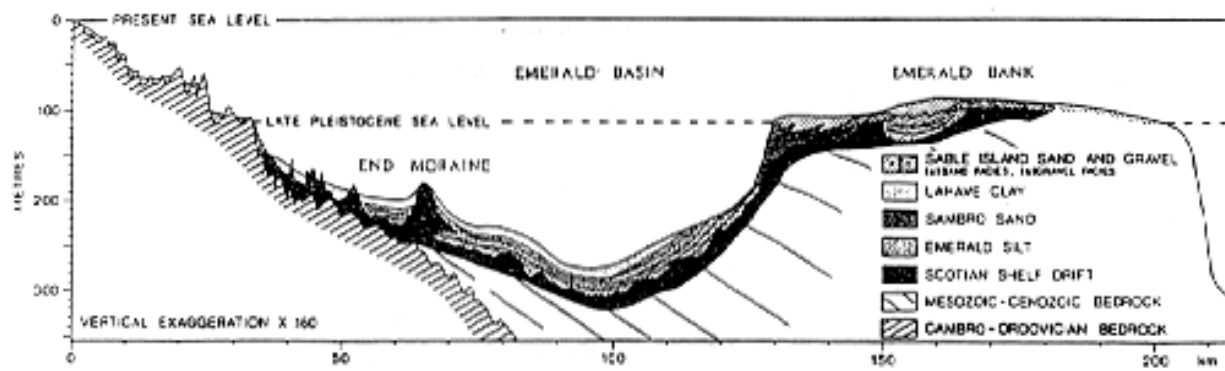


figure 4.1-33 Cross-Section of the Scotian Shelf across Emerald Basin and Emerald Banks showing Surficial Formations, Bedrock, and Last Low Sea Level
(Source: King and Fader, 1986)

The Sable Island Sand and Gravel Formation is a fine to coarse grained, well sorted sand, grading laterally to very coarse, rounded gravel with rounded boulders. The lithology of the clasts of the gravel and boulders clasts is similar to the Scotian Shelf Drift. The unit varies in thickness up to 75 m on Sable Island Bank.

4.1.5.3 Seismicity

The effects of offshore seismicity include: ground shaking, surface faulting, large scale subsidence or uplift, tsunamis, seabed liquefaction, slides, slumps and turbidity currents (Lewis and Keen, 1990). Seismologists assess the likelihood and effects of future earthquakes so that structures may be designed to withstand the expected rate of seismicity to a high degree of probability. In order to do this, they use seismotectonic models to delineate zones of earthquake risk (Lewis and Keen, 1990). Please refer to Figure 4.1-31 for the location and magnitude of earthquake epicentres obtained from the Canadian National Earthquake Database.

In the past, seismic hazard maps were compiled with the assumption that the historical pattern and rate of seismicity would continue. New evidence suggests that most large earthquakes in stable continental areas are caused by the reactivation of rift faults in the continental crust (Adams et al., 1995a). Therefore, the seismicity observed in these settings should be expected elsewhere along the same structures, even in areas which have been historically quiet.

Using a geologically based source model alone will give a much lower estimate of the seismic risk for areas of high historical seismicity while giving only slightly higher estimates in seismic areas. This would not accurately reflect the documented earthquake risk in these areas. Therefore a "robust" approach has been adopted which chooses the higher risk value of either the geological or historical based estimates (Adams et al., 1995a). This approach is experimental at present, but is expected to provide the basis for earthquake risk zones in the year 2000 edition of the National Building Code.

This shift in philosophy from a purely probabilistic approach to one which includes our understanding of geological and tectonic processes has an impact on the seismic hazard zones in Eastern Canada. Previously, the study area was included in the Eastern Background Zone (see Figure 4.1-35). The application of this new approach to seismic risk mapping places the SOEP gas fields and area in the Eastern Continental Margin (ECM) zone, within which magnitude 7 earthquakes have occurred (Grand Banks, 1929; Baffin Bay, 1933), as shown in Figure 4.1-35.

A geological assessment of shallow faults and structural disturbances from the Eastern Scotian Shelf and Laurentian Channel areas was undertaken. Durling and Fader (1986) analyzed over 12,000 km of airgun and Huntect DTS high resolution seismic reflection profiles. Their results showed deformation to be mainly

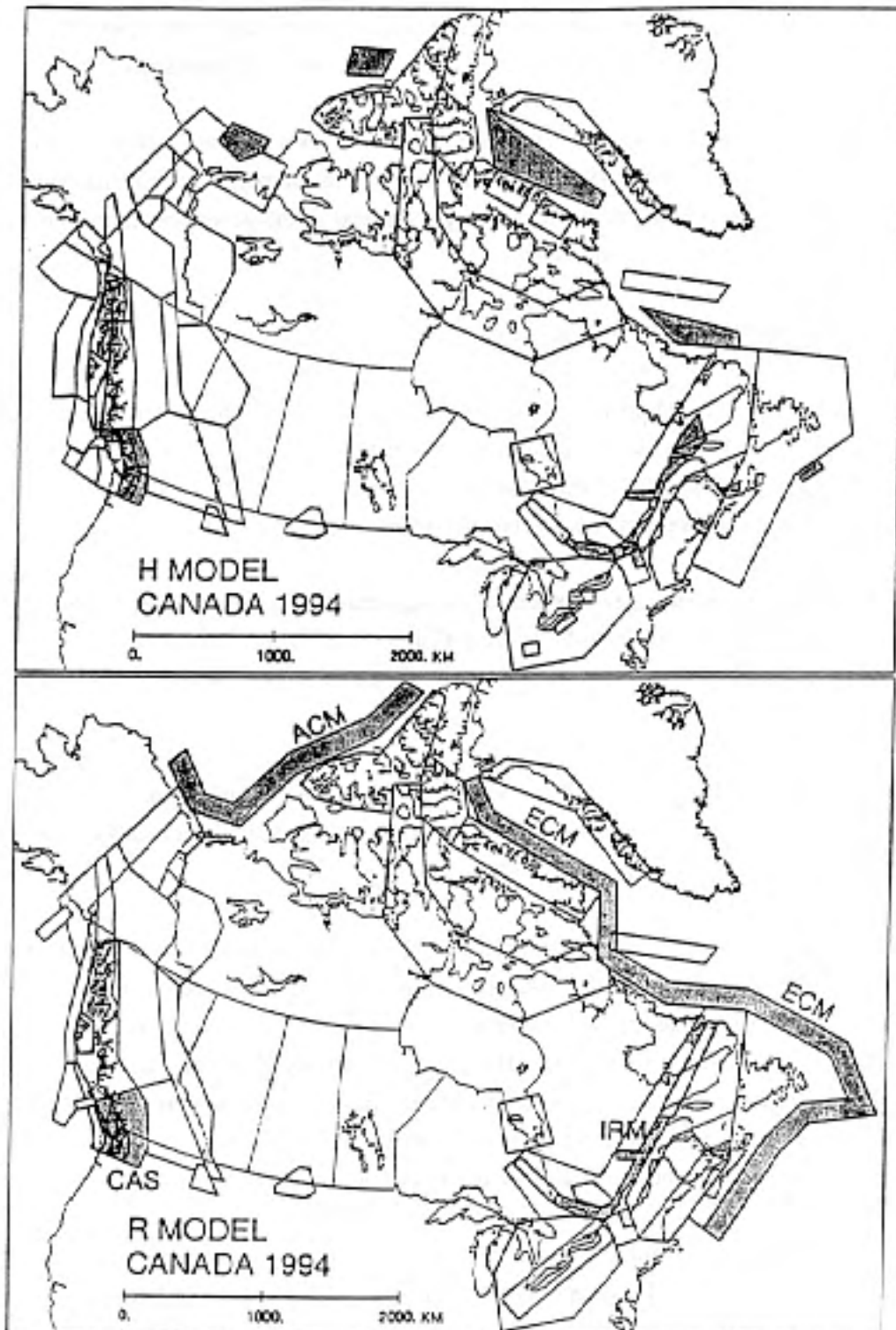


Figure 4.1-35 Previous Earthquake Source Zone Map (top) for Canada,
and Proposed Source Zone Map (bottom)
(Source: Adams et al., 1995b)

pre-Quaternary with surficial sediments exhibiting little deformation (Durling and Fader, 1986). Most of the deformation occurs in the bedrock of the Orpheus Basin and Cape Breton Island Shelf.

The adoption of this new approach to seismic risk mapping results in a slightly higher seismic risk estimated for the study area (Adams et al., 1995b). Future changes in estimated seismic risk should be considered along with physical properties of the underlying sediments in the geotechnical and structural design of the drilling structures and subsea pipelines.

4.1.5.4 Bathymetry

The bathymetry map of the area is based upon the following Canadian Hydrographic Service charts: 4003, 4098, 4099, 4321 and 4335. A shallow water (<30 m) bathymetric survey around the Sable Island area has recently (fall 1995) been completed for SOEP. Swath bathymetry data has also been collected along the proposed pipeline corridor. These data sets can be used to supplement CHS data already compiled.

In the Sable Offshore Energy Project Development Plan Application (Volume 2, Section 5.7.3) an overview of planned survey activities for 1996-97 is presented.

4.1.5.5 Surface Features and Bedforms

The surface features observed on the Scotian Shelf are varied and depend on sediment type, physiography and the hydrodynamic conditions that are present. These surface features include pockmarks, shell beds and a variety of bedforms observed in non-cohesive sediments.

Pockmarks are cone-shaped depressions which can occur in clays, silts, and sands (King and MacLean, 1974; Fader, 1991). They are related to the discharge of shallow gas (methane) in the sediments. Pockmarks are found in the larger basins on the Scotian Shelf (see Figure 4.1-36) (Emerald, LaHave and Roseway Basins). They occur in the Emerald Silt, LaHave Clay and Sambro Sand and are only found in areas overlying the Cretaceous and Tertiary rocks of the Scotian Basin. This suggests a petrogenic gas source for the pockmarks in this area and that it originates from the subsurface bedrock. Pockmarks are not found in the same surficial sediments overlying the pre-Mesozoic acoustic basement.

Pockmarks on the Scotian Shelf were initially thought to be relict features. Evidence now suggests that these features are active (Fader, 1991). They appear to be preferentially aligned along the length of trawl marks, suggesting that their formation may be partly induced by trawling. The fact that trawling is a relatively recent activity, and that the character of the interior of the pockmarks is "fresh," suggests that they are active features.

The routing of a subsea production gathering pipeline over areas of active pockmarks could lead to unsupported spans due to gas-related erosion. Excavation could even induce pockmark activity in the vicinity of the pipeline in pockmark-prone sediments. These areas will be avoided where possible. Soft gas-charged sediments in Country Harbour could have low bearing capacities due to gas-related excess pore pressures. This could lead to differential settlement or slope instability.

Shell beds occur in dense communities of isolated patches on the bank areas of the shelf (Figure 4.1-36). Some areas are composed entirely of dead shellfish, whereas others are live colonies of shellfish. It has been suggested that the occurrence of the shell beds may be controlled by gas escaping from sediments (Fader, 1991). Their distribution could also depend on the combined effects of water temperature, nutrients and current conditions.

The nature of bedforms depends on sediment type and local hydrodynamic conditions. A variety of bedforms have been observed in the mobile sands of the banks on the outer shelf. An analysis of the nature and distribution of bedforms provides clues about the hydrodynamic conditions responsible for sediment transport. This section briefly describes the bedforms found on the outer shelf.

Definitions of the various bedforms are taken from Amos and King (1984). Also included are average heights and wavelengths of the features found on Sable Island Bank.

Sand wave	A composite, flow-transverse, constructive bed feature, formed in medium to coarse sand or gravel, constructed and transported by the superposition and migration of megaripples. Average height - 1.0 m Average wavelength - 116 m Not found on Sable Island Bank (Amos, pers. comm., 1995)
2-D Megaripple	A straight, sharp-crested, flow-transverse, discrete bedform composed of medium to coarse sand and exhibiting a simple ripple-like profile which shows a moderate coherence in crest spacing with adjacent forms. Average height - 0.6 m Average wavelength - 9.3 m
3-D Megaripple	A short-crested, flow-transverse, discrete bedform composed of medium to coarse sand and exhibiting irregularly scoured troughs and a low coherence in crest spacing. Not found on Sable Island Bank.
Sand ridge	A composite, flow-oblique (or parallel) linear accumulation of sand (usually of measurable relief) formed by the superposition and migration of sand wave or megaripple fields. Average height - 4.3 m Average wavelength - 2350 m
Sand ribbon	A current parallel "streak" of sand demarcated laterally by shallow depressions, formed by current scouring.

Average height - negligible
Average wavelength - 80 m

Amos and Nadeau (1988) used reflection seismic and sidescan sonar data to describe the morphology and distribution of bedforms in the coarse-grained Holocene sediments of Sable Island Bank, Middle Bank and Banquereau (see Figure 4.1-36). They define the bedform zonations as:

- A **Highly energetic wave zone**, defined as an area of plane-bedded sands, wave-formed ripples and shore-parallel sand bars.
- B **Storm-dominated energetic zone, nearshore**, characterized by shoreface-connected sand ridges.
- C **Current dominated energetic zone**, characterized by moribund and active (now disputed by Amos) sand waves and active megaripples.
- D **Storm-dominated intermediate energy zone**, characterized by active stormridges migrating over larger-scale offshore features.
- E₁ **Low energy zone**, characterized by large-scale relict or moribund bedforms.
- E₂ **Low energy zone, shelf edge**, characterized by moribund megaripple fields.
- F **Low energy zone**, dominated by specks and shell beds over flat featureless seabed.
- G **Quiescent zone**, with featureless sand, silt, gravel, boulder fields, trawl marks.

With reference to the above zones, Venture and South Venture fields lie in Zone A, Thebaud is in Zone B (close to Zone A), North Triumph on the edge of F and E₂, Glenelg in G and Alma in E₁. Due to the wide variety of hydrodynamic conditions (from highly energetic wave zone to very low energy zone), the sediment transport and the dispersion of drilling muds and cuttings will vary significantly from one site to another.

4.1.5.6 Sediment Transport

Two types of forces are responsible for marine sediment transport. They are gravity-driven and water-driven processes. A brief outline of each follows.

1. Gravity-driven Processes - Seabed Stability

Gravity-driven processes include creep, slumping, sliding and the formation of turbidity currents. In order for these processes to occur, a trigger is needed to initiate movement of sediments that are resting on slopes. Some trigger mechanisms include earthquakes, rapid sea level change, gas venting and oversteepening of slopes due to current scour or retrogressive failure. Prediction of these mechanisms is problematic. However, it is possible to quantify shear strengths for various sediments, define unstable slope angles and predict behaviour under seismic and other types of loading.

Geotechnical investigations at the Venture site reveal overconsolidated sediments with high shear strengths (Moran et al., 1991). The physical properties of the sediments there indicate previous

loading of the area, (possibly by ice) creating good foundation conditions for offshore development. However, driving piles into these sediments will be difficult.

Geotechnical data on other parts of the Scotian Shelf are sparse. Also variability in surficial units makes it difficult to extrapolate physical properties. Detailed geotechnical investigation will be necessary for design purposes.

2. Water-driven Processes

Water-driven processes include wave and current scour, sediment transport and the formation of bedforms and the migration of sea ice and icebergs.

Sediment is transported as bedload or in suspension. Generally, coarser sediment is moved as bedload along the sediment surface by rolling and sliding, or by saltation (bouncing). If the particles are small enough, they are kept in suspension by the turbulence of the fluid and are known as the suspended load.

Biological activity can also induce sediment transport. By disturbing the uppermost layers of fine particles (benthic boundary layer), burrowing organisms, shellfish and bottom fish initiate sediment movement.

Sediment is also transported by ice. Ice rafting is a process where sediment is trapped in, or stuck to, a piece of ice. As the ice travels in the ocean, it melts and rolls. The sediment that was incorporated by the ice is eventually released and settles to the ocean floor. Ice can also move sediment when the ice comes in contact with the seafloor. This is known as ice scour. Depressions from this process can produce localized holes, or if the ice was dragged any distance, it could leave a trench. Presently, ice rafting and scour does not account for significant amounts of sediment transport on the Scotian Shelf.

On the eastern Canadian continental shelf, the effects of sediment transport are apparent. The presence of reworked, sorted sand or gravel on the shallow banks is a result of mobilization of the coarser fraction while the presence of ponded sediments in the basins results from pelagic deposition of suspended particles (King, 1970; MacLean and King, 1971; Amos, 1989; Amos and Judge, 1991).

Sable Island Bank is interpreted to be a region of very active sediment transport. Most sediment transport occurs in water depths of less than 100 m. The intensity of transport increases as depth decreases. The changing morphology of Sable Island itself also demonstrates the dynamism of the area (Cameron, 1965). Several studies have recently been carried out to help quantify the frequency and degree to which sediments are transported (Amos and Judge, 1991; Hodgins et al., 1986 a and b; Hodgins and Sayo, 1986; Amos et al., 1994).

Sand transport across Sable Island Bank, Middle Bank and Banquereau is generally to the northeast and east (Hoogendoorn and Dalrymple, 1986; Amos and Nadeau, 1988) and principally occurs during storms (Hodgins et al., 1986). Sand transport on the outer Scotian Shelf is generally limited

to these areas, and as a result, a wide range of bedforms are found there (see section 4.1.5.5). The seabeds of the remaining banks are dominated by gravel.

The Scotian Shelf seabed is strongly influenced by storm waves and currents, which is extremely important to surficial geological assessment, benthic stock management and offshore development (Amos and Judge, 1991). The general east northeast direction of sediment transport is particularly important as it affects the transport of drilling muds and cuttings away from the main scallop fishing grounds which lie to the west and southwest of the SOEP gas fields.

A clockwise flow of fine sand centred around 20 km southeast of Sable Island was inferred from observations of bedform orientation, grain size trends and cross bedding dip direction, (Figure 4.1-37) (Amos and Nadeau, 1988). At the eastern end of Sable Island Bank, scour and fill structures, comet marks and sand ribbons indicate a net sand transport parallel to bank isobaths and towards the edge of the Scotian Shelf (Amos and Nadeau, 1988).

Amos (1990) reports that at six sites around Sable Island, the transport rates for medium sand varied between 0.036 and 180 kg/m/hr. These rates differ greatly and were observed to modulate with tidal influences and wave conditions. The sediment traps deployed at the sites demonstrate that bedload transport predominates under fair-weather conditions. A situation was observed, however, where a 1 to 2 m-thick zone of suspended sediment was formed during an approximate 1 in 1-year storm event (i.e. the worst storm predicted in a 1-year period). This situation was observed at the Cohasset A-52 discovery site in 37 m of water (Petro-Canada Limited, unpublished data, 1986).

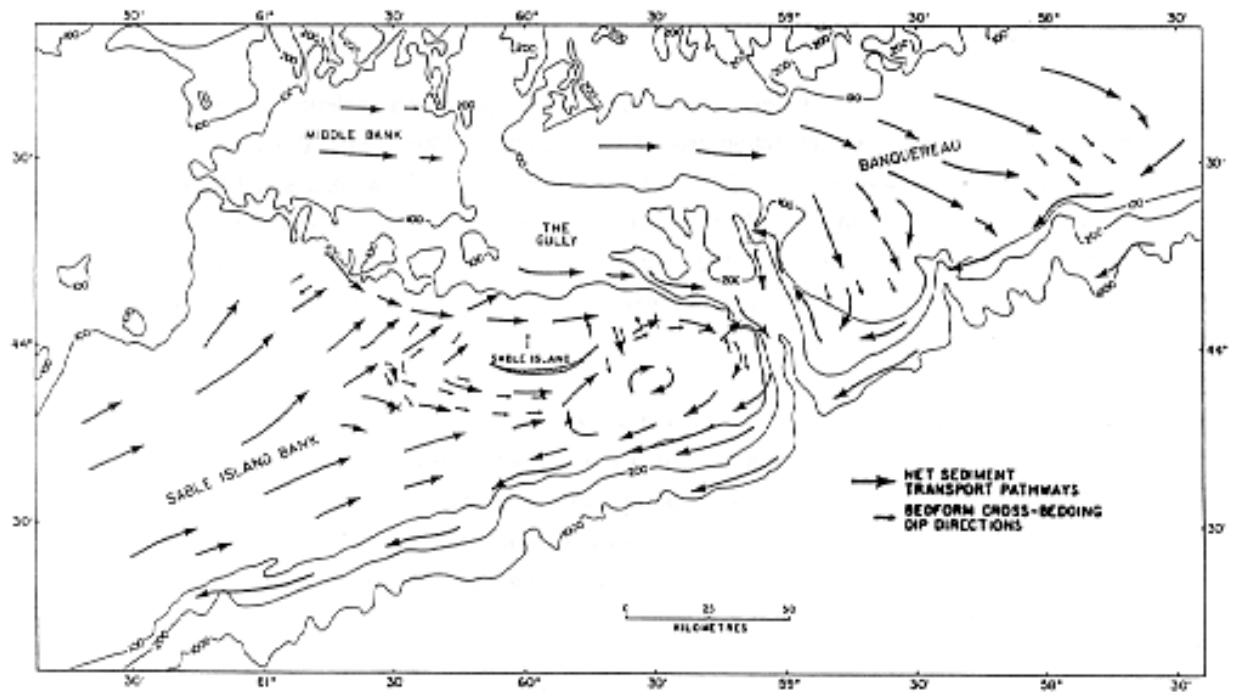


Figure 4.1-37 The Inferred Bedload Transport Paths Based on Grain-Size Trends, Bedform Orientation, and Direction of Dip Cross-Bedding
(Source: Amos and Nadeau, 1988)

Using radio-isotope tracer studies (Hodgins et al., 1986), it was calculated that the rate of long term sediment transport at the Venture site was 20.27 kg/m/hr. This value is a long-term average, and in fact, it is proposed that the transport of sediments during intense storms is one or two orders of magnitude larger than the mean value measured with the tracers.

C.L. Amos and other scientists with GSC Atlantic (formerly Atlantic Geoscience Centre) are involved in constructing a sediment transport model for Sable Island Bank. This computer model is calibrated using seabed observations of hydrodynamic conditions, suspended sediment and evolving morphology (Zevenhuizen and Li, 1994). Early results correlate well with previous work on bedform zonations (Amos and Judge, 1991; Anderson, in review; Amos and Nadeau, 1988).

Numerical simulation of a 1 in 4-year storm on the Scotian Shelf predicts a depletion of sediment in the southwestern part of the bank and accretion around Sable Island. Also predicted are regions of low sediment transport along the eastern and northern margins of Sable Island Bank (Amos and Judge, 1991). This prediction is consistent with the idea of an hydraulic fence which would resist "spillover" of sand into the Gully from the bank. Submersible observations also support this interpretation (Amos, 1989). However sediment slumps and grain flows were observed indicating some transfer of material to deeper water.

A more recent model was run of a 1 in 100-year storm (March 13, 1993) (Anderson, in review). Preliminary results show, in general, sediment accumulation occurs in areas immediately to the east, south and west of Sable Island. These areas correspond to zones A, B and D of Amos and Nadeau (1988), Figure 4.1-36. Zone A is a high-energy, wave-dominated zone while B and D correspond to storm-dominated areas. The models, therefore, corroborate what Amos and Nadeau inferred about dominant sediment transport mechanisms on Sable Island Bank.

The sediment transport model supports the interpretation of bedforms on the outer shelf. It will be an important tool in quantifying the dominant forces at work on the sea floor and in evaluating potential areas of scour and deposition for the design of seafloor structures. Quantitative results, however, should be viewed with some skepticism. The grid cell size (1 km square), is far larger than most of the bedforms observed. Sediment transport modelling at smaller scales will require higher-resolution input data than is currently available (bathymetry, grain size, winds, currents etc.) in addition to needing more computing power.

The fields proposed to be serviced by pipelines in the development area are located in a variety of water depths and environments. The Thebaud, Venture and South Venture sites are in high-energy bedform zones A (wave-dominated) and B (storm-dominated) in 20 to 30 m of water. These are high-energy, wave and storm-dominated zones that are characterized by east- to northeastward-flowing storm-driven currents and strong tidal currents which could induce exposure and/or burial around footings and along the pipeline route.

The remaining fields that are proposed to have pipeline connections with the Thebaud site (Alma, Glenelg and North Triumph) are in deeper water (70 - 80 m) and lower energy environments. Sediment transport should not significantly impact the platforms or pipeline in these areas.

Periodic monitoring of the platforms and pipelines will be necessary, especially in the interpreted high energy and storm-dominated environments.