Proceedings of the 25th International Conference on
Port and Ocean Engineering under Arctic Conditions
June 9-13, 2019, Delft, The Netherlands

Route selection for a marine pipeline linking the Jeanne d'Arc Basin and the Island of Newfoundland

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ABSTRACT

In the late 1990's, the feasibility of constructing pipeline linking offshore oil and gas production facilities on the Grand Banks to the island of Newfoundland was assessed. The industry proponent, North Atlantic Pipeline Partners LLP (NAPP), engaged C-CORE to assist with the evaluation of iceberg contact frequencies to inform the route selection process. The procedure used for determining an optimum pipeline route to minimize the risk of damage from icebergs is described in this paper.

An iceberg model, described in companion paper McKenna et al. (2019), was run for a 500 year simulation period to obtain a map of iceberg grounding locations. This was used as a basis for plotting a series of interlinked pipeline segments covering a wide range of potential routings. From these segments, a few preferred routes were selected based on the modeled frequency of iceberg contact. The preferred routes included a direct route across the Grand Banks for a landfall near St. John's and a more northerly route skirting the Grand Banks.

The model was then used to simulate a 5000 year period, focusing on the regions of the preferred northern routes from which further optimization was carried out. The best northern routes averaged one iceberg contact in 30 to 35 years over the entire ~600 km pipeline length. Contact probabilities were also determined for cases when selected portions of the pipelines were trenched. Using strategic trenching, average iceberg contact probabilities of once in 175 to 450 years were achieved. With the risk of iceberg contact at these levels, the pipeline becomes a technically feasible transportation alternative for Grand Banks oil and gas.

KEY WORDS Iceberg; Pipeline; Grand Banks; Risk; Route.

INTRODUCTION

This paper was originally prepared for publication in 1999, however, it was not released at that time for reasons of commercial propriety. The work is presented here in its unaltered form and it is hoped that despite the passage of two decades it remains relevant and useful. It is noteworthy that in the intervening time a pipeline has not been built in the Grand Banks theatre and as far as the authors know, none have been constructed in iceberg prone waters elsewhere. The companion paper to this, McKenna et al (2019), provides the background work and *reference material related to the iceberg environment, drift deterioration and grounding processes.*

North Atlantic Pipeline Partners (NAPP) plan to develop a gas pipeline linking gas-producing regions on the Grand Banks with markets in eastern Canada and the United States (Figure 1). The easternmost portion of this pipeline connects the northeastern Grand Banks with the island of Newfoundland. The region which this pipeline must pass through is noted for the seasonal presence of icebergs. In order to optimize route selection in these conditions NAPP engaged the services of C-CORE to address the question of iceberg-pipeline contact risk. The first stage of that work is described in a companion paper to this (McKenna et al., 2019). It deals with the development of a computer model to simulate iceberg grounding frequency and distribution on the Grand Banks. The second stage of the work, described in this paper, deals with the application of that model to evaluate pipeline contact frequencies and route selection.

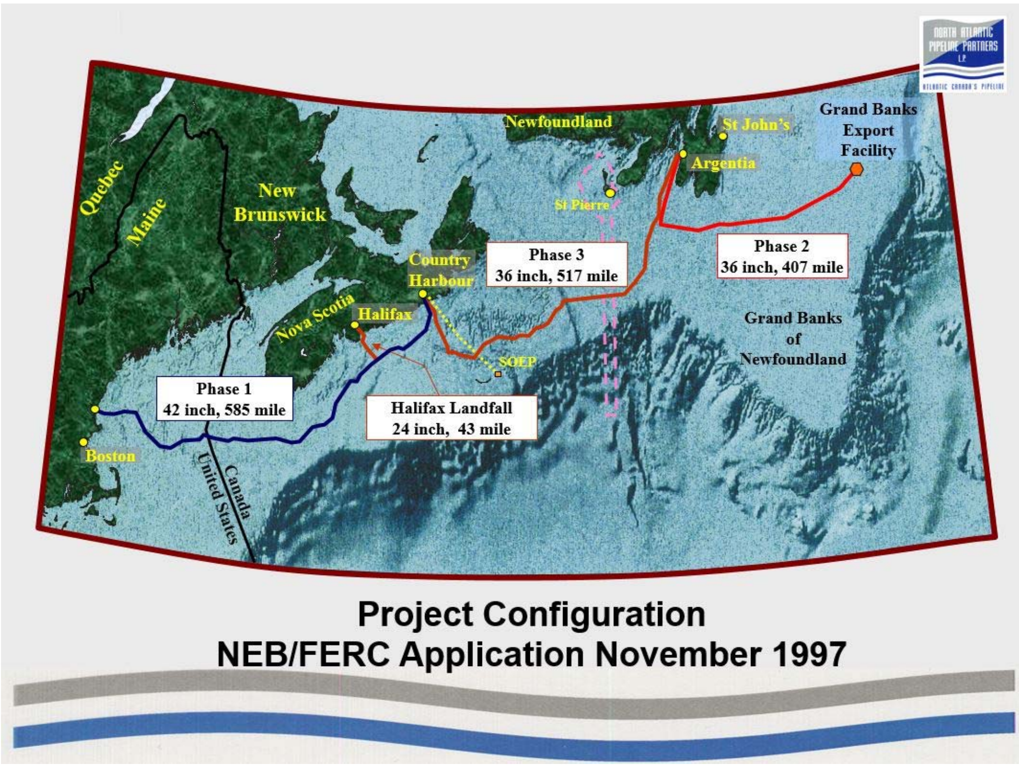

Figure 1. North Atlantic Pipeline Partners Project Configuration in 1997

METHODOLOGY

This work is aimed at answering the question of what might the iceberg contact risk be for a Grand Banks pipeline and how might this risk be minimized through strategic routing. It is expected that the final route selection will involve many other considerations including costs associated with pipeline failure, pipeline protection, looping, landfall and distribution, customer reliability growth and capacity requirements and other. Route analysis for the present study began with the selection of a system of pipeline segments connecting various sources with a range of landfall sites and a web of possible routes avoiding iceberg grounding-prone areas. Next, the different types of contact scenarios involving freely floating and scouring icebergs were defined within the computer model. Based on these contact criteria, contact frequencies for each segment and groups of segments comprising a contiguous route were evaluated. The most promising routes were subject to additional refinement and analysis for which a secondary simulation was performed to improve grounding data resolution. Refined segments were thus analyzed and finalized prospective routes were proposed and assessed for contact risk. The influence of trenching portions of routes was also assessed.

ICEBERG GROUNDING MAP

The primary result from the modeling effort described in the companion paper (McKenna et al., 2019) was the development of the iceberg grounding dataset and map to be used for route selection. The lower map in Figure 2 shows the results of the base-case 500 year iceberg simulation, pinpointing the location of every seabed contact.

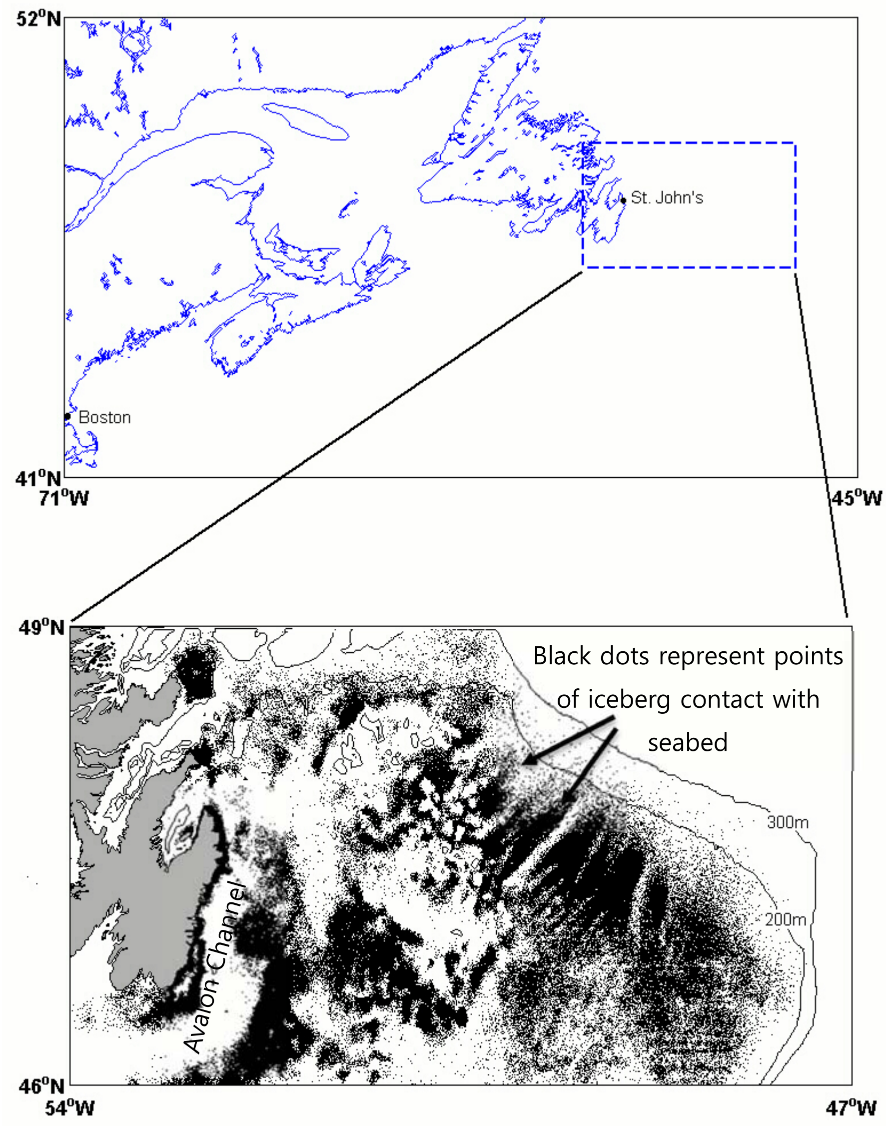

Figure 2. Iceberg Ground Chart – Initial 500 Year Simulation

A total of 152,000 grounding events occurred in this base case simulation. The majority of icebergs grounded on the northern part of the Grand Banks and on the flanks of the Avalon Channel. Evidently, the portion of groundings at water depths greater than 200 m was 0.3% which proved to be a key result for follow-on work. Some sensitivity runs were carried out to indicate the robustness of the base case. Decreasing the deterioration rate of icebergs, for instance, resulted in more icebergs reaching the Southern Banks. In the end, improved bathymetric data was inserted and judgement was applied by all parties to finalize a data set with which pipeline routes could then be selected and analyzed.

SELECTION OF PRELIMINARY PIPELINE SEGMENTS

Early development scenarios considered a large collector pipeline 36 inches in diameter. A round figure of 1m O.D. was recommended for this study as the quantity of concrete coating, and other design factors were not yet fixed. It was proposed that the Grand Banks Pipeline originate in the Jeanne d'Arc Basin and make landfall on the Avalon Peninsula. Preliminary design work by NAPP placed this landfall in Placentia Bay as seen in Figure 1. This location was not viewed as a constraint however when iceberg risk was under consideration. Thus in a deliberate effort to inform without prejudice, six hypothetical landfall sites were selected for investigation, these being widely spaced and representing approaches from the North, South and East (Figure 3). Three origins were likewise selected, Hibernia, White Rose and North Dana, representing potentially marketable resources in water depths approximately 80, 120 and 200m and spatially distributed across 100 km or thereabouts (ends of segment 1 and joint of segment 12) . The locations of pipeline segment nodes were based on consideration of length, depth and apparent iceberg risk identified in the grounding map in Figure 2. In this way a web of 59 segments were developed from which full length routes could be assembled and the associated combined risk, determined.

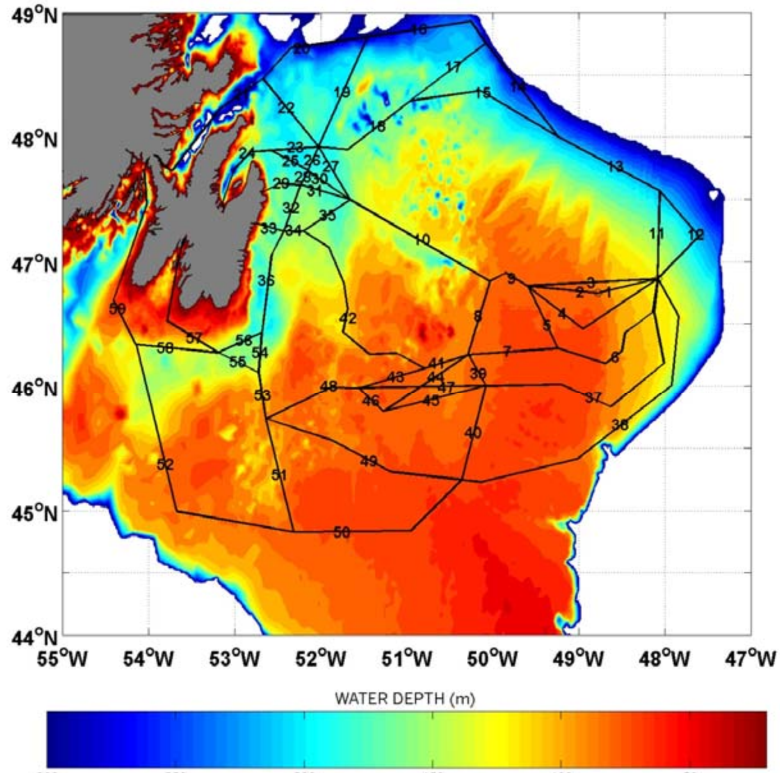

Figure 3. Pipeline segments used in preliminary analysis

ICEBERG/PIPELINE CONTACT SCENARIOS

The three different iceberg/pipeline contact scenarios considered in the analyses are shown in Figure 4. A *scour contact* occurs when a grounded iceberg has scoured far enough to make contact with a pipeline resting on the seabed. A *grounding contact* occurs when an iceberg in the process of grounding makes contact with a pipeline. A *free-floating contact* occurs when a drifting iceberg whose keel is close to the seabed, but not actually touching the seabed, makes contact with a pipeline.

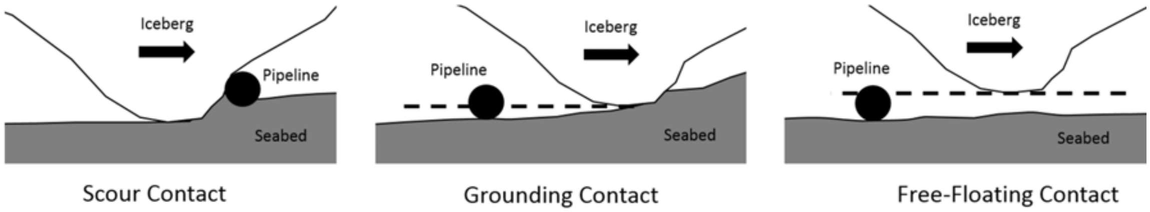

Figure 4. Iceberg contact scenarios considered in the analyses.

Scours were generated from the grounding data produced by the iceberg simulation model McKenna et al. (2019). The location of the groundings and the iceberg drift direction immediately prior to grounding were used to determine the location and orientation of the scours. The scour length was based on a gamma distribution with a mean of 565m and standard deviation of 618m based on data from the northeastern Grand Banks (Terra Nova, 1997). Thus, the start points (grounding locations) and end points of the scours were readily determined and it was a simple matter to determine whether a segment defined by these points intersected a segment representing a portion of a pipeline. However, not all grounding icebergs produced scours. McKenna et al. (1999) found that the proportion of grounding icebergs with sufficient driving forces to scour over significant distances is 3%. A more conservative value of 5% was adopted in this work.

Grounding contacts were generated from the grounding data. The grounding location and the location of the iceberg in the time step (3 hours) prior to grounding were compared with the pipeline segments to determine whether the iceberg crossed the pipeline during the grounding process. When this was the case, the location at which the crossing occurred was determined and the water depth was calculated. If the iceberg draft exceeded the water depth (less the pipeline diameter), a contact was deemed to have occurred.

Free-floating contacts were generated from the iceberg trajectory and draft data from the simulation. Successive iceberg locations defined segments which were compared with pipeline segments. If a crossing occurred, the iceberg draft was compared with the water depth (less the pipeline diameter) at the location of the crossing to determine whether a contact occurred. The process was essentially the same as for the grounding contacts; however, far more data were processed for this operation. For the purpose of reporting the results of the contact analysis, grounding contacts and free-floating contacts are considered collectively as *floating contacts*.

CONTACT ANALYSIS FOR PRELIMINARY ROUTES

The results of the contact analysis for 20 of the 59 pipeline segments (reduced for brevity) are given in Table 1. The table lists the pipeline segment number (as identified in Figure 3) and the pipeline segment length. Column 3 is the number of pipeline contacts associated with iceberg scours, assuming all groundings result in scours, and column 4 is the conversion of these to an annual rate. Columns 5 and 6 do so for floating contacts. The seventh column is the total annual contact frequency, based on the sum of the annual scouring and free-floating contacts. The eighth column lists the total annual risk of iceberg contact per kilometer of pipeline.

Table 1. Pipeline segment contact analysis results based on 500 year data set

Pipeline Segment Number	Segment Length (km)	Scour Contacts		Floating Contacts		Total Contact Frequency	
		Total	*Annual	Total	Annual	Annual	Annual/km
1	54.7	32	0.0032	223	0.446	0.4492	0.008212
2	62.2	15	0.0015	332	0.664	0.6655	0.010699
3	115.2	83	0.0083	664	1.328	1.3363	0.011600
4	142.1	43	0.0043	594	1.188	1.1923	0.008391
5	61.5	8	0.0008	295	0.590	0.5908	0.009607
6	140.6	27	0.0027	341	0.682	0.6847	0.004870
7	80.1	7	0.0007	231	0.462	0.4627	0.005777
8	68.7	11	0.0011	185	0.370	0.3711	0.005402
9	38.3	11	0.0011	199	0.398	0.3991	0.010420
10	142.4	4	0.0004	91	0.182	0.1824	0.001281
11	78.8	0	0.0000	5	0.010	0.0100	0.000127
12	105.9	4	0.0004	12	0.024	0.0244	0.000230
13	101.1	5	0.0005	0	0.000	0.0005	0.000005
14	103.5	1	0.0001	1	0.002	0.0021	0.000020
15	139.3	6	0.0006	19	0.038	0.0386	0.000277
16	112.4	3	0.0003	0	0.000	0.0003	0.000003
17	83.1	7	0.0007	5	0.010	0.0107	0.000129
18	94.4	1	0.0001	5	0.010	0.0101	0.000107
19	106.4	2	0.0002	0	0.000	0.0002	0.000002
20	102	2	0.0002	1	0.002	0.0022	0.000022

* based on scour rate of 5%

The locations of all iceberg/pipeline contacts for the preliminary route segments are marked in red on Figure 5a. A high concentration of contacts is evident in the easternmost region of the Banks surrounding the production area. In this area the seabed trends downwards towards the north which is also the general direction from which icebergs approach. The same trend is noted elsewhere and where the seabed slopes towards the south, groundings and contacts are scarce. Contacts are also concentrated on the slopes around the Avalon Channel through which many icebergs pass. Figure 5b shows when during the year these contacts occurred. The vast majority occur between February and July with highest concentrations around April which correlates directly with seasonal iceberg flux. Very few, less than 2%, occur between August and January.

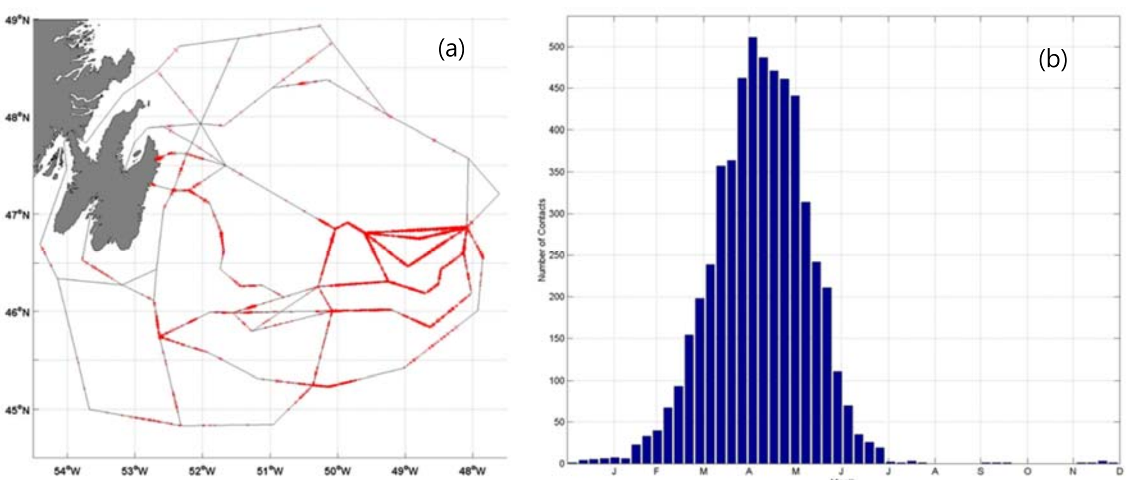

Figure 5. Spatial (a) and temporal (b) distribution of all pipeline contacts – 500 years

Based on the results of the contact analysis, eleven potential pipeline routes were analyzed. The total annual contact frequency associated with a route is the sum of the contacts frequencies associated with the corresponding pipeline segments. The eleven potential pipeline routes and the associated contact frequencies are listed in Table 2.

Table 2. Combined contact frequency for full pipeline routes – 500 year data set

Route Number	Pipeline Segments Used	Route Length (km)	Annual Contact Frequency	Return Period (years)
p1	11, 13, 14, 16, 20, 21	634.0	0.015	66
p2	11, 13, 15, 18, 22, 21	627.2	0.069	14
p3	1, 2, 9, 10, 27, 22, 21	566.1	1.706	0.6
p4	1, 2, 9, 10, 31, 29	378.4	2.224	0.5
p5	1, 2, 9, 10, 35, 34, 33	390.9	1.832	0.5
p6	1, 2, 9, 10, 30, 25, 24	455.0	1.702	0.6
p7	1, 2, 9, 10, 35, 34, 36, 56, 58, 59	749.6	1.792	0.6
p8	38, 50, 52, 59	924.4	0.595	1.7
p9	37, 47, 48, 53, 55, 57	668.5	1.367	0.7
p10	37, 47, 48, 53, 55, 58, 59	789.4	1.329	0.8
p11	6, 7, 41, 43, 48, 53, 55, 58, 59	744.3	1.637	0.6

The annual contact frequency in Table 2 is based on untrenched pipeline sections. Trenching a pipeline section effectively removes the threat from free-floating icebergs. Thus, when a pipeline section is considered to be trenched, the contact frequency associated with the section may be calculated by considering only the annual scour contact rates. The strategy to trench certain portions of routes was examined in this way and the results were very encouraging. Overall contact risk to pipelines could be reduced by as much as a factor of 10 with as little trenching as 10% of the overall length. This, however, did not automatically justify a trenching strategy because the costs of doing so are very high and the uncertainties are great. Thus the concept of strategic trenching was considered but to the greatest extent possible, strategic routing for iceberg contact avoidance was implemented.

Examining Table 2, routes p1 and p2 which pass through deeper waters in the northern portions of the Grand Banks appear to be the most promising. The result for route p1, in particular, with a return period of 66 years was encouraging. Based on these results, the refined routes were focused on northern routes 1 and 2, with White Rose as the source and Bull Arm, Trinity Bay – the landfall. In addition, the scarcity of contacts in the northern area prompted the development of a more extensive data set focused on the northern half of the Grand Banks (46°N and up), and representing a much longer simulation time span of 5000 years.

A couple of steps were taken to allow the generation of a 5000 year data set within a reasonable period of time. Since refined and final pipeline routes were to be limited to the northern portions of the Grand Banks it was unnecessary to model the region south of 46°N. This portion of the data set was discarded and minor modifications were made to the model to accommodate this change. The reduced size of this data set increased execution speed significantly by 70 to 80%. Secondly, the iceberg waterline cutoff length used when icebergs were initially generated was increased from 40m to 100m. A cutoff of 40m excludes 35% of the iceberg population while a cutoff of 100m excludes 77%. The 40m cutoff was used initially since it was thought that icebergs with waterline lengths less than this value would not be of consequence. An analysis of grounding frequencies and iceberg/pipeline interaction frequencies produced from a preliminary data set using the 100m cutoff revealed that the increased waterline cutoff produced only very minor changes in grounding rates or iceberg/pipeline interaction frequencies. The use of a 100m waterline length cutoff further reduced computation time by 50%.

CONTACT ANALYSIS FOR REFINED PIPELINE ROUTES

The refined pipeline route sections are shown in Figure 6. Twenty-eight pipeline route segments were defined and numbered 60 through 87. Pipeline segments 85 through 87 overlap portions of other segments and are shown as dashed magenta lines. Pipeline segment 87 intersects segment 82 a distance of 11.8 km from its endpoint, thus the length of pipeline routes using segments 82 and 87 were adjusted accordingly.

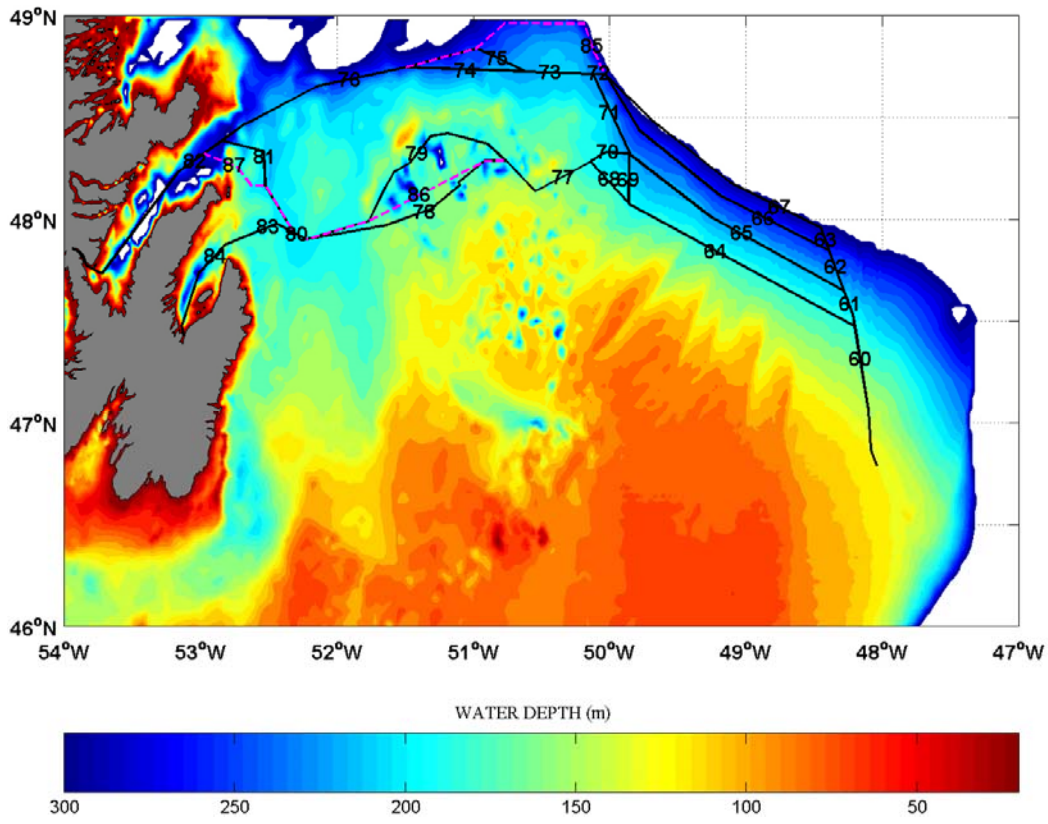

Figure 6. Refined pipeline route segments

The refined pipeline segments were analyzed using the new 5000 year data set. The results of the contact analysis for the 28 pipeline segments were tabulated and the spatial and seasonal distribution of the contacts were plotted. The segments were assembled into 11 plausible pipeline routes for which the combined contact frequency was evaluated. Those results are listed in Table 3. The annual contact frequency is based on untrenched pipeline segments. Return periods are given for the untrenched condition and with pipeline segment 60 trenched. Return periods for untrenched pipelines range from 13 to 32 years. Trenching segment 60 improves this considerably, with return periods ranging from 20 to 197 years. These results were used to develop a final set of pipeline route segments.

Table 3. Annual Probability of Iceberg Contact with Pipeline Routes, Based on Refined Pipeline Sections and 5000 Year Data Set

Route Number	Pipeline Segments Used	Route Length (km)	Annual Contact Frequency	Return Period (years)	Return Period (trench 60)
r1	60, 64, 68, 77, 78, 80, 83, 84	534.6	0.0766	13	20
r2	60, 61, 65, 70, 77, 78, 80, 83, 84	545	0.0632	16	27
r3	60, 64, 68, 77, 79, 80, 83, 84	552	0.0701	14	23
r4	60, 61, 65, 70, 77, 79, 80, 83, 84	562.4	0.0567	18	33
r5	60, 61, 65, 70, 77, 78, 80, 81, 82	639.5	0.0629	16	27
r6	60, 61, 65, 71, 73, 74, 76, 82	614.6	0.0411	24	66
r7	60, 61, 62, 66, 72, 73, 74, 76, 82	616.3	0.0394	25	75
r8	60, 61, 62, 63, 67, 72, 73, 74, 76, 82	615.9	0.0393	25	75
r9	60, 61, 62, 66, 85, 76, 82	641.2	0.0310	32	197
r10	60, 61, 65, 70, 77, 86, 80, 81, 82	635.8	0.0572	18	32
r11	60, 61, 65, 70, 77, 86, 80, 87, 82	621.7	0.0640	16	26

CONTACT ANALYSIS FOR FINAL PIPELINE ROUTES

Ten final pipeline route segments, shown in Figure 7, were analyzed with the 5000 year data set. Five different pipeline segments were used in the range between 50°W and 51°W to assess the effect of using a shorter route in shallower water versus a longer route in deeper water. The resulting contact frequencies for the combined route options for this analysis are listed in Table 4.

Annual contact frequencies in Table 4 are for untrenched pipeline routes. Return periods for untrenched pipelines range from 32 to 35 years. Trenching section 88 improves this considerably, with return periods ranging from 173 to 455 years.

The results of this analysis indicate the clear relationship between bathymetric depth and iceberg contacts. The strategy to keep the pipeline near the 200m depth contour appears to give exceptional results from a risk-avoidance perspective, at the cost of longer routing. Getting from the production area of the relatively shallow Jeanne d'Arc Basin to deeper water on the edges of the Banks clearly attracts the highest contact risk for any Northern route. It may be noted that portions of this segment fall within iceberg management zones for present and proposed production facilities. It is not inconceivable that active management of icebergs near production facilities can further reduce contact risk in this vicinity. It must also be noted that this work identifies only contact events and those for a 1m diameter pipeline with no embedment. It is a matter of further investigation to determine the range of outcomes from the various contacts which may arise given that not all contacts will result in the rupture of a pipe.

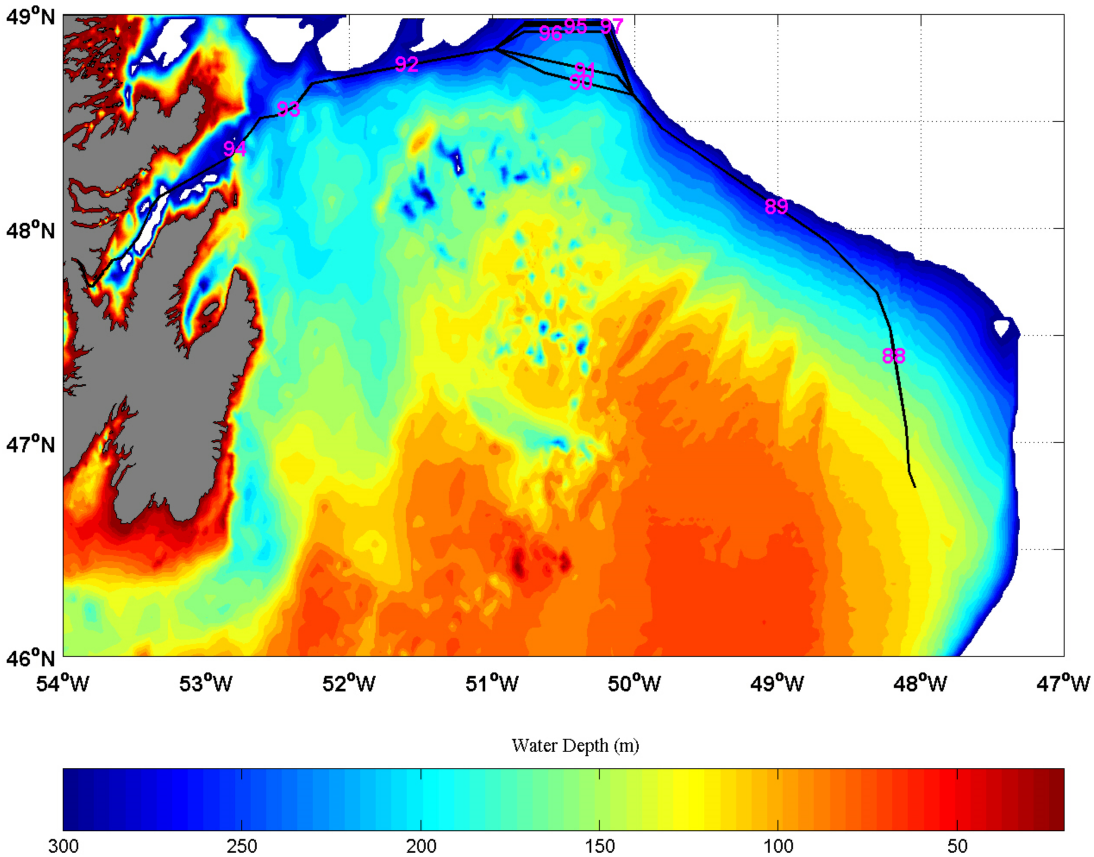

Figure 7. Final pipeline segments for analysis – 5000 year data set

Table 4. Annual Probability of Iceberg Contact with Pipeline Routes, Based on Final Pipeline Sections and 5000 Year Data Set

Route Number	Pipeline Sections Used	Route Length (km)	Annual Contact frequency	Return Period (years)	Return Period (trench 88)
f1	88, 89, 90, 92, 93, 94	616.4	0.0318	32	173
f2	88, 89, 91, 92, 93, 94	618.4	0.0318	32	174
f3	88, 89, 96, 92, 93, 94	635.7	0.0286	35	389
f4	88, 89, 95, 92, 93, 94	641.2	0.0284	35	417
f5	88, 89, 97, 92, 93, 94	644.1	0.0282	35	455

CONCLUSIONS

This project involved the calculation of iceberg/pipeline contact frequencies for a variety of potential pipeline routes. The analysis was based on the iceberg simulation developed by C-CORE (McKenna et al., 2019), with iceberg/pipeline contacts including those due to free floating icebergs, icebergs in the process of grounding, recently grounded and scouring icebergs.

The selection of optimum pipeline routing was accomplished in three iterations. The initial iteration included potential pipeline sections with locations ranging over most of the Grand Banks region, with landfalls in the vicinity of Bull Arm, Holyrood, St. John's, Bay Bulls, St. Mary's and Come-by-Chance. The second iteration was restricted to the northern portion of the Grand Banks, with landfalls in the vicinity of Holyrood and Bull Arm. The final iteration was limited to essentially a single deep-water route on the northern Grand Banks with minor variations between 50^{o}W and 51^{o}W and a landfall in the vicinity of Bull Arm.

The final set of pipeline routes had iceberg/pipeline contact frequencies with return periods ranging from 32 to 35 years for untrenched pipelines and return periods ranging from 173 to 455 years with the initial portion of the pipeline trenched. The vast majority of iceberg/pipeline contacts occurred in the months of February through July. Less than 2% of iceberg/pipeline contacts occurred between August and January for the final pipeline routes with the 5000 year data set.

The recommended pipeline route for minimizing iceberg contact risk progresses northward from 46.7904^{o}N, 48.0386^{o}W and passes north of the Grand Banks, primarily in water depths between 190m and 270m, into Trinity Bay and makes a landfall in Bull Arm. Trenching the easternmost pipeline section appears to be necessary and would decrease overall iceberg contact risk by a factor of about 10.

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Companion paper to this:
McKenna, R.F, King, T., Crocker, G., Bruneau, S., and German, P. (2019) Modelling Iceberg Grounding on the Grand Banks. Proceedings of the 25th International Conference on Port and Ocean Engineering under Arctic Conditions, June 9-13, Delft, The Netherlands.

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