3. PHYSICAL, HYDRODYNAMIC AND CLIMATIC CONDITIONS OF SITES

3.1 TIDES AND TIDAL CURRENTS

Tides influence water levels in the St. Lawrence River up to Trois-Rivières. Tides are semi-diurnal, which means that there are two complete tidal cycles daily with small inequalities in height and time. Tidal ranges at the sites of interest vary from 3 to 6 m, as described in Table 3.1.

Table 3.1 also summarizes peak current velocities in the direction parallel to shore at selected sites of interest. The tidal current velocity data is a rough estimate, read from the charts of the atlas of tidal currents (Canadian Hydrographic Service, 1997).

Table 3.1 - Tide data and approximate tidal currents for sites of interest

Site	Ville-Guay	Pointe Saint-Denis	Cacouna
Mean water level (m)	2.5	3.3	2.6
Tidal range (m)			
-mean tide	4.7	4.2	3.7
-large tide	6.2	6.2	5.3
Extreme water levels			
-low (m)	-0.8	-0.7	-0.9
-high (m)	7.0	7.5	6.5
Max. current velocity (kn)	3.0	3.5	1,5
Minimum current velocity (kn)	-2.5	-1.0	-1,0
Velocity range (kn)	5.5	4.5	2,5

Current velocity signs: + : downstream
- : upstream

Notes: Tide data from Canadian tide and current tables 2003
Canadian Hydrographic Service, 2003
Elevations are in m above chart datum
Current velocities are approximate, interpreted from atlas diagrams (Canadian Hydrographic Service, 1997)
1 kn = 1 nautical mile per hour = 6080 ft/h = 1.85 km/h = 0.51 m/s

3.2 WINDS

Table 3.2 summarizes key indicators of monthly wind conditions, extracted from the Climatological Charts (Environment Canada, 1994) at the proposed sites. It should be noted that the wind conditions for Rivière-du-Loup have been used as the reference location for Gros Cacouna, being the closest to the site, although it is well established that the wind climate is more severe on the river than on land. All data extracted from atlases should therefore be considered only as initial approximations of the site conditions. Site specific wind measurements would be useful to calibrate historical data.

Wind roses giving seasonal statistics of directional frequencies are also presented in Figure 3.1. These roses have been compiled using a numerical model (Dr. Yvon Ouellet, Laval University) from datasets extracted from Environment Canada's meteorological databases at three different wind recording stations along the St. Lawrence (Lauzon, Fleuve VI, Île Rouge). Two wind roses are presented for each site, the top one showing winter period winds (1 January – 31 March) and the bottom one covering the rest of the year (1 April – 31 December). Seasonal variability can be seen from these, both in velocities and directions. Detailed results from the analysis are presented in Appendix A.

Exceedance percentages may be extracted from these results. Table 3.3 gives exceedance percentages for the 25 knot and 40 knot wind velocities; these velocities are of special interest since they represent weather limits in use at Montoir-de-Bretagne and Bonny terminals (see section 2.2) for interrupting berthing/unberthing manoeuvres (25 kn) or unloading operations (40 kn). The results indicate that no particular problem is to be expected due to winds as to the unloading operations for any of the three sites under study. However, the berthing/unberthing manoeuvres might be disrupted occasionally during the winter season at the Gros Cacouna site: on a statistical basis, assuming statistical independence between arrival and departure dates (2 events per week, a frequency of 2/7 = 28.6%) and winds unacceptable for berthing 28 days (or 7.7% frequency), it can be expected the berthing or unberthing manoeuvres might be delayed (28 x 2/7=) 8 days per year.

Table 3.2 – Wind characteristics at selected sites, by month, from Environment Canada's Climatological Charts

	Site	Ville Guay	Pointe-Saint-Denis	Cacouna,
	Station in Weather Atlas	**St-Jean-Port-Joli**	**Rivière-Ouelle**	**Rivière-du-Loup**
January	Dominant direction (frequency)	SW(23%)	SW(28%)	NW(35%)
	Corresponding avg. velocity *	20 km/h	24 km/h	38 km/h
	Freq. wind >20 kn (38km/h) **	6%	8%	35%
	Freq. wind >33 kn(61km/h) **	0%	3%	3%
February	Dominant direction (frequency)	SW(24%)	NW(20%)	NW(36%)
	Corresponding avg. velocity	22 km/h	18 km/h	39 km/h
	Freq. wind >20 kn (38km/h)	6%	35%	36%
	Freq. wind >33 kn(61km/h)	0%	5%	3%
March	Dominant direction (frequency)	NE(24%)	NE(30%)	NW(29%)
	Corresponding avg. velocity	24 km/h	24 km/h	35 km/h
	Freq. wind >20 kn (38km/h)	9%	11%	26%
	Freq. wind >33 kn(61km/h)	1%	0%	2%
April	Dominant direction (frequency)	NE(32%)	NE(30%)	NE(30%)
	Corresponding avg. velocity	20 km/h	26 km/h	24 km/h
	Freq. wind >20 kn (38km/h)	11%	16%	13%
	Freq. wind >33 kn(61km/h)	1%	1%	0%
May	Dominant direction (frequency)	NE(22%)	N(22%)	NE(28%)
	Corresponding avg. velocity	22 km/h	23 km/h	20 km/h
	Freq. wind >20 kn (38km/h)	10%	12%	8%
	Freq. wind >33 kn(61km/h)	0%	0%	0%
June	Dominant direction (frequency)	SW(19%)	SW(30%)	NE(20%)
	Corresponding avg. velocity	22 km/h	23 km/h	18 km/h
	Freq. wind >20 kn (38km/h)	7%	10%	6%
	Freq. wind >33 kn(61km/h)	1%	0%	0%
July	Dominant direction (frequency)	SW(21%)	SW(25%)	SW(23%)
	Corresponding avg. velocity	22 km/h	24 km/h	18 km/h
	Freq. wind >20 kn (38km/h)	6%	9%	4%
	Freq. wind >33 kn(61km/h)	0%	3%	0%
August	Dominant direction (frequency)	W(22%)	SW(28%)	SW(25%)
	Corresponding avg. velocity	20 km/h	19 km/h	18 km/h
	Freq. wind >20 kn (38km/h)	3%	5%	3%
	Freq. wind >33 kn(61km/h)	0%	0%	0%
September	Dominant direction (frequency)	W(22%)	SW(26%)	SW(22%)
	Corresponding avg. velocity	20 km/h	25 km/h	22 km/h
	Freq. wind >20 kn (38km/h)	5%	10%	8%
	Freq. wind >33 kn(61km/h)	0%	0%	0%
October	Dominant direction (frequency)	SW(23%)	SW(20%)	NW(20%)
	Corresponding avg. velocity	20 km/h	23 km/h	23 km/h
	Freq. wind >20 kn (38km/h)	9%	11%	10%
	Freq. wind >33 kn(61km/h)	1%	0%	0%
November	Dominant direction (frequency)	W(22%)	SW(20%)	NW(26%)
	Corresponding avg. velocity	22 km/h	25 km/h	30 km/h
	Freq. wind >20 kn (38km/h)	9%	15%	22%
	Freq. wind >33 kn(61km/h)	2%	1%	1%
December	Dominant direction (frequency)	W(21%)	SW(26%)	NW(32%)
	Corresponding avg. velocity	21 km/h	30 km/h	36 km/h
	Freq. wind >20 kn (38km/h)	7%	21%	33%
	Freq. wind >33 kn(61km/h)	0%	1%	3%

Notes:
* Corresponding avg. velocity: mean speed of winds blowing from the dominant direction only
** all directions being considered
1 kn =1 nautical mile per hour = 6080 ft/h = 1.85 km/h = 0.51 m/s
Ref: Environment Canada - Climatological Charts of the Saint Lawrence, 1994

Table 3.3 - Exceedance percentages of typical wind velocities, by month, as established from numerical modelling (Laval University)

	Exceedance of 25 knot (46 km/h) wind velocity * (percent)			Exceedance of 40 knot (74 km/h) wind velocity * (percent)		
Site	**Ville Guay**	**Pointe-Saint-Denis**	**Cacouna**	**Ville Guay**	**Pointe-Saint-Denis**	**Cacouna**
Wind recording station (duration of dataset)	Lauzon (1991-2002)	Fleuve VI (1980-1993)	Île Rouge (1988-2002)	Lauzon (1991-2002)	Fleuve VI (1980-1993)	Île Rouge (1988-2002)
January	1.454	1.384	18.159 (135 h)	0	0	0.7
February	1.557	1.020	16.982 (114 h)	0	0	0.35
March	2.510	1.062	11.635 (86 h)	0.07	0	0.25
April	1.295	0.864	5.622	0	0	0.28
May	1.873	0.126	2.611	0	0	0
June	0.762	0.033	1.481	0	0	0
July	0.199	0.021	0.748	0	0	0
August	0.320	0.063	0.818	0	0	0
September	0.429	0.105	2.212	0	0	0.01
October	0.925	0.503	3.947	0	0	0.01
November	1.154	1.182	9.135	0.04	0	0.08
December	1.430	1.565	18.803 (140 h)	0.01	0	0.55
All Year	0.948 3 days	0.483 2 days	7.721 28 days	0.01	0	0.25 0.9 day

<u>Notes</u>: * All wind directions considered
1 kn = 1 nautical mile per hour = 6080 ft/h = 1.85 km/h = 0.51 m/s
Ref: Laval University model, Environment Canada datasets

3.3 Waves

Figure 3.2 shows series of wave roses for each of the sites, based on a preliminary hindcast analysis using the wind data presented above and an evaluation of the appropriate fetch distances in every direction. This computation has also been performed using Laval University's numerical modeling tools. The period of time usually considered for possible wave generation is April 1 – December 31 since the presence of ice during winter limits the formation of waves. However, it is noted that particular water temperature conditions at the mouth of the Saguenay river, close to the Gros Cacouna area, prevent formation of an ice cover over a fairly large area for most of the winter season. Therefore the formation of waves is considered possible yearlong at Cacouna. The influence of ice cover should be evaluated more precisely at a subsequent stage of the project. Complete analysis results are presented in Appendix B.

Table 3.4 presents exceedance percentages of 1.5 m high waves along with corresponding peak periods at each site, extracted from the model outputs. As compared with the 1,5 m / 9 s operating limit in use at Bonny terminal (see Section 2.2), these preliminary results indicate that the wave conditions are within acceptable limits at the three proposed sites.

Table 3.4 – Approximate wave characteristics at selected sites

Site	Ville-Guay	Pointe Saint-Denis	Gros Cacouna
Exceedance percentages of 1,5 m waves	0,02% (1,2 h / season*)	0,54% (31,5 h / season*)	2,08% (182 h / yr)
Corresponding peak period	5-6 s	5-7 s	5-8 s

season = from April 1 to December 31. For Gros Cacouna, a complete year period is considered to account for the absence of an extended ice cover due to particular regional climatic conditions.

WINTER (1 JANUARY – 31 MARCH) (Top) AND SUMMER (1 APRIL - 31 DECEMBER) (Bottom) WIND ROSES

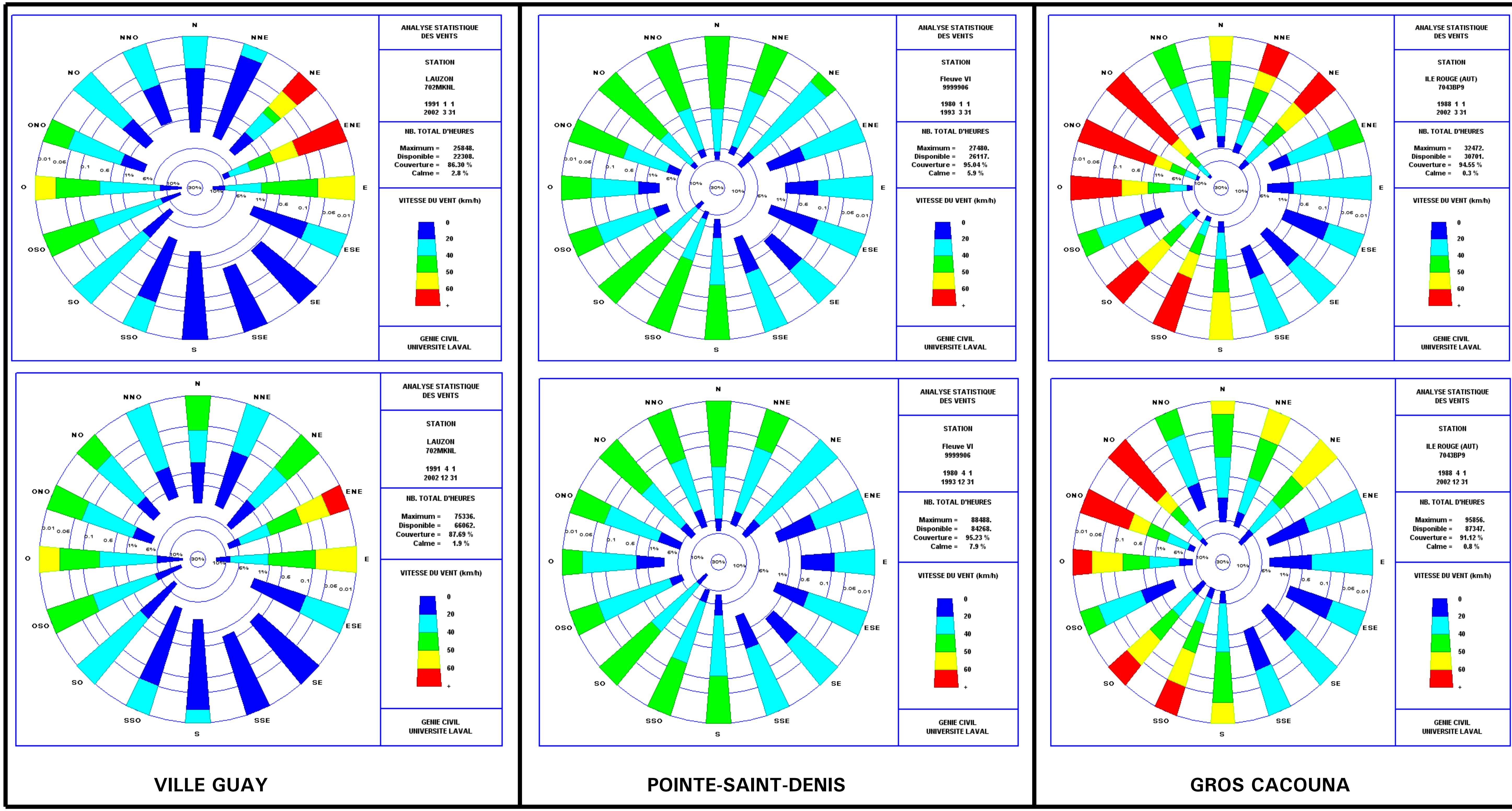
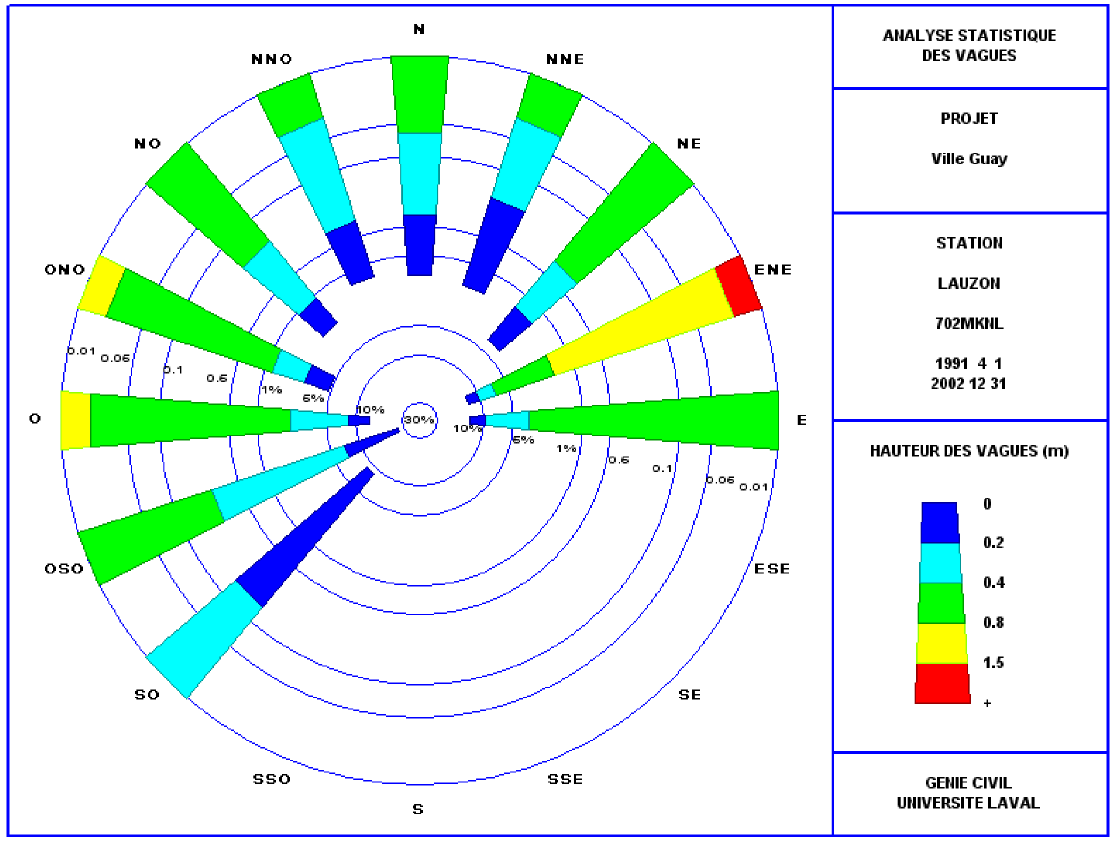
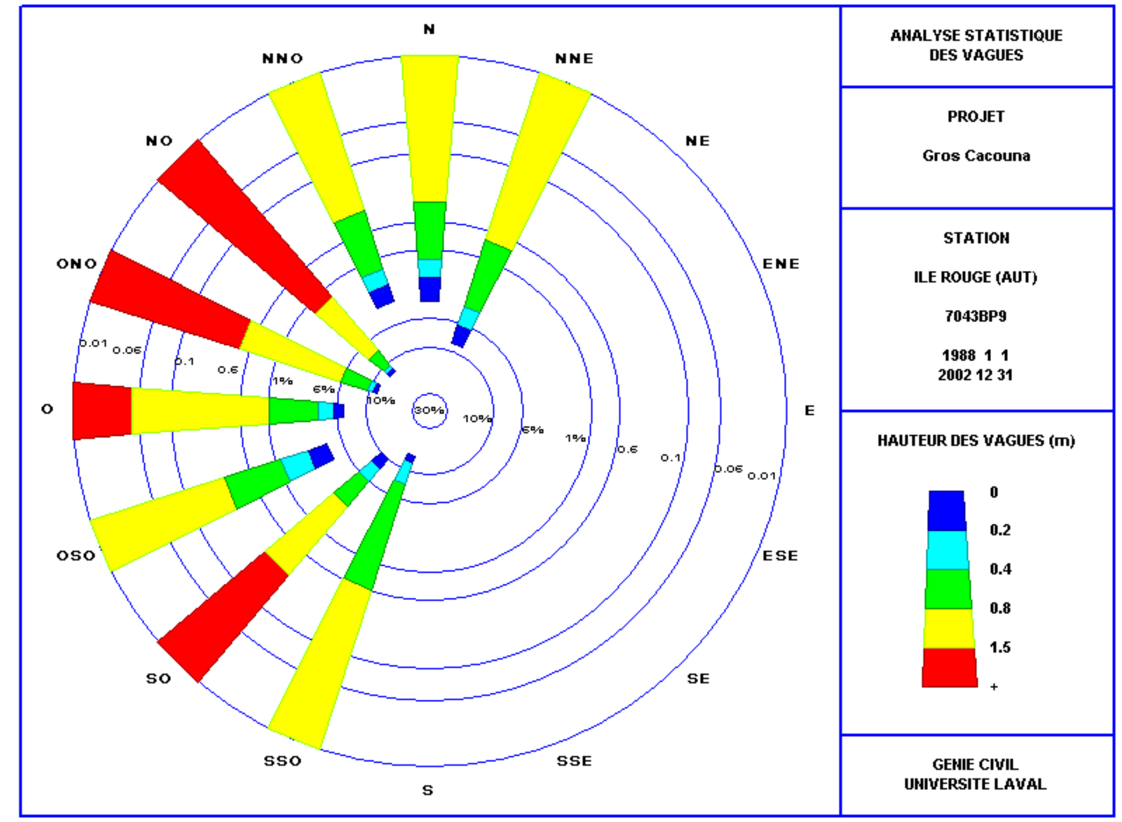


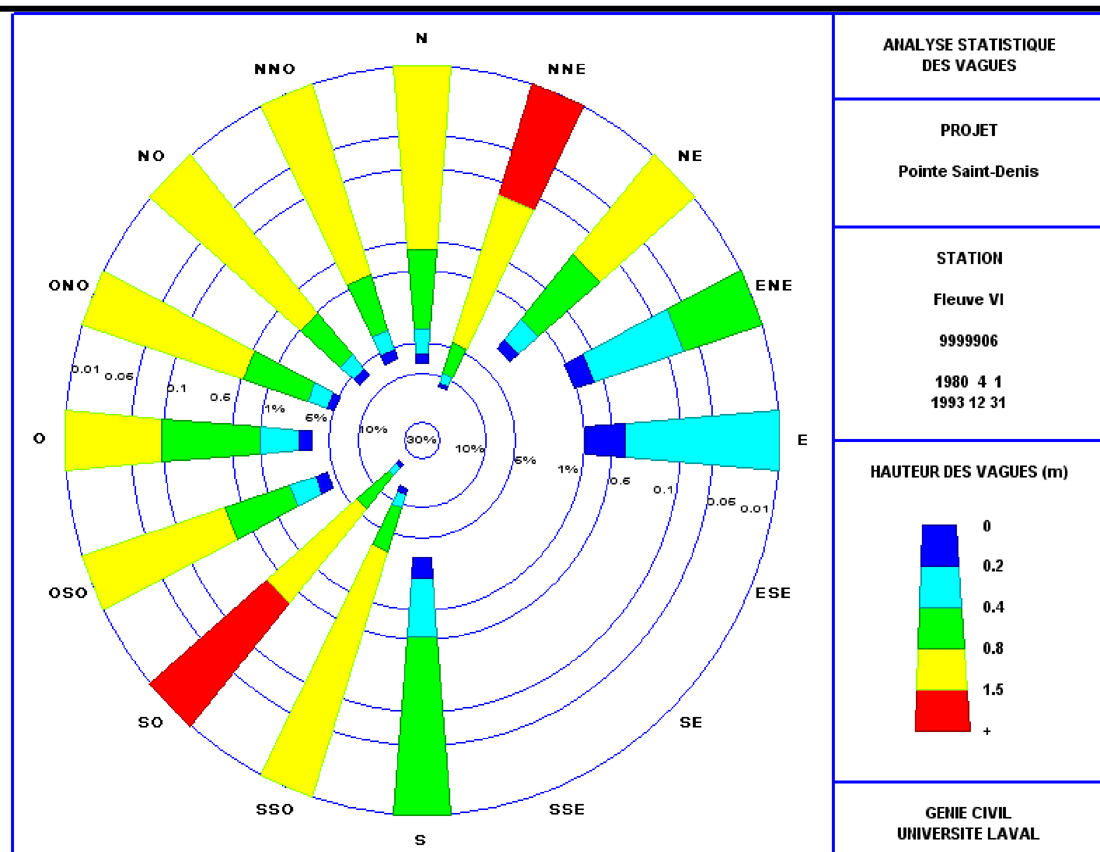
Figure 3.1
WIND CONDITIONS AT THE THREE SITES UNDER STUDY



VILLE GUAY



GROS CACOUNA



POINTE-SAINT-DENIS

Figure 3.2
WAVE CONDITIONS AT THE THREE SITES UNDER STUDY

3.4 AIR TEMPERATURE, WATER TEMPERATURE

Monthly average air and water temperatures (at 1 m depth) are summarized in the following Table 3.5. Approximate data, read from the Climatological Charts of the St-Lawrence (Environment Canada, 1994) are presented for Ville-Guay and Cacouna, and also for Cabot Strait, the narrowest passage between Cape Breton Island and Newfoundland, considered as the entrance into the Gulf of St. Lawrence.

Table 3.5 – Air and water temperatures at selected sites, by month

Site	Ville Guay	Cacouna,	Cabot Strait
Station in Weather Atlas	**St-Jean-Port-Joli**	**Rivière-du-Loup**	-
January Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 -10 0	 -8 0	 -4 1
February Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 -10 -1	 -8 -1	 -6 0
March Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 -4 0	 -5 0	 -4 0
April Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 2 2	 2 2	 2 1
May Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 10 9	 6 4	 6 4
June Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 16 14	 12 7	 10 8
July Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 19 19	 14 10	 14 13
August Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 18 19	 14 9	 18 16
September Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 15 16	 10 8	 12 14
October Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 9 9	 6 6	 8 10
November Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 2 4	 1 3	 4 6
December Avg. air temperature (deg. C) Avg. water temperature (deg. C)	 -8 2	 -6 2	 0 3

Notes: data from Climatological Charts of the St. Lawrence (Environment Canada, 1994)
1 kn =1 nautical mile per hour = 6080 ft/h = 1.85 km/h = 0.51 m/s

3.5 VISIBILITY

General visibility, expressed as the frequency of visibility less than 1 km is available from the Climatological Charts of the St. Lawrence (Environment Canada, 1994). This data is presented by month in Table 3.6. It should be considered only a rough indication.

Table 3.6 - Visibility characteristics at selected sites, by month

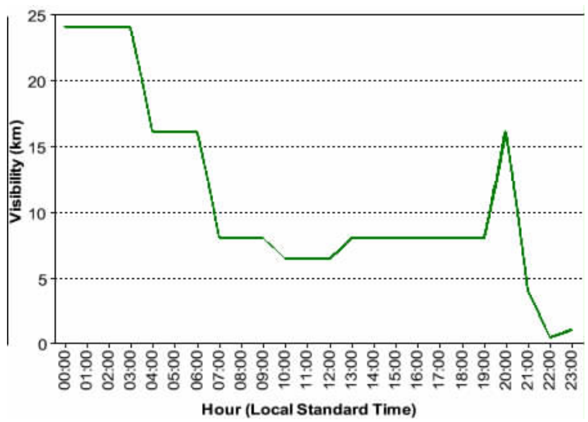
Site	Ville Guay	Cacouna,
January	<5 %	5-10 %
February	<5 %	5-10 %
March	<5 %	10 %
April	<5 %	<5 %
May	<5 %	<5 %
June	<5 %	5 %
July	<5 %	5-10 %
August	5 %	10-15 %
September	<5 %	5-10 %
October	<5 %	<5 %
November	<5 %	5 %
December	<5 %	<5 %

Note: Table shows frequency of visibility less than 1 km;
data from Climatological Charts of the St. Lawrence (Environment Canada, 1994)

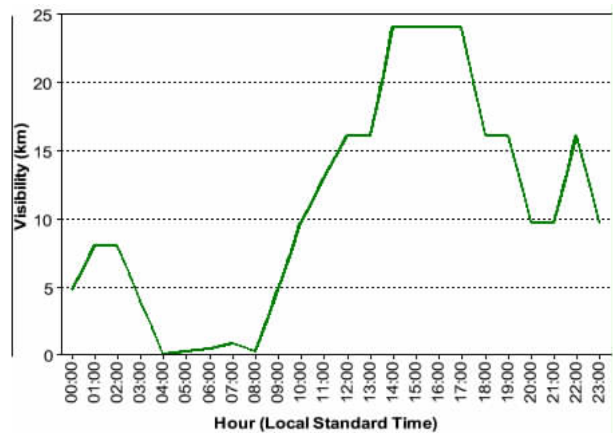
Following a verification with Environment Canada's Meteorological Service in the course of this study, it appears that visibility has never been considered a high priority parameter (partly due to the difficulty of evaluating this parameter – a human observer is required, no automatic recording station takes any measurements of this data). Available data are rather scarce within the region of interest for this study: only Quebec City and Mont-Joli (located about 150 km downstream from Gros Cacouna) recording stations include observations about visibility distances.

The following graphs give an idea of the type of information available on Environment Canada's web site. This information can be accessed only for a single day at a time, which makes the analysis more complicated.

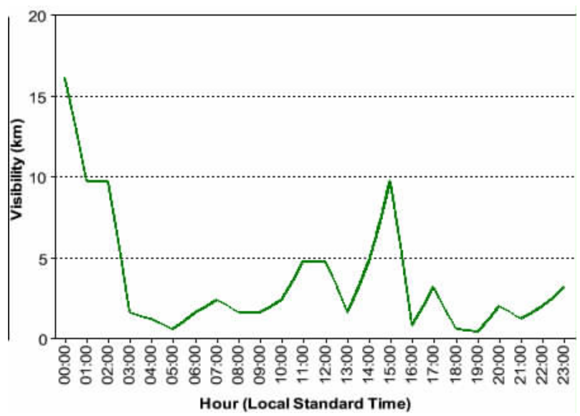
Hourly Visibility for July 9, 2001



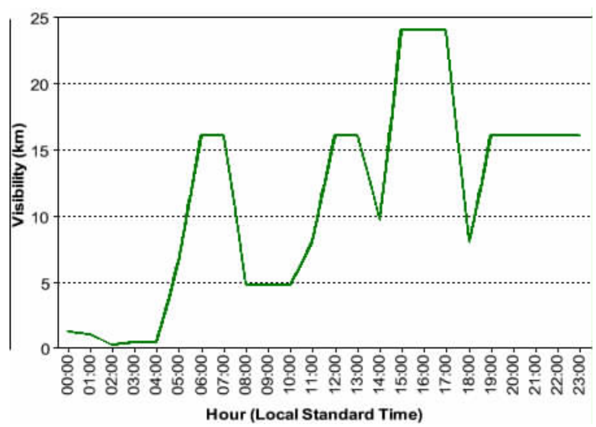
Hourly Visibility for July 10, 2001



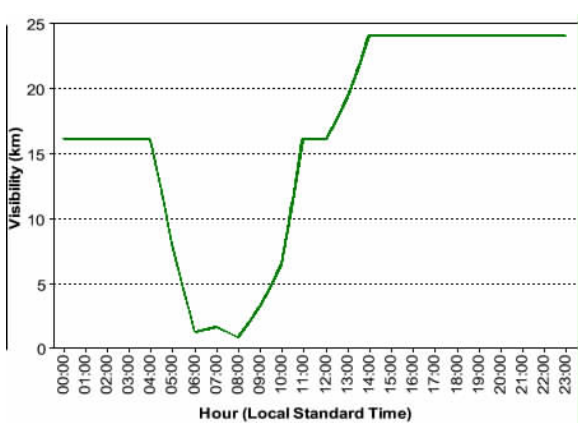
Hourly Visibility for July 11, 2001



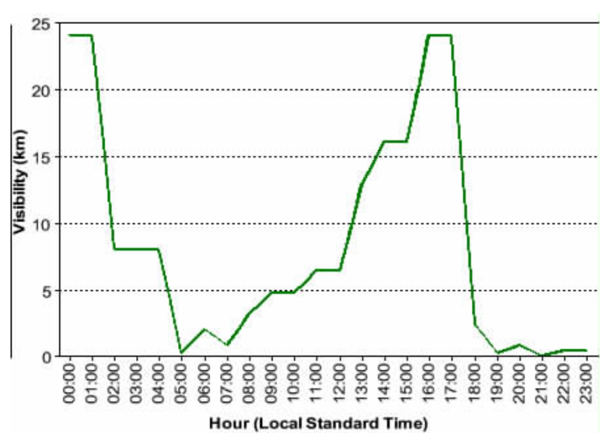
Hourly Visibility for July 12, 2001



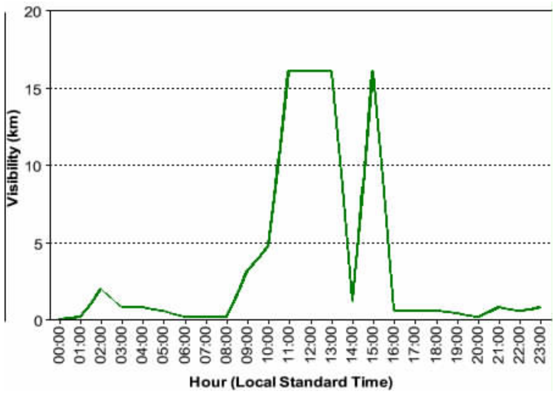
Hourly Visibility for July 13, 2001



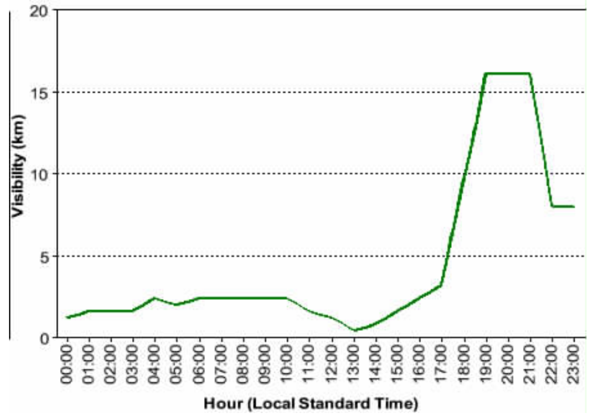
Hourly Visibility for July 14, 2001



Hourly Visibility for July 15, 2001



Hourly Visibility for July 16, 2001



(web address to access visibility graphs – this example applies to July 31, 2001-
http://www.climate.weatheroffice.ec.gc.ca/climateData/generate_chart_e.html?timeframe=1&Prov=XX&StationID=5814&Year=2001&Month=7&Day=31&MeasTypeID=visibility&Type=line)

These graphs were extracted from Mont-Joli weather station data and they represent all days of July 2001 for which visibility distances were below 1,0 nautical mile (= 1,8 km); this distance has been suggested by Client as an operational limit for safe berthing / unberthing manoeuvres. According to the pilots consulted in the course of the mandate, adverse visibility conditions are often encountered during the month of July. For this particular month (July 2001), short visibility distances were observed between the 9th and the 16th ; conditions were normal during the rest of the month.

As can be seen, these constraining conditions usually occur for rather short periods of time, generally in the range of 2-6 hours, up to 10-12 hours for the longest foggy episodes. A similar verification with the Cap-Chat station data, for the period from July 1 to September 30, 2001, has given similar results.

3.6 SEISMICITY

New seismic loading rules will be incorporated in the next edition of the National Building Code of Canada (NBCC), which will be in application by the time of construction of the facilities. The new rules, which are based on dynamic analysis techniques, are published (Canadian Journal of Civil Engineering). In the same publication, the mapping of seismic design parameters is also presented. The general conditions at the three sites may be generally described by the maps of Figure 3.3, showing the 0,2 s spectral accelerations for Canada, and details for Eastern Canada. It is immediately noticeable that Pointe Saint-Denis, which is located directly in front of La Malbaie, on the south shore of the St. Lawrence, is located in one of the most severe seismic areas of the country. Sites located downstream or upstream have a decreasing seismic exposure.

Table 3.7 provides the spectral accelerations to be used in the application of the new code. The design spectra corresponds to a 2% probability of recurrence in 50 years. Noting that a gravity-based caisson of the size discussed later would have period between 0.2 and 0.5 s, consider the spectral acceleration corresponding to a structure with a 0.5 s natural period of vibration. The seismic acceleration is 0.3 g at Ville Guay, almost doubling to 0.54 g at Gros Cacouna, and doubling again to 1.2 g for Pointe Saint-Denis. The seismic exposure at Ville Guay is not negligible, although not of the same severity as some LNG sites in Alaska or Japan. The different seismic conditions at each site are likely to entail significant design and the cost differences for both the marine and the land-based facilities.

Table 3.7 - Spectral accelerations and PGA for sites of interest

Site	Montreal	Ville-Guay	Pointe Saint-Denis	Cacouna
Closest location Longitude Latitude	Montreal N 45.5 W 73.6	Lévis N 46.8 W 71.2	La Malbaie N 47.7 W 70.2	Cacouna N 47.9 W 69.5
S (0.2)	0.69	0.58	2.3	0.98
S (0.5)	0.34	0.30	1.2	0.54
S (1.0)	0.14	0.14	0.60	0.25
S (2.0)	0.048	0.049	0.19	0.084
PGA	0.43	0.36	1.1	0.56

Notes: S (T) designates the spectral acceleration for a period of T seconds, in units of g.
PGA designates peak ground acceleration
Reference: Adams, J. and S. Halchuk. 2003.

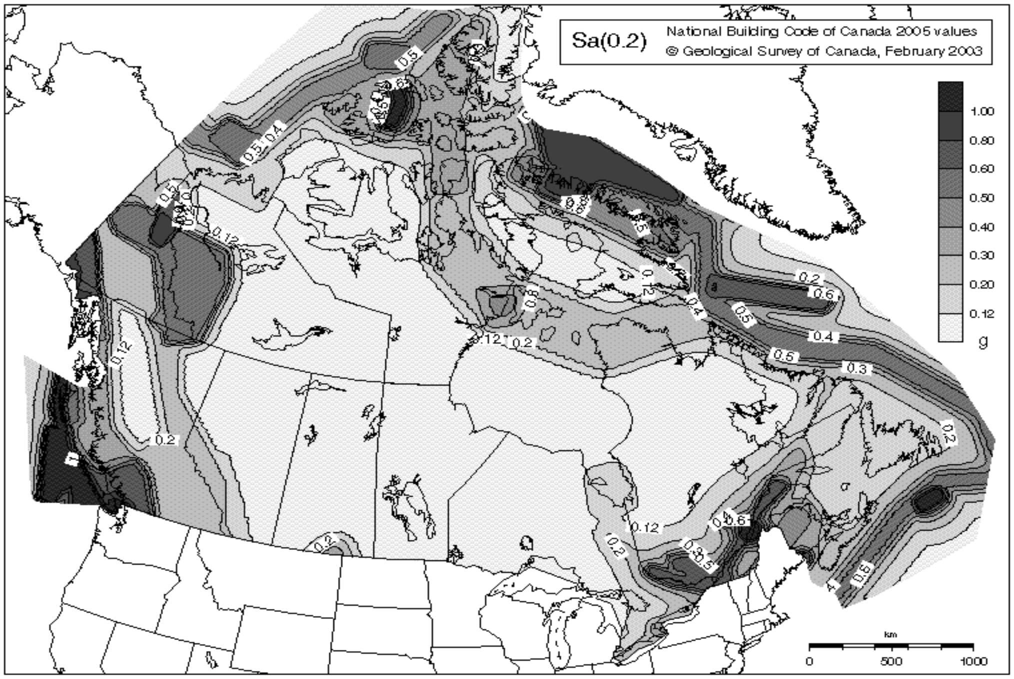


Figure 8. Sa(0.2) for Canada (median values of 5% damped spectral acceleration for Site Class C and a probability of 2%/50 years).

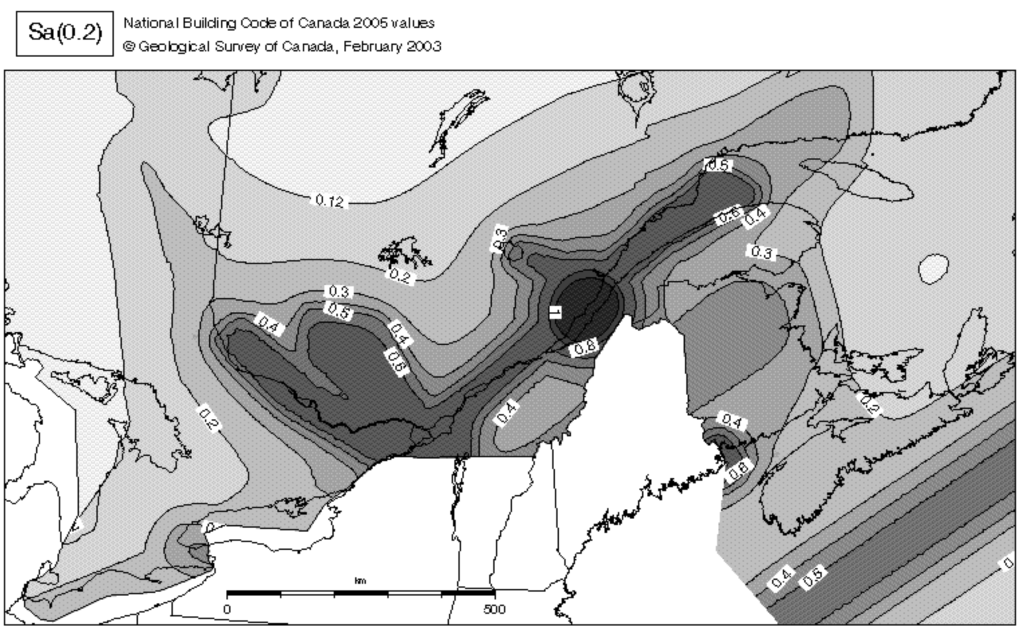


Figure 9. Sa(0.2) for southeastern Canada (median values of 5% damped spectral acceleration for Site Class C and a probability of 2%/50 years).

Source : Adams, j., and S. Halchuk. 2003. Fourth generation seismic hazard maps of Canada : values for over 650 Canadian localities intended for the 2005 National Building Code of Canada. Geological Survey of Canada, Natural Resources Canada, Open file report 4459.

Figure 3.3 Mapping of seismic spectral accelerations for a period of 0.2 s for Canada and eastern Canada

3.7 Geotechnical conditions

3.7.1 Ville Guay

With the exception of a biophysical and a geological map, we have not been able to identify any geotechnical data in the Pointe-de-la-Martinière/Ville Guay vicinity, despite the existence of several prior studies in view of establishing port and other land-based industrial operations in the area. However, several studies conducted in a radius of 8 kilometres from the sector have been found and consulted. These reports and the field visit carried out during the course of this study indicate the following general points:

- Soil deposits are generally composed of granular, non cohesive soils, typically silty sands and gravely silts, of medium to high density, of variable thickness, between 0 and 13 m.
- Bedrock is of sedimentary origin, generally consisting of clayey shale, mudstone, siltstone or calcareous conglomerate; occasionally very fractured; poor to good quality, according to RQD indices; sloping 20° to 60° from horizontal; according the geologic maps, a presumed overlapping fault (faille de chevauchement) is present near the site.
- Seismicity: as seen before, the peak ground acceleration (PGA) is 0,36 g for a probability of exceedance of 2% in 50 years, and the foundation conditions would be of Category C or D in accordance to the applicable future NBCC.
- Other observations:
    - At Ville Guay, bedrock is visible from the shore;
    - According to other studies near the shoreline, it has been observed that the bedrock slopes gently and regularly towards the navigation channel; however, we believe that a rapidly increase in depth of the bedrock is likely in this sector;
    - The thickness of the soil deposits may therefore increase rapidly, away from the shoreline.
- Comments :
    - The non cohesive nature of the soil deposits and compacity between medium and very dense would suggest bearing capacities on the order of 200 kPa, which would be well suited for gravity-based caisson-type foundations. The bedrock observed on the shore or underlying these soil deposits would also provide excellent bearing conditions for this type of structure.

- The establishment of deep pile-type foundations bearing on the bedrock would also be a viable solution, provided the overburden is sufficient to provide sufficient lateral support.

3.7.2 Pointe Saint-Denis

A single geotechnical report prepared for the wharf at Pointe-aux-Orignaux, neighbouring Pointe Saint-Denis, has been examined. The borings have been made no further than 100 m from the shore. The main observations are as follows:

- Soil deposits are generally composed of granular, non cohesive soils, typically silty sands; density .loose to very loose, with the exception of the effect of stones and blocks; thickness between 2 and 4.5 m.

- Bedrock is of sedimentary origin, generally shale and siltstone; quality very poor to good, according to RQD indices; sloping 40° from horizontal.

- Seismicity: the peak ground acceleration (PGA) is 1,1 g for a probability of exceedance of 2% in 50 years, using La Malbaie as the reference location, located 25 km to the NW across the river; the foundation conditions would be of Category F in accordance to the future NBCC.

- Other observations:

  - At Pointe-aux-Orignaux, the bedrock is on the surface at the shoreline, but becomes rapidly covered by soil deposits offshore;

  - Bedrock has a constant slope of about 12% towards the channel;

  - We would expect the slope to be steeper at Pointe Saint-Denis, based on the topography of the land,

- Comments :

  - From a geotechnical standpoint, the presence of very loose to loose granular soils is problematic because of the potential for liquefaction in an earthquake, the site having one of the most severe seismic exposures in Canada. Consequently, caisson structures and even piled foundations are likely to be problematic, because of poor lateral support. Bored piles, encased into the bedrock, some of which inclined for lateral resistance, would be the likely solution.

3.7.3 Gros-Cacouna

At Gros-Cacouna, there are many geotechnical investigation reports available, due to the existing port facilities. The following general information may be extracted from this work :

- Soil deposits: from the river bottom to an elevation of approximately -10 à -18 m, silt and sand deposits, of loose to medium density, alternating with silty clays, of soft to firm consistence and medium to dense sands. Below this superficial layer, a clayey till is encountered, having a stiff or very stiff consistency, strongly overconsolidated.

- Bedrock of sedimentary (shale, conglomerate, mudstone) or igneous origin, is encountered at elevations between –15 and –45 m; quality estimated to be good, according to RQD indices; fractures sloping 20 to 45° from the horizontal are generally closed; slope of the mudstone 60°.

- Seismicity: the peak ground acceleration (PGA) is 0,56 g for a probability of exceedance of 2% in 50 years, at Saint-George-de-Cacouna; considering the till deposit for bearing, the foundation conditions would be of Category C in accordance to the future NBCC

- Other observations:

  - All of the geotechnical data comes from the area of the existing dock or from the inside of the port, limited by the breakwater.

- Comments :

  - Due to the generally poor and variable nature, thickness, density and consistence of the soil deposits above the till, these soils are unsuitable to serve as a base for any marine structure. Caissons or piles must bear of the clayey till, located between elevations –10 to –18 m. In this layer, bearing capacities between 300 and 500 kPa are allowable, according to the studies.

  - However, settlements of the dock caissons between 125 and 310 mm have been observed, and have taken place for the most part during the first year after construction.

  - The layer of soil to be removed by dredging in order to reach a suitable bearing layer could be on the order of 5 to 10 m.

  - Marine structures based on deep-seated piled foundations supported in the till or at the surface of the bedrock is also a valid solution.

- Previous investigations indicate the presence of boulders on the beaches; detection of large blocks or boulders would be essential, prior to the placement of caissons.

3.7.4 Summary of geotechnical considerations

Based of the available reconnaissance studies and observations made during the site visit of the three (3) sites considered for the LNG terminal, Ville Guay and Gros-Cacouna are clearly more favourable from a geotechnical standpoint.

Pointe-Saint-Denis is much less suitable, due to its thick, soft soils and high seismic exposure.

No borings have been made at any of the specific locations for the marine structures considered in this study. A complete geotechnical investigation at the preferred site is recommended.

Table 3.8 – Summary of geotechnical parameters at selected sites

Site	Ville-Guay	Pointe Saint-Denis	Cacouna
Source of geotechnical data	Interpretation based on general knowledge of regional geology and some borings located at MIL Davie Shipyard (7 km upstream) and St-Laurent wharf (5 km downstream, on Île d'Orléans)	Interpretation based on 4 boreholes on Rivière-Ouelle wharf, 4 km west of proposed site. The boreholes are located about 100 m from shoreline whereas LNG wharf would be implemented 3 km from shore;	Data from various geotechnical studies within the limits of the existing port of Gros Cacouna, next to proposed LNG terminal site ;
Stratigraphy from available borings	Surface soil consists of silty sand and gravel, compact to very dense relative density, bearing capacity 200 kPa; Bedrock probably near river bottom (depth 0 – 10 m) at wharf location, 300 m from shoreline.	Bedrock: shale and siltstone (sedimentary), low to fair bearing capacity; Surface deposit consists of silty sand, very loose to dense relative density. May have a potential for liquefaction in case of earthquake, if very loose density is confirmed on site.	From river bottom down to –10 @-18 m, alternate deposits of silt and sand (loose to compact relative density), silty clay (soft to firm consistency), and sand (medium to dense density) Below –10 to -18 m, clayey silt till with very stiff to hard consistency; Bedrock consists of sound fine grained igneous rock with occasional fractures. Bedrock dips into the harbour area with a relatively steep angle;
Other observations	Bedrock outcrops on shore;		Bedrock outcrops on shore (Gros Cacouna Island). Also, check for presence of boulders (TBD by further geotechnical study).
Seismicity	Moderate	Extreme	High
Probable design	Suitable for caisson type marine structure	Structure on piled foundation proposed for the port infrastructure.	Suitable for gravity-type caisson structure; May require removal of surface low density soils and boulders.

3.8 ICE CONDITIONS

3.8.1 Ice Thickness

Since 1961, Environment Canada has collected ice thickness data at a number of sites throughout Canada, and relevant information for several sites of interest is reported in the ice study (PCAI, 2003). This data is for sheet ice growing naturally in calm conditions and sampling of the thickness takes place throughout the winter. Based on data from the stations closest to the sites under study, the estimates of the mean and maximum (assumed to equal the mean plus twice the standard deviation) ice thickness are summarized in Table 3.9.

Table 3.9 – Estimates of sheet ice thickness at selected sites

Site	Ville Guay	Gros Cacouna
Mean thickness (cm)	40	30
Std. Dev. (SD) thickness (cm)	30	30
Maximum thickness (cm) =Mean + 2 SD	100	90

Note that these estimates do not include the potential effects of ice dynamics which may produce grounding, rafting, piling, accumulations of brash, consolidation and refreezing. Therefore, the actual deformed ice cover may be several times thicker.

On some parts of the shore, the growth of the stable land-fast ice occurs under the influence of dynamic tidal conditions and the so-called *batture* ice may attain several metres in thickness locally, and several kilometres in size. When a *batture* becomes dislodged, it becomes a formidable ice feature likely to impinge on a fixed structure and/or obstruct navigation. There is not any statistical data on the thickness and sizes of these features. However, the Canadian Coast Guard closely monitor ice conditions on the St. Lawrence, including the stability of the land-fast ice. When a *batture* becomes free-floating, ice breakers may be sent to break it up so that the risk of a dangerous impact or obstruction to navigation is mitigated.

3.8.2 Assessment of ice conditions at the sites under consideration

Cacouna

The ice conditions are somewhat influenced by the Saguenay polynya, an area of open water present at the mouth of river most of the winter, and also by dynamic hydraulic conditions. The location is shielded by Île Verte from the influence of weather or waves from the deeper estuary, but at the same time, swept by a dynamic tidal current regime. Strong, sustained winds from the NW sector are present close to 40% of the time during January, February and March, which pushes the ice towards the south shore. Ice may therefore jam the area occasionally. Winds blow from the SW sector for another 20% of the time, which has the opposite tendency of clearing the area. From historic sources quoted in the ice study (PCAI, 2003), a N or NW wind can cause ice to remain for some time, forming a belt fringing the NW shore of the island, stopping temporarily the net progression of the floating ice. Stable shore-fast ice develops on the shoals east of the deep water area up to Île Verte. However, shore ice is least extensive along the upstream part of the ridge. The tidal currents are too active to allow locally formed ice to ground itself firmly, particularly where water depth increases rapidly. While stable shore ice is unlikely, thick floating ice covers will come and go.

Flow velocities in the south channel are far more restricted than in the north channel due to broad shoals and a succession of shallows and islands extending upstream to Kamouraska. The north channel which is often clear of ice, is the preferred route for large floes drifting from upstream, causing the floe to come out past Île aux Lièvres and to float clear of the site. The likelihood of large *batture* floes impinging upon the Cacouna site is low, but possible.

Ice is far more prevalent and persistent in the south channel, where progress of the ice is slower. As this drifting ice emerges from the channel south and east of Île aux Lièvres, currents will tend to steer the ice clear of Île Verte, and therefore clear of the Cacouna Island. Ice incursions from upstream are unlikely because of the limited strength of the driving force from the wind compared to that of the strong ebb currents, and because of the rampart created by Île Verte. However, a band of concentrated ice can form along the northwest sh ore, passing in front of the Island. In fact, ice concentrations of 9-10, including significant partial concentrations of first year (30-70 cm) ice are not unusual.

The presence of this floating ice which could persist hours or days depending on conditions, is not likely to hinder the movement of a large powerful LNG carrier, but would render difficult if not impossible the clearing of ice from the face of the jetty before docking. In addition, an ice intrusion while the carrier is docked could complicate an emergency departure.

Pointe-Saint-Denis

The site off Pointe-Saint-Denis is located 50 km upstream from Cacouna, in deep water, just upstream from the entrance of the south channel described above. Because of the shape of the shoreline, the site is a zone of convergence for ice. This is borne out clearly by the statistics from river ice charts presented in the ice study. Because of the focus to the north side, there is less ice data available at this site, compared to the other two.

Stable shore ice forms on the shoals on both sides of the Cap-aux-Orignaux, but there is little extension into the river. In any case, present day shore ice does not extend to the site, which has to be away from the coast to reach sufficient water depth. The construction of a long jetty would significantly increase the extend of the fast ice offshore, which would become stable up to the berth.

With a broad river section upstream, strong currents and dominant SW winds, the site is likely to be impacted by large *batture* floes, although the frequency of such an occurrence cannot be determined from current data.

With the slower flow of ice in the south channel, immediately downstream from the site, drifting ice with 9-10 concentrations is a common occurrence. As for the other sites, there is no indication, from the available data or comments received, that sustained congestion from ice occurs, which would render this site unsuitable. As mentioned earlier, available ice observations are less frequent at this particular site. From a navigation standpoint, further site specific observations are required.

Ville-Guay

This site is located on the south shore, across from of Île d'Orléans, in a passage of the St. Lawrence of a width similar to that in front of the Ultramar terminal in Lévis. Deep water is accessible very close to the shore. Since water depth increases rapidly, fast ice does not develop much at the headlands on each side, but does in the bay. The construction of a terminal would stabilize land-fast ice on the upstream side, but this would not encroach into the river beyond the last protective dolphin. The combination of deep water and very high tides creates a discontinuity at the edge of the ice cover, which breaks off at low water and can remain grounded until the next high tide, or several tidal cycles later. Eventually the broken ice floats away during a subsequent high water interval.

The likelihood of encountering large ice floes is very remote at Ville-Guay, due to the active management by the Canadian Coast Guard in the vicinity if the Quebec bridges.

The passage at Ville-Guay has a heavy ice load, with typical concentrations from 7 to 10 tenths. The moving pack ice is rarely pushed against the south shore, because the site is protected from northerly winds by the landscape of Île d'Orléans. High tidal currents keep the ice in motion.

Close to the south shore, this site is rarely free of ice because of the narrowness of the river, but the portion of the river closest to Île d'Orléans is frequently open water.

3.8.3 Ice Force estimates

From the ice study, a conservative estimate of the factored ultimate ice load to be applied for the design is 52 MN for a 30 m diameter structure, or 1.75 MN/m of diameter.

3.8.4 Summary of Ice Conditions

All three (3) sites have high tides, strong tidal currents, dynamic ice conditions. From the point of view of ice conditions, the following observations may summarize the situation:

- **Gros Cacouna** is an established industrial site for which there is some knowledge of ice conditions, including ice management experience at nearby Port of Cacouna. The site is close to shore and protected to some extent from large floes. Despite dominant winds tending to push ice against the south shore, there does not appear to be a tendency for this site to become congested with ice for very long periods. However, thick ice may immobilize in front of the island for periods of up to a few days.

- **Pointe-Saint-Denis** has less database for ice conditions than the other sites, is more vulnerable to impact by *batture* floes, being far from the shore. There are no indications that this site would have a tendency to become congested with ice. However, the construction of a long jetty would have a significant effect on the extend of the shore-fast ice, which would probably reach the berth.

  Neither of these sites is close to a tug boat operator and both are several hours away from the headquarters of the Canadian Coast Guard, where ice management operation are controlled.

- **Ville-Guay** is located in a rather narrow portion of the river, where the width is similar to that at the Ultramar terminal. It has deep water close to the shore and very dynamic ice and hydraulic conditions.

Aerial picture of Ultramar Terminal taken on March 6, 2003

Docking manoeuvres in severe ice condition, Ultramar Terminal

Figure 3.4 – Photographs of Ice Conditions at Ultramar Terminal