Iceberg Scour Risk in the Strait of Belle Isle

April 2004
C-CORE Report R-04-004-011

This page is intentionally left blank

Iceberg Scour Risk in the Strait of Belle Isle

Version 1

Prepared for:
SGE Acres Limited

Prepared by:
C-CORE

C-CORE Report:
R-04-004-011

April 2004

C-CORE
Captain Robert A. Bartlett Building
Morrissey Road, St. John's, NL
Canada A1B 3X5

T: (709) 737-8354
F: (709) 737-4706

Info@c-core.ca
www.c-core.ca

The correct citation for this report is:

C-CORE (2004). Iceberg Scour Risk in the Strait of Belle Isle. Contract Report Prepared for SGE Acres Limited. C-CORE Report R-04-004-011, April 2004.

Project Team:

Tony King

EXECUTIVE SUMMARY

Iceberg scour risk and required cover depths were determined for a proposed tunnel crossing in the Strait of Belle Isle running from Yankee Point to Pointe Amour. Grounding rates were determined using a grounding model that uses the mean iceberg drift speed, iceberg keel depth distribution, iceberg frequency, water depth and seabed slope.

Iceberg drift speed was based on 21 iceberg trajectories collected off Pointe Amour. Iceberg frequency was determined from an analysis of Canadian Ice Service iceberg charts from 1988 to 2004. Iceberg keel draft distribution was based on observed iceberg waterline length data collected off the coasts of Newfoundland and Labrador. Water depth and seabed slope were determined using data from a bathymetric chart.

The results of the grounding model were then used to determine iceberg risk using iceberg scour and pit data from the White Rose region of the Grand Banks. Required clearances between scouring and pitting iceberg keels were based on pipeline risk analyses from the same site. The required cover depths over the top of the tunnel as a function of the mean return periods between damage events are shown on Figure 1. Required cover depths are on the order of 3 to 5.5 m for return periods of 100 and 1000 years, respectively, to prevent damage from scouring and pitting icebergs. A preliminary investigation indicates that bathymetric shielding is unlikely to have a significant effect on overall cover depth requirements.

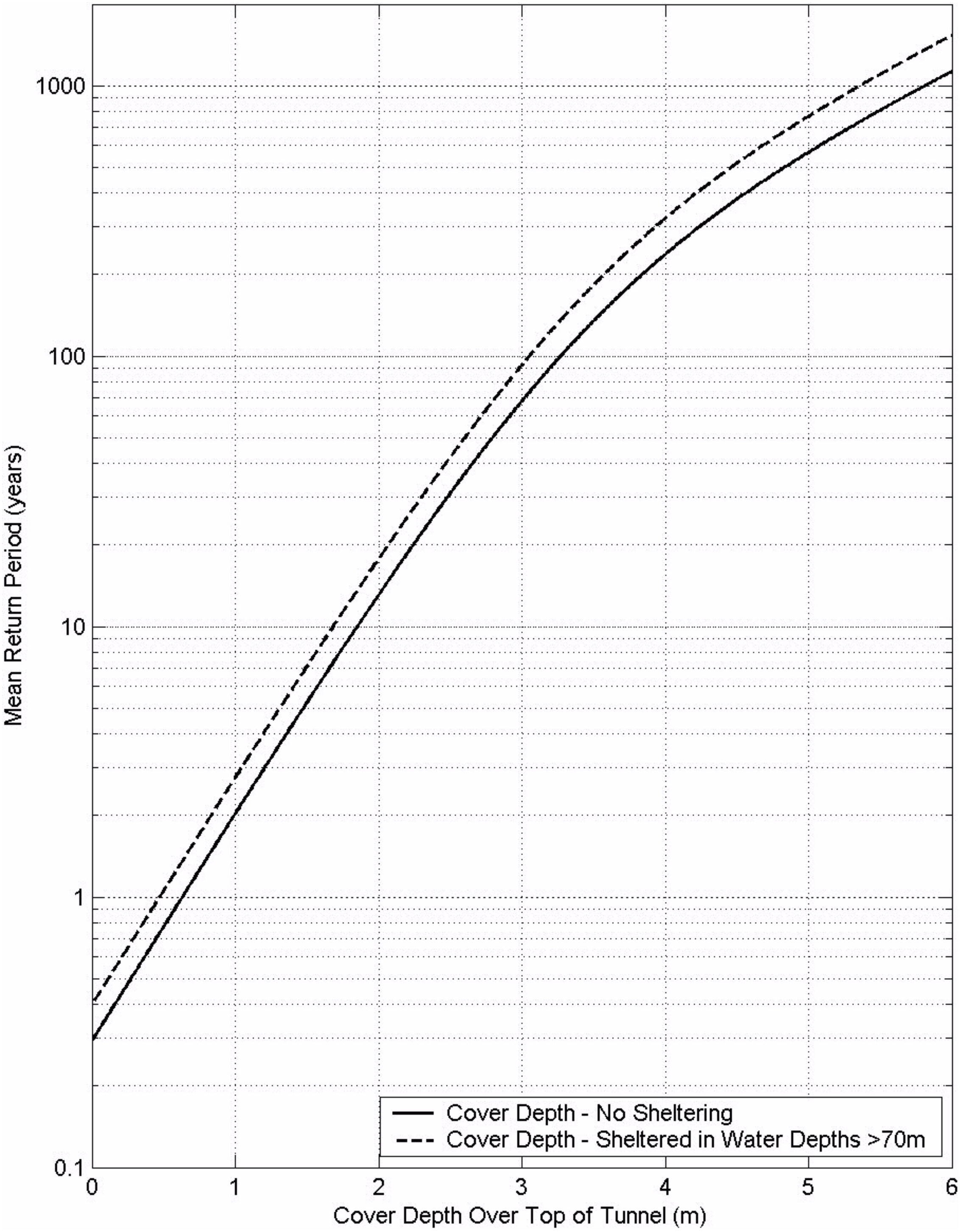

Figure 1. Required cover over top of tunnel to prevent iceberg damage.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Background

The origin and movement of icebergs off eastern Canada are generally well understood. For the purposes of this study, the concerns are with the potential for scouring and collision with bottom founded structures. Scours are a concern with only an immersed tunnel concept that would have shallow burial.

A number of studies were done on the scour question in the 1970's and early 1980's in consideration of a submarine transmission cable from the proposed Lower Churchill development. A fundamental question relates to the potential for scour southwest of a 70 m shoal that is 45 km upstream of the proposed crossing line. This subject is discussed at length in Woodworth-Lynas et al. (1992) and will be addressed in this report.

Approximately 10-15% of the icebergs that pass the latitude of the Strait of Belle Isle drift into the Strait, with the largest number been seen in May and June. Most of these enter on the Labrador side and exit on the island of Newfoundland side in concert with the prevailing currents. A few of these icebergs move into the Gulf and ground along the Quebec shore (a few have been known to penetrate to Anticosti Island or the Bay of Islands area, with one small iceberg reaching the Cabot Strait in 1960 before melting). The greatest number of icebergs observed in the Strait of Belle Isle at one time was 496, recorded by the Belle Isle lighthouse keeper on May 30, 1858.

The shoal area previously mentioned was thought to act as an iceberg filter and prevent any deeper icebergs from drifting into the proposed cable crossing area. However, scours in deeper water further into the Strait have been observed thus causing one to question this theory. A number of researchers have postulated that because icebergs roll, the previous draft may increase thereby permitting the iceberg to contact the seabed in water deeper than 70 m. Risk analysis studies commissioned as part of the Lower Churchill program suggested that the probability of an iceberg scouring along the proposed cable route is 0.5 events for every 100 icebergs in water depths greater than 75 m and 0.1 events per 100 icebergs in water depths greater than 85 m. In engineering studies of the cable crossing, the concept was to trench and bury the cable to a water depth of 85 m.

While there is some doubt about the risk associated with scour, there is also no data on the depth of scour in the area, thus making a recommendation of scour depth difficult. However, there is such data from other areas and reasonable extrapolations are possible.

In recent years, significant work has been done on the subject for the protection of seabed equipment on the Grand Banks.

For the purposes of the current study, the risk of scour in the Strait was analyzed using the most recent work by researchers at C-CORE and a design burial depth was determined. A description of this analysis follows.

1.2 Objectives

The objectives of this report were:

- to estimate the frequency of scour crossing events over a proposed “fixed link” option (consisting of a prefabricated concrete tunnel placed in a trench and backfilled) connecting Newfoundland and Labrador, and
- to estimate the required cover (distance from mudline to top of structure) required to prevent damage due to iceberg scour for a range of return periods.

2 GROUNDING MODEL

2.1 Background

A number of techniques have been used to estimate iceberg scour rates on the Grand Banks. These techniques include those based on repetitive mapping, seabed scour density, iceberg trajectories, sedimentation rates, sediment mobility and numerical models. A number of sites on the Grand Banks have been repeatedly surveyed in order to determine the number of new scours formed. The results of these repetitive mapping surveys have been analyzed using both Monte Carlo modeling (C-CORE, 2003) and statistical approaches (C-CORE, 2004), allowing the distribution of possible scour rates in the area to be defined. Lewis et al. (1988) suggested, based on data obtained from the analysis of sediment cores, that “modern” scouring began on the Grand Banks about 2500 years ago with the strengthening of the inner branch of the Labrador Current, allowing scour rates to be estimated by dividing the observed seabed scour density by 2500. Banke (1989a,b) developed an approach for analyzing iceberg drift tracks to determine iceberg grounding frequencies on the northeast Grand Banks. Gaskill et al. (1985) used observed scour densities and inferred sedimentation rates to estimate scour rates for three sites on the Grand Banks. Amos and Barrie (1982) used the density of scours observed in a megaripple field near Hibernia and the estimated time since these features were last reworked by a storm to calculate scour rates for the area. Numerical models (d’Apollonia and Lewis, 1986; King et al., 2003) have also been developed to estimate iceberg grounding rates based on iceberg frequency, draft distribution, drift and bathymetric data.

With the exception of numerical models, these approaches for estimating scour rate depend on field data that are not available for the Strait of Belle Isle. No repetitive mapping has been performed and insufficient seabed mapping exists to get a reliable measure of seabed scour density. Additionally, the high current speeds in the area would likely result in relatively rapid infilling of scour features, which would render both of these approaches useless for estimating scour rate. Trajectory analysis also cannot be used due to the limited available data. Likewise, approaches based on sedimentation or seabed processes are not applicable due to limited data. However, the data required for a grounding model (iceberg density, drift speed, keel draft distribution and bathymetry) are available and may be used to estimate grounding rates.

2.2 Derivation of Grounding Model

Figure 2-1 depicts iceberg keels with sufficient draft to impact the seabed and an areal density ρ_k drifting with a mean drift speed $\overline{U}$ towards a section of seabed of width W. In the case where the icebergs are drifting in a direction normal to the bathymetric contours, the frequency, f_g, at which iceberg keels impact, or ground on the seabed is:

$$f_g = \rho_k \overline{U} W \tag{2.1}$$

Iceberg keels grounding in adjacent sections of seabed are not considered, even if some small portion of the keel extends over the boundary. This distinction is made to avoid double counting of grounding events and to make the solution independent of the width of the specified section of seabed. Figure 2-1 shows the influence of the relative orientation between the seabed slope and the iceberg keel drift direction. If the orientation is changed by some angle θ, then the size of target presented to the keels is reduced and the iceberg keel grounding frequency is:

$$f_g = \rho_k \overline{U} W \cos(\theta) \tag{2.2}$$

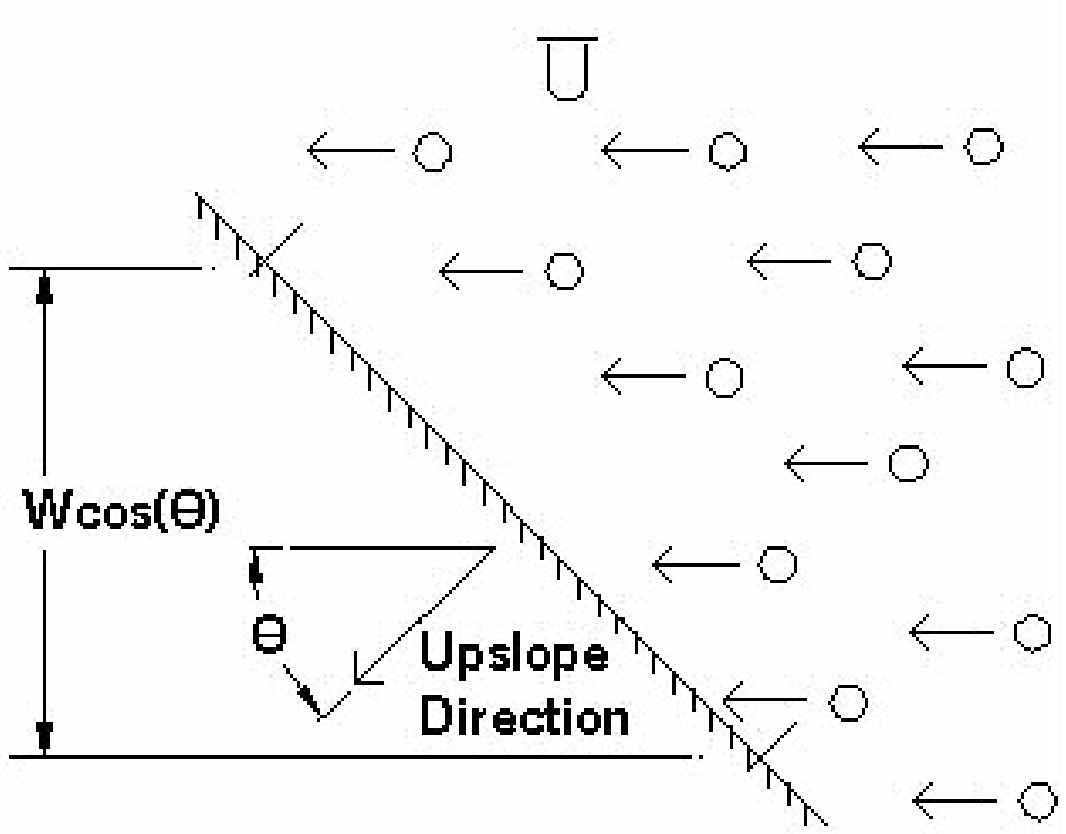

Figure 2-1 Iceberg keels approaching seabed.

Thus far, consideration has been given only to the density of iceberg keels capable of striking the seabed. However, the available data only give the density of icebergs that can be observed on the surface, n_o (with icebergs with waterline lengths < 16 m excluded). The number of icebergs that can strike a section of seabed covering a specific water depth range is limited to those with drafts in this depth range. Icebergs with lower drafts will ground in shallower water (if at all) and icebergs with greater drafts will ground in deeper water depths. A reduction factor (r_d), equal to the proportion of icebergs with drafts in the appropriate depth range (units: m^{-1}) was applied to the iceberg density to account for this effect, giving:

$$f_g = n_o r_d \overline{U} W \cos(\theta) \tag{2.3}$$

where θ is the orientation of iceberg drift direction relative to the upslope direction. The range of drift direction that needs to be considered is ± 90° relative to the upslope direction. If the drift direction relative to the upslope direction exceeds ± 90° then the iceberg is drifting down-slope and will not ground, unless it undergoes some draft change due to rolling or calving. This latter effect was ignored in this formulation. To calculate the total grounding frequency it was recognized that the mean drift speed usually varies with drift direction and that the distribution of drift direction is not uniform. An additional term, r_θ, was introduced to specify the proportion of time that icebergs drift in a specified direction. This allowed the total grounding rate to be expressed as:

$$f_g = r_d n_o W \int_{-\pi/2}^{\pi/2} r_\theta(\theta) \overline{U}(\theta) \cos(\theta) d\theta \tag{2.4}$$

Thus far, no consideration has been given to the seabed slope or the proportion of iceberg keel to be considered for grounding. Figure 2-2 shows a square sample section of seabed with a dimension W parallel and perpendicular to the seabed isobath and with a slope of S. The sample seabed section was defined on the basis of a 1 m rise, so $S=1/W$ and, except for extreme slopes, the area of the seabed section was considered to be W^2 or $1/S^2$ (the error is less than 5% for a slope of 30%). The frequency of groundings, f_g, was expressed in terms of grounding rate per unit area, ρ_g, as follows:

$$\rho_g = r_d n_o \frac{W}{A} \int_{-\pi/2}^{\pi/2} r_\theta(\theta) \overline{U}(\theta) \cos(\theta) d\theta \tag{2.5}$$

where r_d is now more specifically defined as the proportion of iceberg keels in a 1 m increment above the seabed. Expressing W and A in terms of slope gives:

$$\rho_g = r_d n_o S \int_{-\pi/2}^{\pi/2} r_\theta(\theta)\overline{U}(\theta)\cos(\theta)\,d\theta \qquad (2.6)$$

If directional drift data are available, Equation (2.6) can be evaluated using numerical integration. Alternatively, when directional drift data are not available, a non-directional form of Equation (2.6) can be used. By assuming a mean drift speed that is independent of direction and a uniform distribution of drift direction ($r_\theta = 1/2\pi$), Equation (2.6) can be integrated over the prescribed limits to yield:

$$\rho_g = \frac{1}{\pi} r_d n_o S \overline{U} \qquad (2.7)$$

Since the available iceberg drift data in the Strait of Belle Isle are limited and not suitable for generating mean drift speeds as a function of drift direction, iceberg grounding rates will be estimated using Equation (2.7).

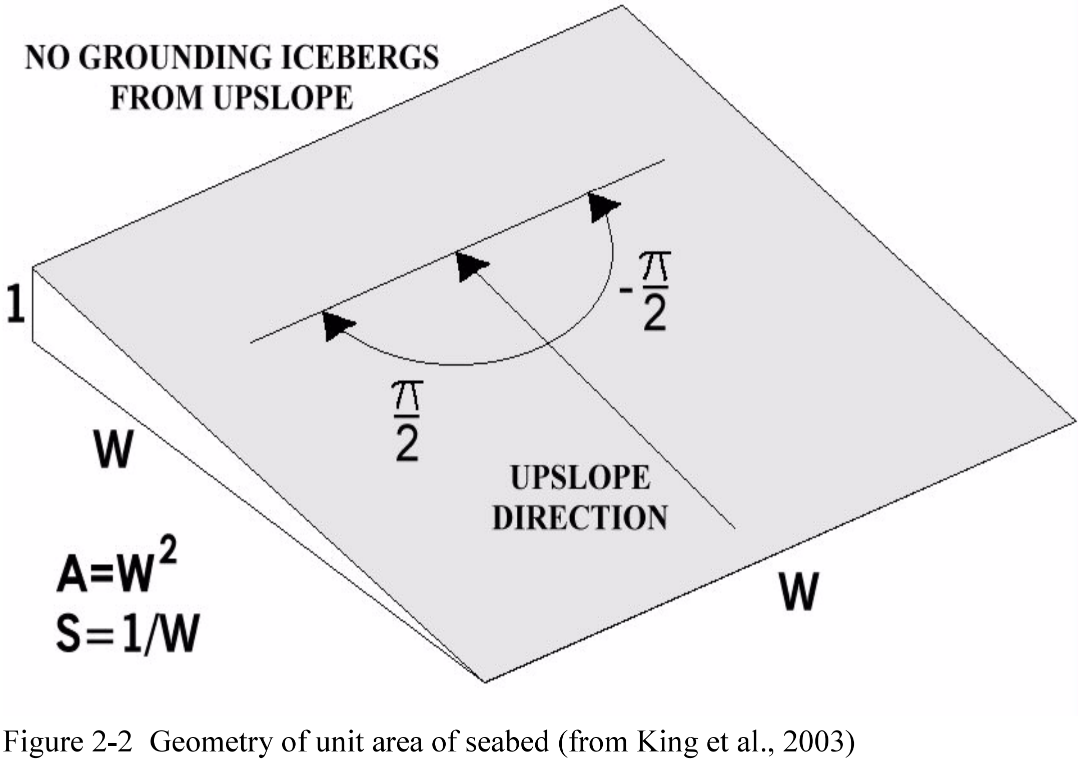

Figure 2-2 Geometry of unit area of seabed (from King et al., 2003)

2.3 Grounding Model Input

2.3.1 *Iceberg Frequency*

Iceberg frequency is expressed in terms of areal density, which is the average number of icebergs in a given area (typically a degree square) at any given instant in time, averaged over a long time period. The most reliable source of iceberg sightings on the Grand Banks in terms of frequency and coverage of surveys is the International Ice Patrol (IIP). However, IIP coverage of the Strait of Belle Isle is infrequent so iceberg charts issued by the Canadian Ice Service (CIS) were analyzed to determine iceberg frequency. A total of 481 charts were analyzed, covering a period from May, 1988, to April, 2004. Figure 2-3 shows the resulting average annual iceberg areal density per degree square for the Strait of Belle Isle and the adjacent degree squares. Iceberg density expressed on a degree square basis can be converted to density per square kilometer as follows:

$$n_o\,(km^{-2}) = n_o\,(degree^{-2}) \,/\, (\cos(\phi)\times 1.237\times 10^4) \qquad (2.8)$$

where ϕ is degrees latitude. Therefore, the average iceberg density for the Strait of Belle Isle degree square is 1.25×10^{-3} km^{-2}. However, approximately 70% of the degree square in question is covered by land (with icebergs limited to the remaining portion), therefore the actual iceberg density (used for risk calculations) is 4.1×10^{-3} km^{-2}. This is approximately 40 times higher than the iceberg density in the Jeanne d'Arc region of the Grand Banks.

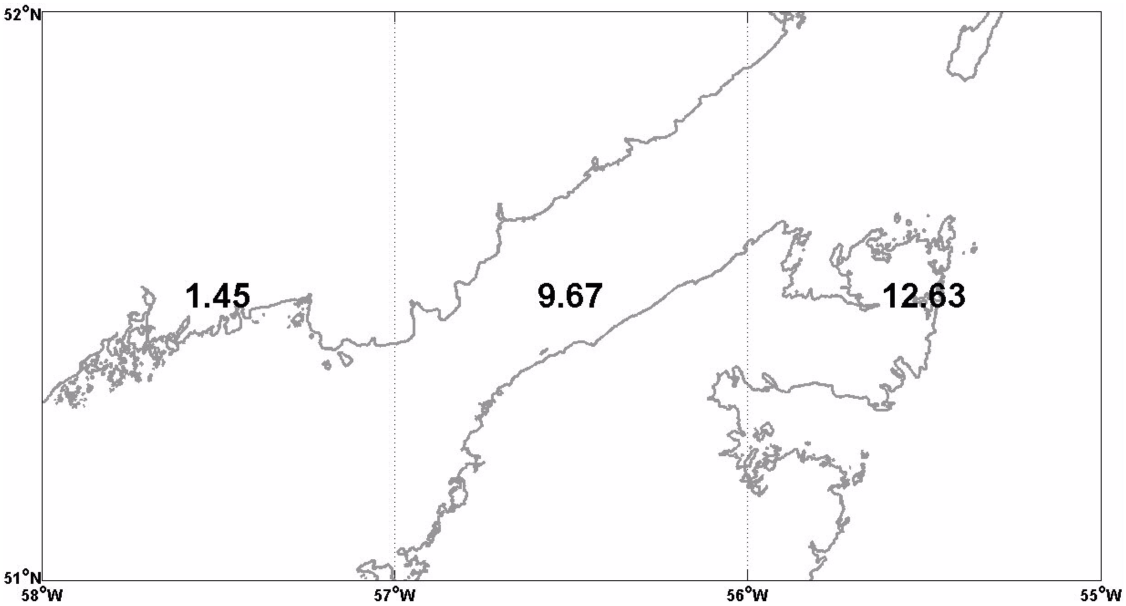

Figure 2-3 Annual average iceberg density per degree square for study area.

2.3.2 *Iceberg Drift Speed*

A limited amount of iceberg drift data has been collected in the study area. In 1979 and 1980, iceberg trajectory data were collected for 21 icebergs using a X-band marine radar mounted on the Pointe Amour lighthouse, at an elevation of approximately 43 m (Roche, 1980). These data are shown in Figure 2-4. The distribution of drift speed (excluding periods where the icebergs were grounded) is shown in Figure 2-5. These data are appropriate for determining the kinetic energy of icebergs during collision events, however due to the fact that icebergs in this area frequently ground for extended periods, the overall mean drift speed (including grounded intervals) is 0.12 m/s. This is the appropriate drift speed for calculating grounding rates.

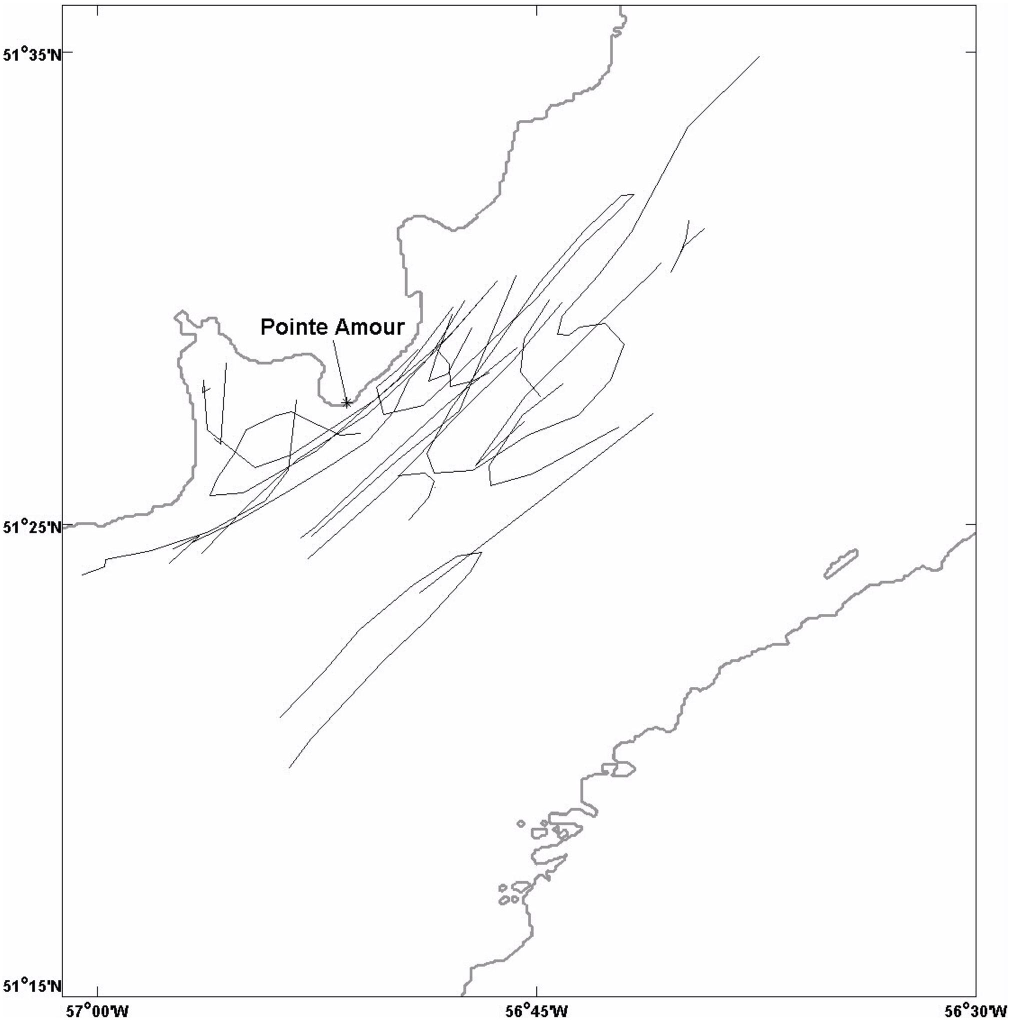

Figure 2-4 Iceberg drift track data from Strait of Belle Isle (Roche, 1980).

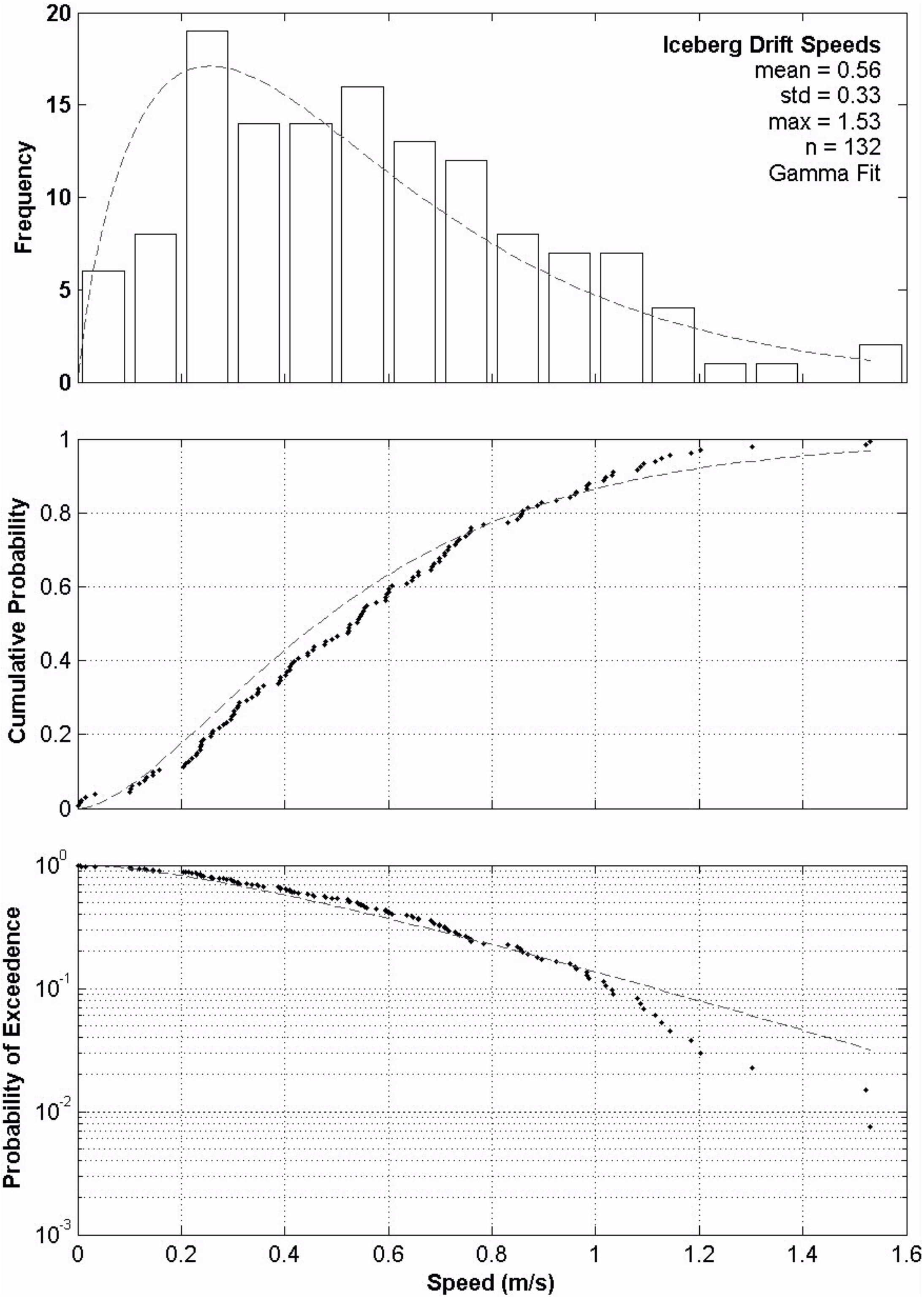

Figure 2-5 Iceberg drift speed in Strait of Belle Isle, excluding grounded icebergs.

2.3.3 Iceberg Keel Draft Distribution

The iceberg waterline length distribution on the Grand Banks follows an exponential distribution with a mean of 59 m (Jordaan et al., 1995). While icebergs numbers are much greater off the coast of Labrador, the available data indicates the distribution of iceberg lengths is roughly the same (King, 2002). Iceberg surveys have resulted in 211 iceberg length/draft measurements off the coast of Newfoundland. In order to relate iceberg waterline length to draft the following equation was derived (King, 2002):

$$D_i = exp(ln(3.23) + 0.68\ ln(L_i) + N(0,0.25)) \qquad (2.9)$$

where D_i is iceberg draft and L_i is waterline length. The scatter in the original data set is simulated using $N(0,0.25)$, which is a normally-distributed random variable with a mean of 0 and a standard deviation of 0.25. A large sample of waterline lengths, exponentially distributed with a mean of 59 m, was generated and the corresponding drafts were calculated using Equation (2.9). Waterline lengths less than 16 m were excluded since areal density values exclude these icebergs. The proportion of iceberg keels per metre of the water column is shown in Figure 2-6.

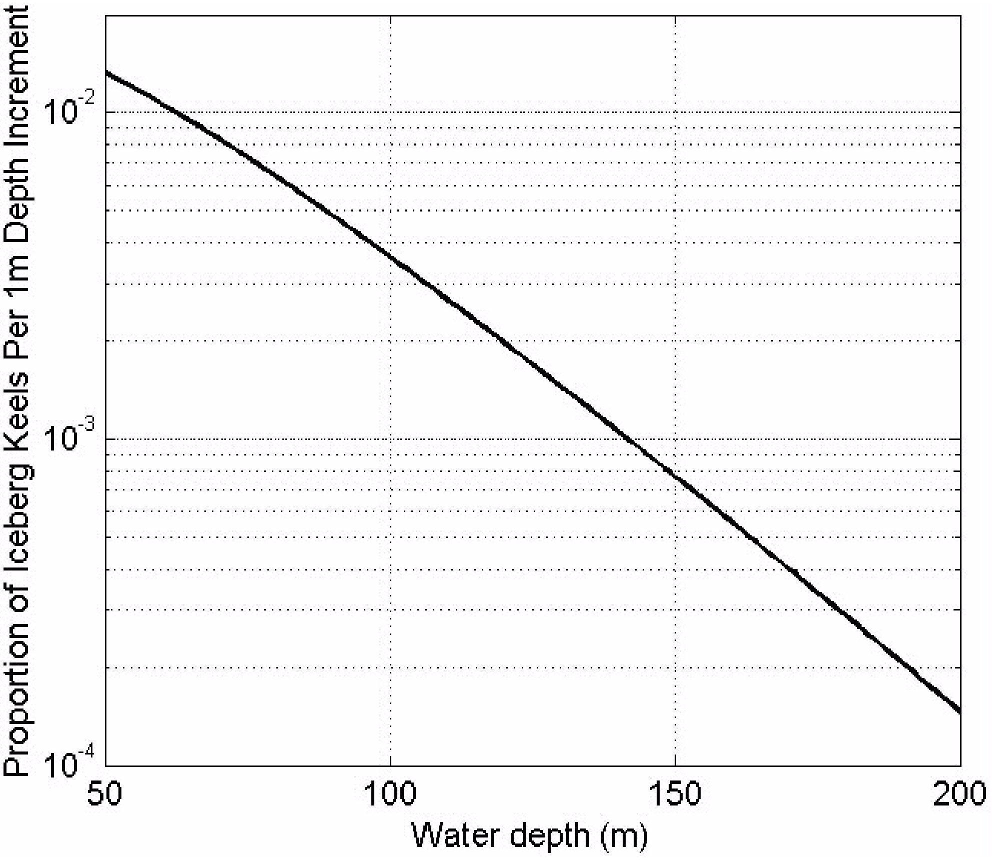

Figure 2-6 Iceberg keel draft distribution (from King et al., 2003).

2.3.4 Bathymetry

Bathymetric data were required to determine water depth and seabed slope. Bathymetry data were manually digitized from a scanned version of CHS Chart 4020. The resulting dataset was put on a grid with a 0.005° latitude and 0.005° longitude resolution. The resulting data, plotted as a filled color contour plot, are shown in Figure 2-7. This figure also shows the location of the proposed tunnel crossing (dotted line) and the sill to the northeast, which is thought to offer some shielding from iceberg keels for certain water depths. This data set was further processed to give seabed slopes. The average seabed slope in the area shown in Figure 2-7 is ≈1%, approximately 10 times greater than on the northeast Grand Banks.

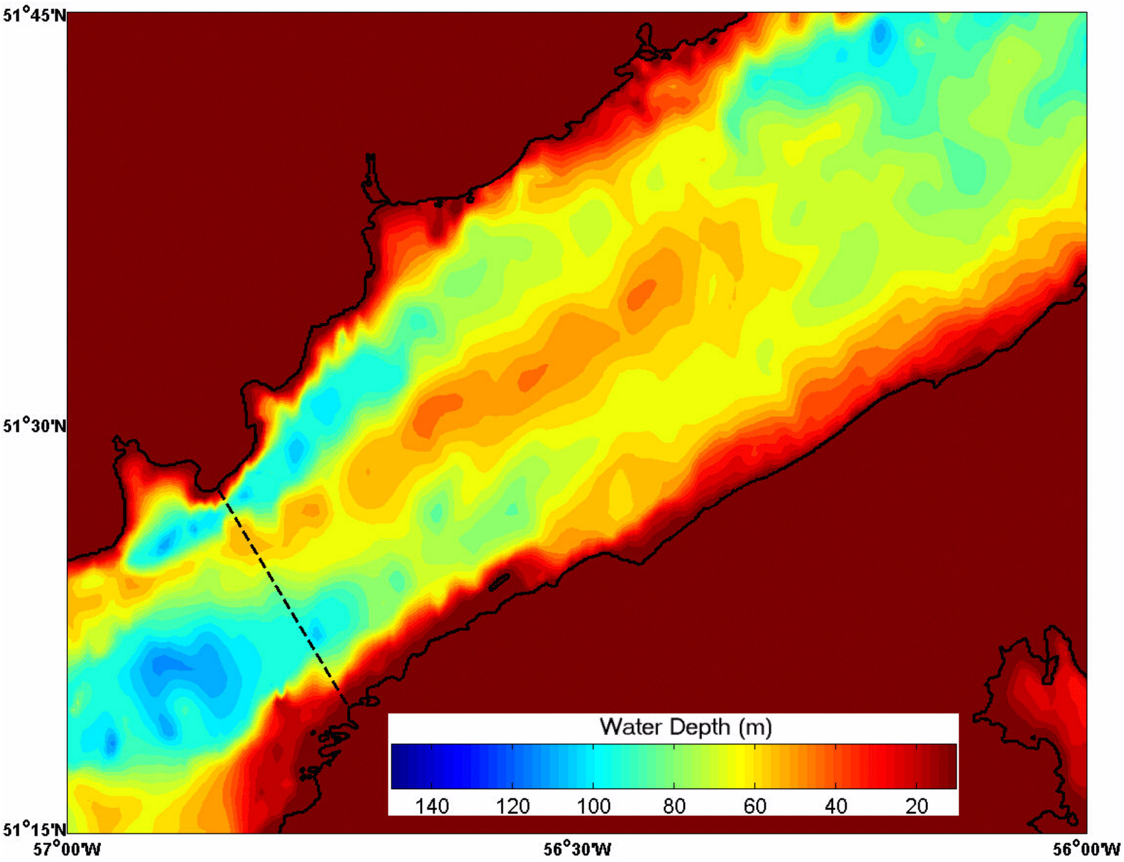

Figure 2-7 Bathymetry for study area, showing tunnel route (dotted line).

2.4 Modeled Grounding Rate

Figure 2-8 shows grounding rates modeled using Equation (2.7). These grounding rates apply only to icebergs with waterline lengths ≥ 16 m. Smaller icebergs (bergy bits and growlers) will ground in shallower water close to shore, but are unlikely to pose a significant hazard. It can be seen that the highest grounding rates are predicted relatively close to shore where seabed slopes are relatively steep in the 30-60 m water depth range.

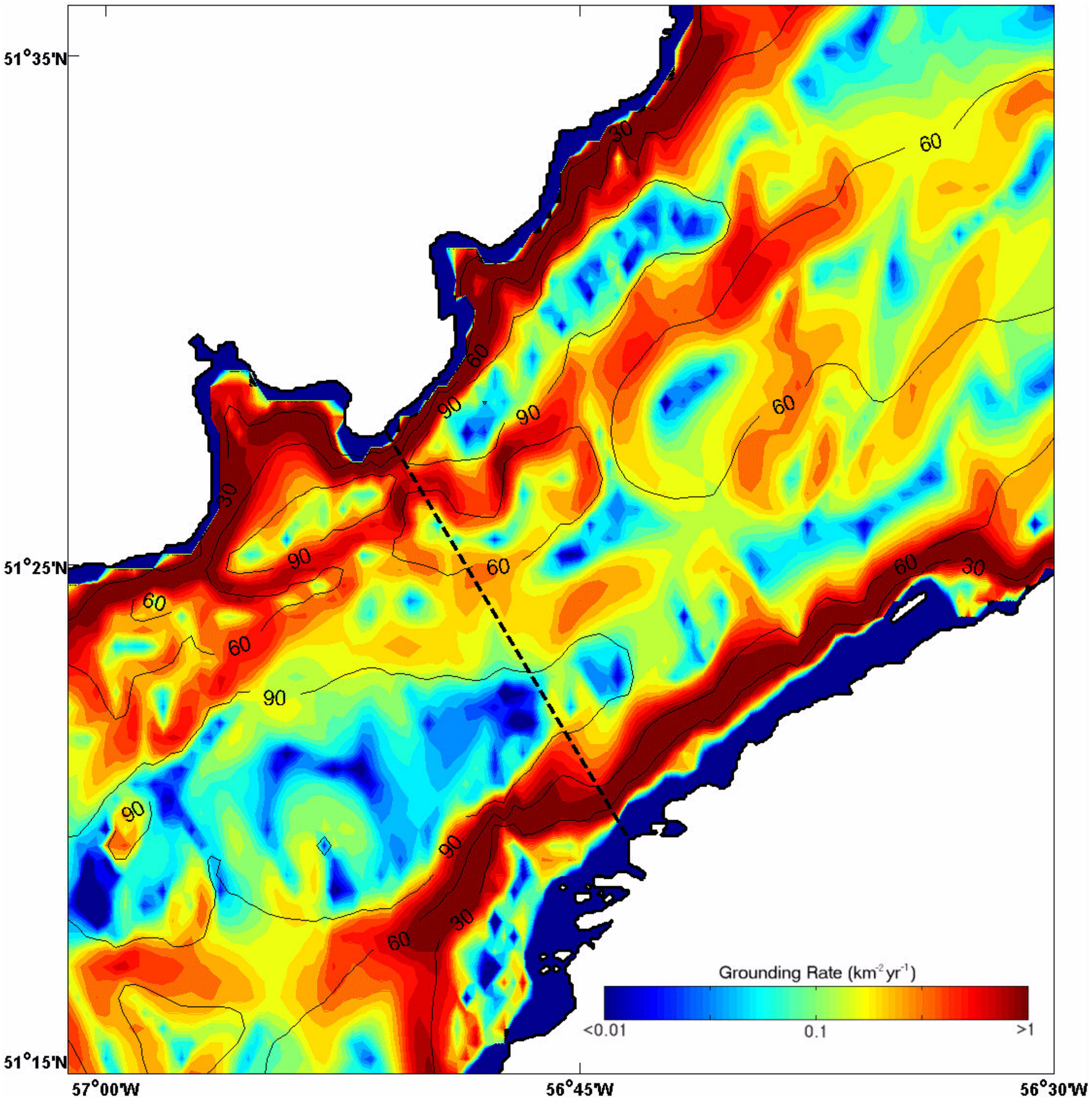

Figure 2-8 Grounding rates calculated using Equation (2.7).

3 SCOUR RISK

3.1 Methodology

The risk analysis methodology is broken down into three basic steps:

- interpolate the grounding rate along the proposed tunnel route;
- convert the grounding rate into scour and pitting rates and using scour/pit geometric data, calculate crossing events over the tunnel route; and
- determine the number of pitting/scouring events occurring over the tunnel with the potential to cause damage, based on cover depth, pit/scour cover depth and the acceptance criteria.

3.1.1 Scour Data

There is insufficient site-specific scour data for use in the tunnel risk analysis. Therefore, it is necessary to rely on scour data (here collectively refering to both scours and pits) collected elsewhere. Scour features can be broken down into scours (long furrows) and pits (circular or oval features), and both of these types of scour features have different shape and depth characteristics. C-CORE (2001a,b) documented iceberg scour parameters for the White Rose region and these data, given in Table 3-1, will be used here for the risk analysis. The corrected scour length given in Table 3-1 accounts for the truncation of scours at the edge of seabed survey. Approximately 10% of the scour features observed at White Rose were pits. Both scour and pit depths are considered to follow an exponential distribution.

Table 3-1 Iceberg Scour Parameters at White Rose (from C-CORE, 2001b).

Parameter	**Mean**	**Standard Deviation**	**Maximum**
Measured Scour Length	588 m	784 m	10710 m
Corrected Scour Length	*650 m*	-----	-----
Scour Width	24.9 m	14.4 m	-----
Scour Depth	0.34 m	0.30 m	2.5 m
Average Pit Dimension	57.0 m	37.2 m	199 m
Pit Depth	1.1 m	0.9 m	5.2 m

3.1.2 Crossing Rates

The annual number of scours occurring over the tunnel (or subsection of tunnel) can be calculated following the approach described by Astafyev et al. (1997) as follows:

$$N_s = \frac{2}{\pi} f_{sc} L_T \overline{L}_s \tag{3.1}$$

where f_{sc} is the scour rate, L_T is the length of the tunnel (or section of tunnel) $\overline{L}_s$ is the mean scour length (650 m). Likewise, Equation (3.1) can also be used to calculate the annual frequency of pit features, N_p, occurring over the tunnel by substituting f_p (pitting frequency) for f_s and substituting the mean pit width (55 m) for the mean scour length. This approach assumes a uniform distribution of scour direction.

3.1.3 Acceptance Criteria

There is insufficient data to perform an analysis of the response of the tunnel to scour and pit events, therefore it is necessary to rely on other work. In order to limit distress in the structure an acceptance criteria (using a minimum distance between the bottom of a scouring or pitting iceberg keel) was established. At White Rose, a sub-scour clearance equal to half the scour depth was sufficient to prevent damage (C-CORE, 2001b) to a trenched pipeline. For a 2 m deep scour this means that an additional clearance of 1 m would be required to prevent damage, for a total cover depth of 3 m. Although a detailed analysis has not been performed for pitting icebergs, the same criteria will be applied. These criteria are reasonable, however it is expected that for any follow-up work a detailed analysis would be performed for a tunnel structure once sufficient scour, soil and structural data are available.

The annual number (N) of iceberg scour features (scours and pits) penetrating deep enough to exceed the acceptance criteria (i.e. cause damage) to the tunnel can be calculated, following the approach outlined by Pilkington (1986), using:

$$N = N_s e^{-2C/3\overline{D}_s} + N_p e^{-2C/3\overline{D}_p} \tag{3.2}$$

where N_s and N_p are the annual number of scour and pit features crossing over the tunnel, C is the tunnel cover depth (top of tunnel to mudline), and $\overline{D}_s$ and $\overline{D}_p$ are the mean scour and pit depths.

3.2 Risk Analysis Results

Figure 3-1 (top) shows the water depth along the proposed tunnel route from Yankee Point to Pointe Amour. The maximum water depth along the route is 94 m. Figure 3-1 (bottom) shows the annual frequency of scour and pit events along the tunnel route. As would be expected from the results shown in Figure 2-8, the majority of events occur on the steep slopes on either side of the Strait of Belle Isle.

Figure 3-2 shows the required cover depth above the top of the tunnel to prevent iceberg scour/pit damage as a function of the mean return period between damage events. In order to achieve a mean return period of 100 years a cover depth on the order of 3 m is required This increases to approximately 5.5 m for a 1000 year return period.

The total annual number of scour and pit events occurring over the tunnel is 3.4. If it is assumed the tunnel is shielded from iceberg keels in water depths greater than 70 m then this number drops to 2.5 events per year. As shown in Figure 3-2, this has a negligible effect on cover depths required to meet target return periods (i.e. a difference of 0.2 m for a return period of 100 years).

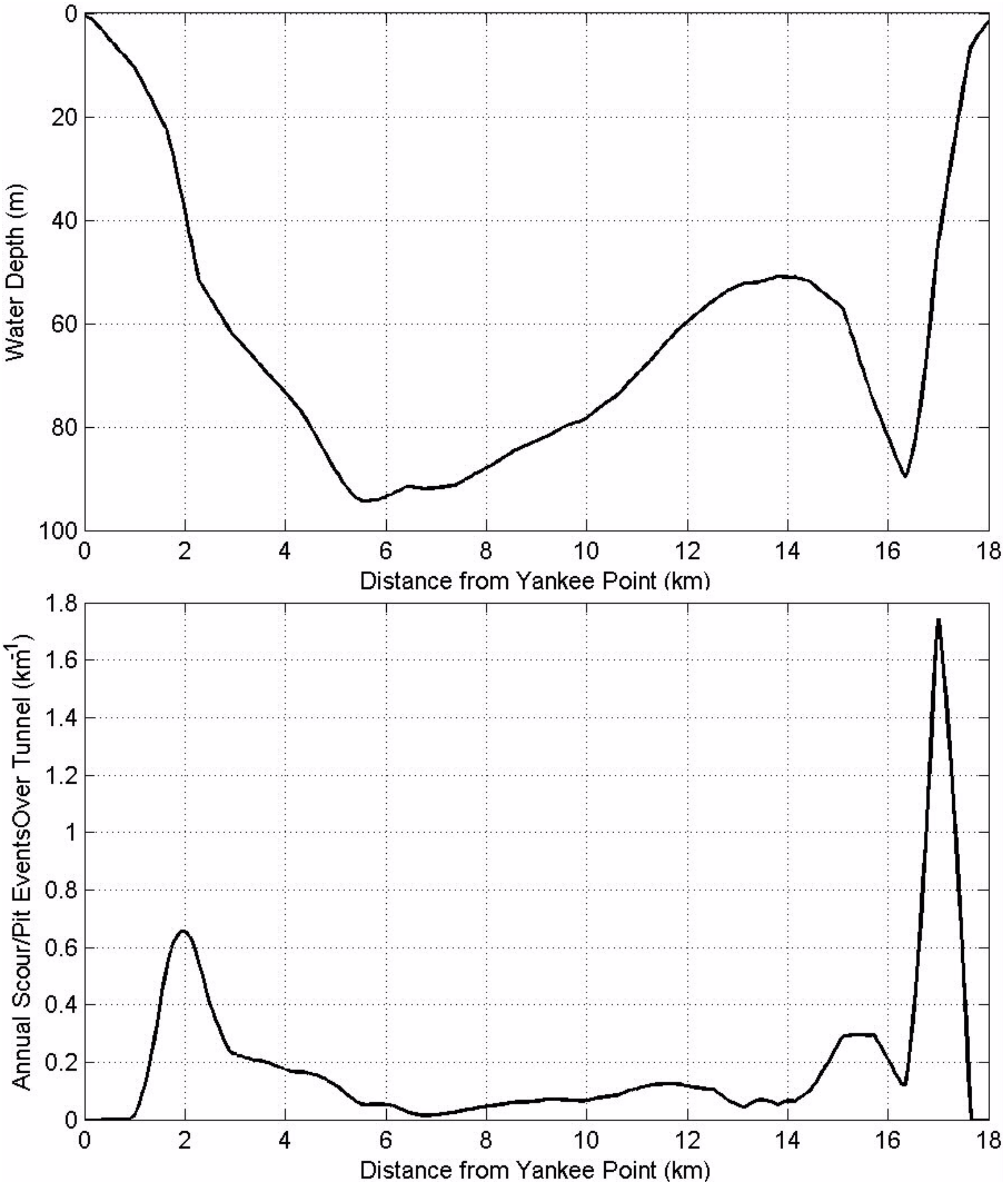

Figure 3-1 Water depth along proposed tunnel route and annual scour/pit crossings.

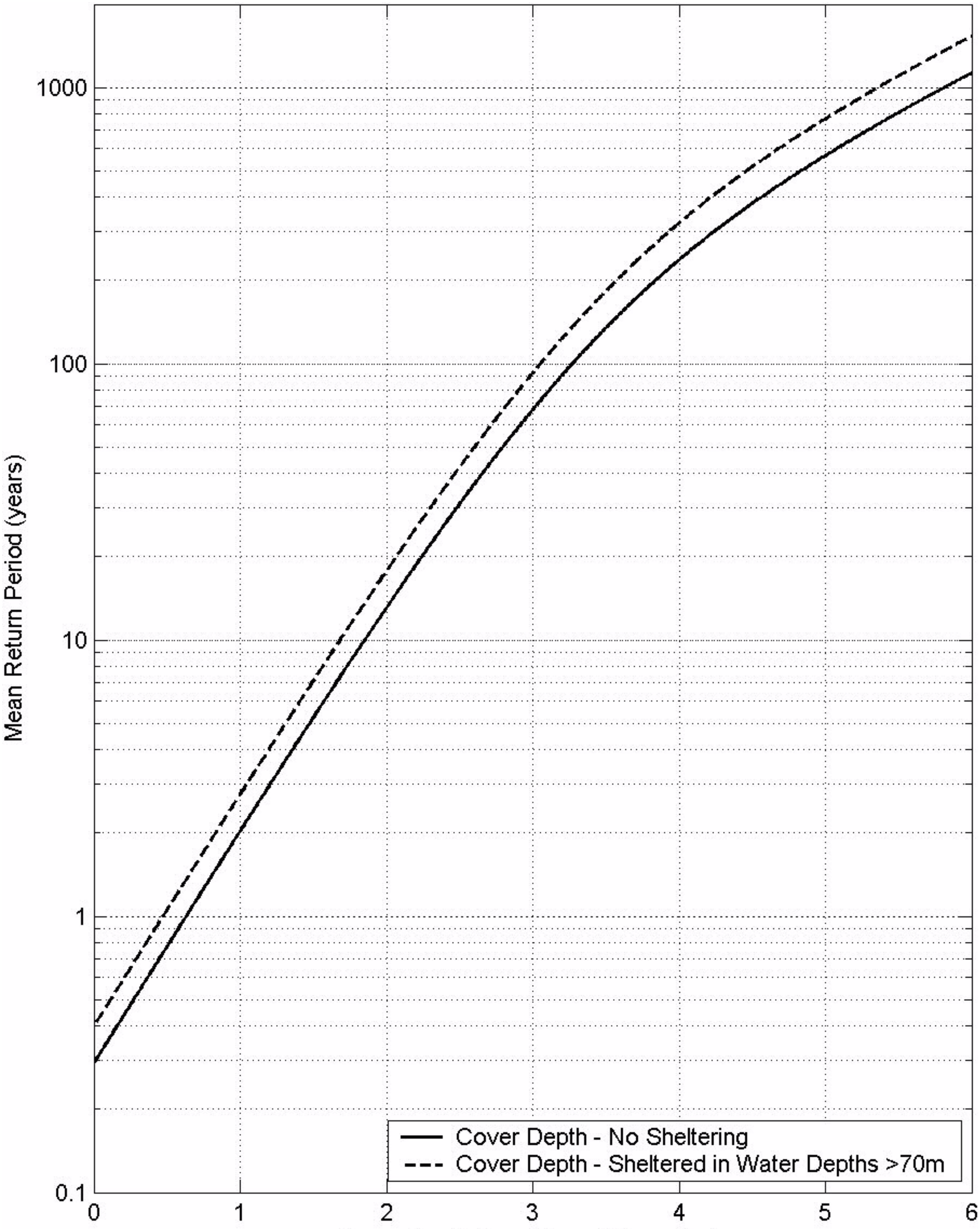

Figure 3-2 Mean return period between scour/pit events where acceptance criteria are exceeded as a function of cover over top of tunnel.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Required cover depths over a proposed tunnel crossing in the Strait of Belle Isle running from Yankee Point to Pointe Amour are on the order of 3 to 5.5 m for return periods of 100 and 1000 years, respectively, to prevent damage from scouring and pitting icebergs. The Strait of Belle Isle is an area with high iceberg densities, shallow water depths and steep slopes, all of which contribute to increased iceberg risk. A preliminary investigation indicates that bathymetric shielding is unlikely to have a significant effect on overall cover depth requirements.

4.2 Recommendations

Scour data in the Strait of Belle Isle is extremely limited. Additional seabed surveys need to be conducted to collect site-specific data to determine the relative number of scours and pits, their shapes (lengths and widths) and depths. Iceberg drift data is also limited. A longer term monitoring program would allow drift characteristics to be more accurately determined.

The use of a drift-based grounding model (rather than the geometric model employed here) incorporating iceberg drift, iceberg deterioration, rolling, etc. would allow the effect of bathymetric shielding to be more accurately determined. There are presently insufficient data and resources to attempt this approach. (However, such bathymetric shielding is not a consideration for present purposes since a tunnel would be constrained to a straight line unlike a submarine cable.)

Required clearances between scouring/pitting iceberg keels and the top of the tunnel are based on analyses of pipeline response to scour events. These analyses should be performed specifically for a concrete tunnel once the appropriate site-specific scour parameters and the structural configuration has been defined.

It is not known whether pack ice ridge keels are a common event in the Strait of Belle Isle. However, in some areas (such as the Beaufort Sea and off Sakhalin Island) ice ridge keels are a significant factor affecting pipeline burial requirements. Iceberg ridge keels are a factor in shallower water depths (<25m). If ice ridge keels are present in the Strait of Belle Isle then these may require additional consideration, although it is likely that the cover depths maintained to protect the tunnel from iceberg risk would also suffice for ice ridge keels.

5 REFERENCES

Amos, C.L. and Barrie, J.V. (1982). The frequency of ice scouring on the northeastern Grand Banks of Newfoundland using the interrelationship of scours and bedform migration. Natural Resources Council of Canada Workshop on Ice Scouring, Montbello, Quebec, February, 1982.

Astafyev, V.N., Surkov, G.A., and Truskov, P.A. (1997). Methods for determining optimal subsea pipeline burial cross section. Translation of Chapter 8 of: Ridges and Stamukhas of the Okhotsk Sea. VV Panov (ed.). Progress-Pagoda, St. Petersburg.

d'Apollonia, S.J. and Lewis, C.F.M. (1986). Numerical model for calculating spatial distribution and mean frequency of iceberg grounding events. *In* Ice Scour and Seabed Engineering. Lewis, C.F.M., Parrott, D.R., Simpkin, P.G., and Buckley, J.T. (eds). Environmental Studies Revolving Funds Report No. 049. Ottawa, pp. 287-292.

Banke, E. (1989a). Recent Iceberg Groundings on the Grand Banks of Newfoundland. Geological Survey of Canada, Open File 2528.

Banke, E. (1989b). Listing of Possible Groundings by Icebergs on the Grand Banks of Newfoundland Between 1983 and 1989. Geological Survey of Canada, Open File 2530.

C-CORE (2001a). Iceberg Scour Characteristics at White Rose. Contract Report Prepared for Husky Oil Operations Ltd., C-CORE Report Number 00-C44, May.

C-CORE (2001b). Iceberg Risk to Pipelines at White Rose. Contract Report Prepared for Husky Oil Operations Ltd., C-CORE Report Number 00-C45, May.

C-CORE (2003). Probabilistic Analysis of Return Interval of Iceberg Scouring, Grand Bank. Report Prepared for Geological Survey of Canada (Atlantic). C-CORE Report Number R-02-039-214, March 2003.

C-CORE (2004). Statistical Methodologies for Analysis and Application of Repetitive Mapping Data. Contract Report Prepared for Geological Survey of Canada (Atlantic). C-CORE Report R-04-002-273, April 2004.

Gaskill, H., Nicks, L. and Ross, D. (1985). A non-deterministic model of populations of iceberg scour depths. Cold Regions Science and Technology, 11, pp. 107-122.

King, A.D. (2002). Iceberg Scour Risk Analysis for Pipelines on the Labrador Shelf. M.Eng. Thesis, Memorial University of Newfoundland, 210 p.

King, A.D., McKenna, R.F., Jordaan, I.J., and Sonnichsen, G.V. (2003). A model for predicting iceberg grounding rates on the seabed. POAC '03, Trondheim, Norway.

Lewis, C.F.M., Parrott, D.R., d'Apollonia, S.J., Gaskill, H.S., and Barrie, J.V. (1988). Methods of estimating iceberg scouring rates on the Grand Banks of Newfoundland. Ninth International Conference on Port and Ocean Engineering Under Arctic Conditions (POAC), August 17-22, Fairbanks, Alaska, 1987, pp. 229-254 (vol. 3).

Pilkington, R. (1986). Estimating ice-scour frequency and the risk to buried pipelines. *In* Ice Scour and Seabed Engineering. Lewis, C.F.M., Parrott, D.R., Simpkin, P.G., and Buckley, J.T. (eds). Environmental Studies Revolving Funds Report No. 049. Ottawa, pp. 213-220.

Roche, C. (1980). Iceberg Tracking Program, Pointe Amour, Labrador. Report Prepared for SNC-Lavalin Newfoundland Limited. Report Number 80-15. 71 p.

Woodworth-Lynas, C.M.T., Guigné, J.Y., and King, E.L. (1992). Surficial and Bedrock Geology Beneath the Strait of Belle Isle in the Vicinity of a Proposed Power-Cable Crossing. Report Prepared for the Department of Mines and Energy, Government of Newfoundland and Labrador, Report 92-2. 53 p.