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Aleutian Islands Risk Assessment
Phase A-Preliminary Risk Assessment

Task 2A: Marine Spill Frequency and Size Report

Prepared For:

National Fish and Wildlife Foundation

United States Coast Guard

Alaska Department of Environmental Conservation

Report no. / DNV ref no: EP007543-1

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ATTACHMENTS

1 INTRODUCTION

Task 2 of the Aleutian Islands Risk Assessment (AIRA) Phase A Preliminary Risk Assessment Scope of Work requires a Baseline Spill Study to be performed. Subtask 2A within the Baseline Spill Study is an analysis that estimates the spill frequency, spill size by Vessel Type and spill origination by geographical location. As described in the Risk Analysis Team's amended proposal (dated August 27, 2009), this analysis (Task 2A of the AIRA Request for Proposal) was conducted using the Marine Accident Risk Calculation System (MARCS) tool. This document, Task 2A - Marine Spill Frequency and Size Report (Task 2A Spill Frequency Report), describes the approach, summarizes the results of the MARCS modeling, and defines the Baseline Spill Scenarios.

This final Task 2A Spill Frequency Report incorporates comments on the draft report received from the Management Team (consisting of the National Fish and Wildlife Foundation (NFWF), United States Coast Guard (USCG), and Alaska Department of Environmental Conservation (ADEC), the Advisory Panel members, and the Peer Review Panel.

1.1 Objective

The objective of this document is to present the methodology, assumptions and results concerning estimation of spill frequency, spill size by Vessel Type, spill origination by geographical location, and establish baseline spill scenarios for the base year (2008/2009) and the predicted future year (2034).

1.2 Purpose

This document describes initial spill risk results which have been generated on the basis of the assumptions stated and traffic data presented in AIRA Preliminary Risk Assessment Task 1 Semi-Quantitative Traffic Study. The spill risk results provide guidance and input for the COSIM model in order to complete the Baseline Spill Study.

1.3 Scope

The scope of this report is to address marine risk assessment aspects of Task 1 and Task 2, and to develop sufficient likely baseline spill scenarios based upon multiple data inputs into the Marine Accident Risk Calculation System (MARCS) tool for the base year (2008/2009) and the predicted future year (2034). The MARCS tool is used to calculate the spill frequency, spill size by Vessel Type and spill origination by geographical location to develop baseline spill scenarios to model spill impact consequences to the environment.

The Aleutian Islands Risk Assessment was designed to be performed in two phases (Phase A and Phase B). This deliverable is part of the Task 1/Task 2 report from Phase A. There are an additional 6 tasks defined in Phase A, plus the work not yet defined for Phase B. The stated objective of the Request for Proposal (RFP) is that Task 1/Task 2 should provide a "semi-quantitative risk assessment."

The risk assessment results presented in the Task 1/Task 2 report have been obtained by a relatively quick identification of relevant data and presenting that data to the risk calculation models to generate results. The objectives of this exercise are to:

- Provide sufficient data and methodological basis for subsequent project tasks;
- Generate initial risk results to provide an overview of the key risk issues;
- Present the data and results obtained to study stakeholders;
- Focus subsequent project tasks towards the important factors that are likely to improve safety in the system.

Since these risk assessment results are not the final risk assessment results, either for Phase A or for the overall project, and because the objective was to provide "semi-quantitative" results, it is entirely justified to not fully report and discuss the results as if they represent a state-of-the-art risk assessment. The results and discussion presented in this report are fit for their intended purpose as defined in this section.

1.4 Report Organization

This report presents the risk results obtained to date under Task 1 and Task 2A. It does not re-present the results reported in the traffic study report, nor does it present the spill impact consequence modeling results. The report is organized as follows:

- Section 1 provides introduction.
- Section 2 outlines the MARCS model and its input data (also see Attachment 1).
- Section 3 presents accident frequency and risk results calculated by the MARCS model for the base year of 2008/2009.
- Section 4 presents accident frequency and risk results calculated by the MARCS model for the future year of 2034.
- Section 5 presents bunker and cargo spill risk evaluations for the base year (2008/2009) and future year (2034).
- Section 6 presents a discussion of probabilistic spill models utilized in this study.
- Section 7 presents spill scenarios for the base year of 2008/2009. These are derived from examination of preliminary MARCS results and are used as inputs into the Baseline Spill Study.
- Section 8 discusses model dependencies, sensitivities and uncertainties that need to be taken into account when interpreting these results.

Traffic Plots and geographical distributions of cargo spill risk for base year and future year are provided in Section 12. An overview of the MARCS Methodology is provided in

Attachment 1. This attachment provides additional general information and overview on how the MARCS model operates.

2 MARCS INPUT DATA

The MARCS model classifies input data into four main types:

1. Shipping lane data. Describes the movements of different marine Vessel Types within the study area;
2. Environment data. Describes the conditions within the calculation area, including the location of geographical features (land, offshore structures etc) and meteorological data (visibility, wind rose, currents and sea state);
3. Internal operational data. Describes operational procedures and equipment installed onboard ship – such data can affect both accident frequency and accident consequence factors; and
4. External operational data. Describes factors external to the ship that can affect ship safety, such as VTMS (Vessel Traffic Management Systems), TSS (Traffic Separation Schemes), and the location and performance of emergency tugs – such data can affect both accident frequency and accident consequence factors.

Figure 2-1 illustrates the different types of inputs used to calculate the spill frequency, spill size by Vessel Type and spill origination by geographical location using the MARCS tool.

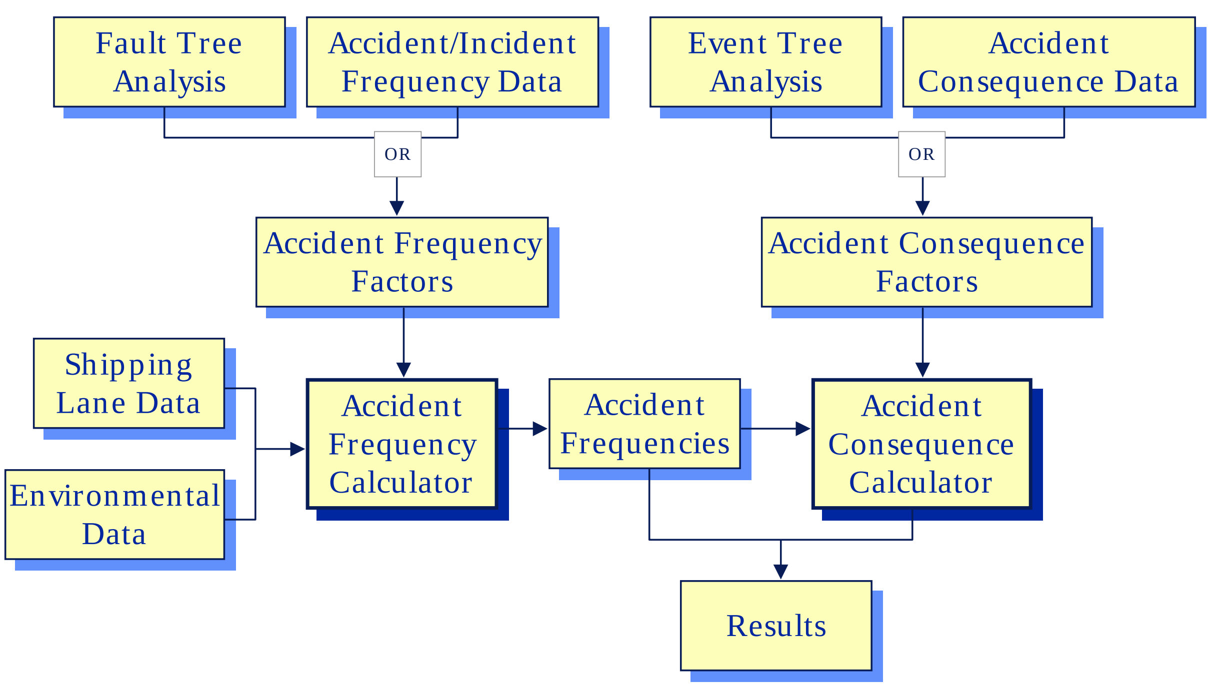

Figure 2-1 MARCS Diagram

As indicated in Figure 2-1, accident frequency and consequence factors can be derived in two ways. For this assessment, fault tree analysis and event tree analysis was used and corroborated using analyzed data from worldwide historical accident data databases, the event tree and fault tree results were then compared to regional historical accident/incident frequency data and accident consequence data. The factors for this assessment are taken from a worldwide historical accident data database as well as fault tree analysis. Attachment 1 further describes the MARCS model methodology and the components of the methodology shown in Figure 2-1.

2.1 Shipping Lane Data Input

The traffic data is the primary input into a marine risk assessment. The description of the data modeled and analyzed can be found in AIRA Preliminary Risk Assessment - Task 1Semi-Quantitative Traffic Study.

The data manipulation process which refined AIS Traffic data into a useable MARCS input format is briefly described in Figure 2.2. These steps began with three hundred million rows of comma separated value (normally referred to as csv) AIS data files provided by the Marine Exchange of Alaska. The next step was to generate ArcGIS polyline shape files reflecting the AIS data received. Once the polyline shape files reflected the data received, the polylines were grouped into shipping lanes. The shipping lane widths were determined by analyzing the lane width experienced by grouping ~95% of the polylines in order to attain a 2 sigma level of confidence, adequate for this study.

From this point, the basis for MARCS input spreadsheets were generated and data gaps were identified.

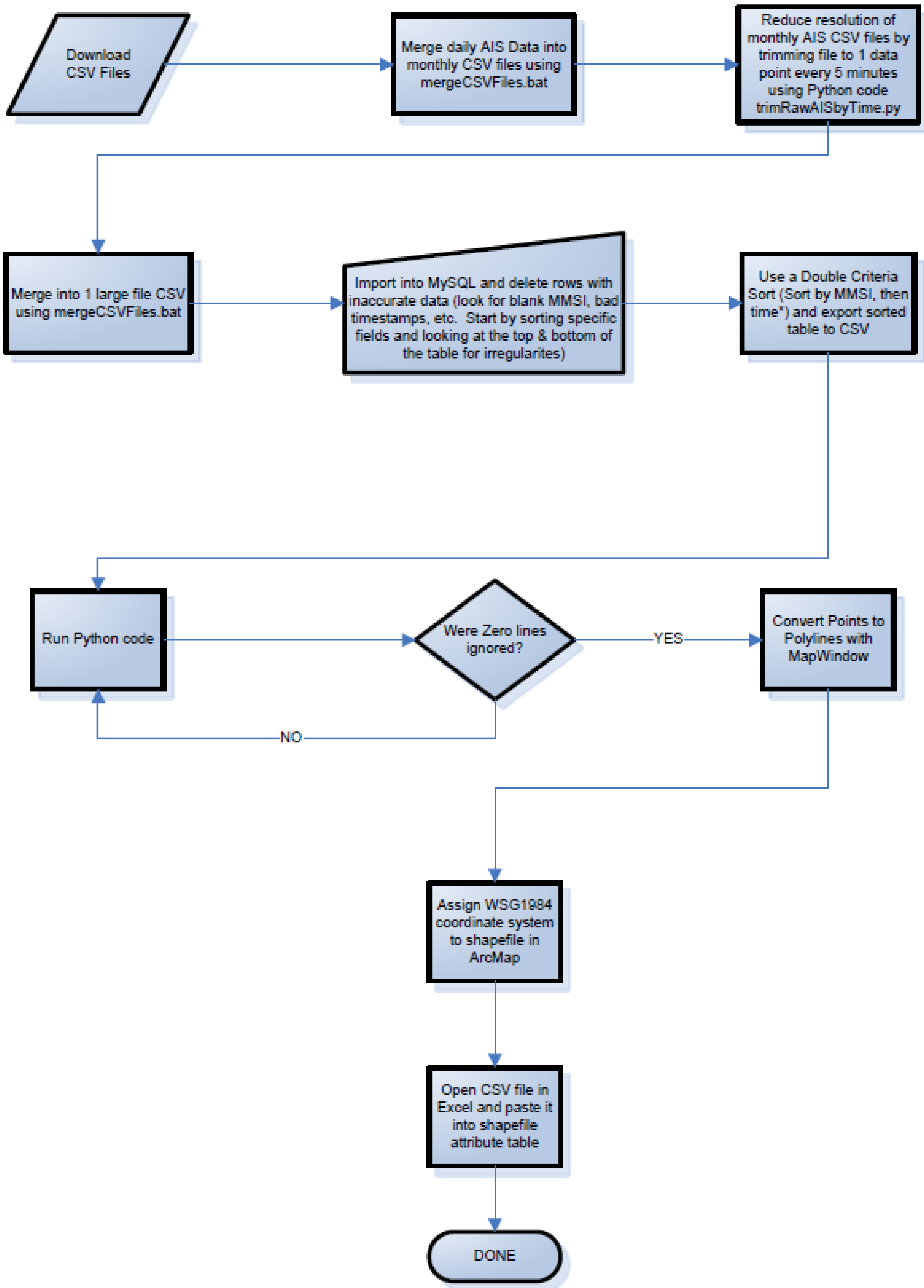

Figure 2-2 AIS Data Manipulation Process

The subsequent subsections include a discussion of the Vessel Types, vessel speeds and cargo status.

2.2 Marine Vessel Types

AIRA Preliminary Risk Assessment - Task 1 Semi-Quantitative Traffic Study discusses the approach to identifying Vessel Type categories. Table 2-1 reflects the Vessel Types used in the risk calculations. It is assumed that no bunker (fuel oil) tanks are protected by double hulls in the base year (2008/2009) traffic data since double hulled bunker tank requirements did not go into effect until 2006 for new construction vessels. Though it is possible that there may have been vessels in the transpacific route with double hull bunker tank protection in the base year data, there are no firm indicators available to assess the number or type of vessels or transit routes. The assumption is a best estimate based on consultation with senior maritime surveyors.

Table 2-1 Marine Vessel Types Defined in AIRA

Vessel Type		Bunker* Spill Model	Cargo Spill	Comment
1	Container Ships < 4500 TEUs	Included	Included	Hazardous cargo is no more than 10% of the total carried
2	Container Ships > 4500 TEUs	Included	Included	Hazardous cargo is no more than 10% of the total carried
3	Bulk Carriers < 60,000 DWT	Included		Significant spill of hazardous cargo not credible
4	Bulk Carriers > 60,000 DWT	Included		Significant spill of hazardous cargo not credible
5	General Cargo Vessels	Included	Included	Hazardous cargo is no more than 10% of the total carried
6	LNG and Gas Carriers	Included	Included	
7	Ro/Ro and Car Carriers	Included		No hazardous cargos
8	Cruise Ships	Included		No hazardous cargos
9	Crude Oil Carriers	Included	Included	
10	Product Tankers	Included	Included	
11	Chemical Carriers	Included	Included	
12	Tank Barges		Included	
13	Cargo Barges			Cargo barges are not explicitly represented in traffic data
14	Fishing Vessels	Included		No hazardous cargos
15	Tugs	Included		No hazardous cargos
16	Government Vessels	Included		No hazardous cargos
17	Refrigerated Cargo Ships (Tramp trade)	Included		No hazardous cargos
18	Other Vessels	Included		No hazardous cargos

* Bunker in this table is used as a generality to make reference to fuel oil (bunker or diesel fuel)

Table 2-1's Bunker Spill Model column indicates whether the risk of each Vessel Type's fuel oil was included in the set of MARCS model results presented below. Only barges, which do not carry bunker fuel, do not have bunker oil spill models included. The bunker spill risk for barge towing vessels is included under Vessel Type 15 (Tugs).

Table 2-1's Cargo Spill column describes Vessel Types which had cargo spill risk considered in the results of this document. Cargo spill models were conducted only for Vessel Types that carry hydrocarbons or hazardous cargo in bulk. The majority of cargo spill risk originates from ship categories 6, 9, 10, 11 and 12. These ship categories can carry hydrocarbon and hazardous cargo in large quantities. Vessel Types 1-5, 7, 8 and 13-18 do not normally transport significant quantities of liquid hydrocarbon or hazardous cargo. It is possible for Container Ships or General Cargo Vessels to carry some packaged hydrocarbons or other dangerous goods, but these amounts are much smaller than the cargo volumes carried in crude oil tankers, large product and chemical tankers.

2.3 Vessel Speed

Table 2-2 shows the average traffic speeds assumed for each Vessel Type and applied throughout the study area. It is assumed that 20% of all ships navigate 20% faster than average and 20% of all ships navigate 20% slower than average. Thus some collision risk will be due to ships overtaking within a single lane. Though vessel speeds are available from the AIS data, the data available was unreliable with many indicators of 0 and 99 knots speeds, indicating non-values. Thus, the average speeds used were derived from available historical data for vessels types held by DNV and expert judgment.

Table 2-2 Average Vessel Speeds for Each Vessel Type

Vessel Type		Ship speed (knots)
1	Container Ships < 4500 TEUs	22
2	Container Ships > 4500 TEUs	22
3	Bulk Carriers < 60,000 DWT	12
4	Bulk Carriers > 60,000 DWT	14
5	General Cargo Vessels	12
6	LNG and Gas Carriers	14
7	Ro/Ro and Car Carriers	14
8	Cruise Ships	14
9	Crude Oil Carriers	14
10	Product Tankers	12
11	Chemical Carriers	12
12	Tank Barges	10
13	Cargo Barges	10
14	Fishing Vessels	10

Vessel Type		Ship speed (knots)
15	Tugs	10
16	Government Vessels	12
17	Refrigerated Cargo Ships (Tramp trade)	12
18	Other Vessels	10

2.4 Determination of Cargo Status

There is no practical way to identify whether ships navigate laden, their laden fraction (cargo carried as a fraction of cargo capacity) or be certain of the type of cargo. The following assumptions have been made to address this issue:

- All laden LNG and gas tankers (Vessel Type 6) are loaded with LNG.
- All laden crude carriers (Vessel Type 9), product tankers (Vessel Type 10) and chemical tankers (Vessel Type 11) are loaded with crude oil, refined liquid hydrocarbon fuels and other liquid hydrocarbon chemicals (which are immiscible with water and are lower density than water), respectively.
- All laden Tank barges (Vessel Type 12) are loaded with refined liquid hydrocarbon fuels.
- 50% of all LNG, crude, product and chemical tankers are laden and 50% are in-ballast. When laden, the laden fraction is 1.0.
- Tank barges (Vessel Type 12), container ships (Vessel Types 1, 2) and general cargo ships (Vessel Type 5) are assumed to be always laden, but the average laden fraction is 80% (these Vessel Types tend to both load and discharge at each port they visit, so are rarely empty).

The traffic data indicates that all gas tank ships (Vessel Type 6), product tankers (Vessel Type 10) and chemical tankers (Vessel Type 11) are double hulled in the base year. It is assumed this Vessel Type will continue to be double hulled in the future year as international tanker double hull regulations are fully enforced.

The traffic data assumed that 75% of all crude tankers (Vessel Type 9) are double hulled in the base year (2008-2009). This is a base year best estimate as tanker double hull regulations were not fully in force during that year and is based on best available data at the time of evaluation. It is assumed this Vessel Type will all be double hulled in the future year as international tanker double hull regulations are fully enforced.

The traffic data indicates that all Tank barges (Vessel Type 12) are single hulled in the base year. It is assumed this Vessel Type will all be double hulled in the future year as the existing fleet of single hull barges is replaced with double hull barges.

It is assumed that no bunker tanks are protected by double hulls in the base year traffic data and that 80% of all bunker tanks for all Vessel Types are protected by double hulls in the future year as international double hull bunker tanks regulations are phased in. Figure 2-3 illustrates the general arrangement of a typical double hull tank ship (94,500 DWT crude oil tank ship) with single hull bunker tanks.

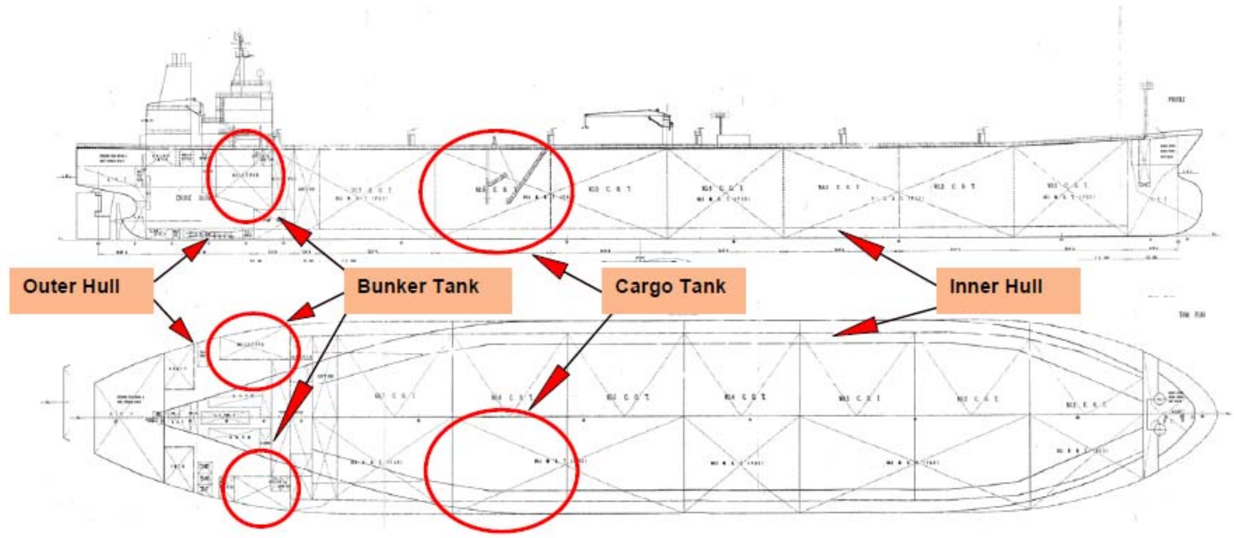

Figure 2-3 General arrangement of a typical double hull tank ship

The probabilistic bunker and cargo spill models are described further in the section below.

2.5 Determination of Bunker (Fuel Oil) Status

The average bunker (fuel oil) capacity for each ship type is provided in Table 2-3. This is based on vessel data collected during the traffic study (Task 1).

Table 2-3 Average Fuel Oil Capacity for Each Vessel Type

Vessel Type		Estimated average fuel capacity (Tons)	Estimated average fuel capacity (bbl)
1	Container Ships < 4500 TEUs	5410	35,706
2	Container Ships > 4500 TEUs	8433	55,658
3	Bulk Carriers < 60,000 DWT	1830	12,078
4	Bulk Carriers > 60,000 DWT	2944	19,430
5	General Cargo Vessels	1973	13,021
6	LNG and Gas Carriers	3283	21,733
7	Ro/Ro and Car Carriers	2944	19,430
8	Cruise Ships	1750	11,550

Vessel Type		Estimated average fuel capacity (Tons)	Estimated average fuel capacity (bbl)
9	Crude Oil Carriers	2864	18.902
10	Product Tankers	1432	9,451
11	Chemical Carriers	1034	6,824
12	Tank Barges	0	0
13	Cargo Barges	0	0
14	Fishing Vessels	95	627
15	Tugs	375	2,475
16	Government Vessels	3182	21,001
17	Refrigerated Cargo Ships (Tramp trade)	1177	7,768
18	Other Vessels	2582	17,041

It was assumed that all ships are 70% full of bunker / fuel oil at the time of the accident and that the bunker capacity of all ships is sub-divided into 2 tanks. For modeling purposes, the type of bunker oil is assumed to be the same for all ship types, though it is understood that for the most part, vessel types 14, 15, 16 and 18 operate on diesel fuel.

2.6 Shipping Lane Traffic Data for the Base Year (2008/2009)

Table 2-4 displays the nautical mile distance travelled during the analyzed period (2008-2009), within the study area as a function of Vessel Type and ship size range categories by the ship's Deadweight Tonnage (DWT). Table 2-4's data is generated as an output of the MARCS model and is based upon the input data provided by the AIS data as manipulated by Figure 2-2. Table 2-4 is a summary of the vessel movement input data and gives the analyst or reader a description of the activity and size of each Vessel Type. Vessel miles are a relevant measure of both absolute and relative traffic intensity. The relationship between vessel-miles and vessel-hours is mostly straightforward since as a single average vessel speed is used independent of vessel location (but dependent on vessel type). The MARCS model does not fully represent vessels while not in transit (i.e., fishing vessels while actually fishing), but this simplification is not considered to significantly affect the results because these activities do not generally interact with the main ship traffic lanes.

Table 2-4 Number of Vessel-Miles for Each Vessel Type and Ship Size Category in the AIRA Study Area for the Base Year (2008/2009)

Vessel Type		Ship Size [1] and Vessel Miles								Total Vessel Miles[2]
		0k-2k DWT	2k-6 DWT	6k-14k DWT	14k-30k DWT	30k-50k DWT	50k-90k DWT	90k-130k DWT	130k->130 DWT	
1	Cont. <4500 TEUs	0	0	0	3.94E+04	4.02E+05	1.26E+05	0	0	5.68E+05
2	Cont. >4500 TEUs	0	0	0	0	3.55E+03	1.08E+06	1.53E+05	0	1.23E+06
3	Bulk <60kDWT	0	0	0	4.02E+05	3.85E+05	2.04E+05	0	0	9.91E+05
4	Bulk >60kDWT	0	0	0	0	0	6.73E+05	3.06E+04	1.05E+05	8.09E+05
5	Gen. cargo	0	1.24E+03	2.05E+04	7.36E+04	1.11E+05	1.82E+04	0	0	2.24E+05
6	Gas tanker	0	0	0	0	4.54E+04	1.15E+03	0	0	4.65E+04
7	RoRo	0	0	3.92E+04	1.73E+05	0	0	0	0	2.12E+05
8	Cruise	3.59E+03	4.31E+03	4.27E+03	0	0	0	0	0	1.22E+04
9	Oil tanker	0	0	0	0	1.62E+03	0	8.23E+03	0	9.85E+03
10	Product tanker	0	0	5.74E+03	3.27E+04	1.58E+04	0	0	0	5.43E+04
11	Chemical tanker	0	0	0	3.04E+04	0	0	0	0	3.04E+04
12	Tank barge	4.24E+03	1.26E+04	7.99E+04	4.24E+03	0	0	0	0	1.01E+05
13	Cargo barge	0	0	0	0	0	0	0	0	0.00E+00
14	Fishing Vessel	4.05E+05	4.05E+05	0	0	0	0	0	0	8.10E+05
15	Tug	1.43E+05	0	0	0	0	0	0	0	1.43E+05
16	Gov. Vessel	2.35E+04	5.87E+03	0	0	0	0	0	0	2.93E+04
17	Reefer	5.39E+03	2.87E+04	7.40E+03	0	0	0	0	0	4.15E+04
18	Other	3.09E+04	2.55E+03	2.55E+03	2.55E+03	2.55E+03	0	0	0	4.11E+04
Sum		**6.16E+05**	**4.60E+05**	**1.60E+05**	**7.57E+05**	**9.66E+05**	**2.10E+06**	**1.92E+05**	**1.05E+05**	**5.36E+06**

Notes:

[1]. Although the ship size categories are specified in terms of deadweight, the concept of deadweight is difficult to apply to some Vessel Types (e.g. cruise ships) and in this case the different ship size categories should be interpreted as different relative ship sizes.

[2]. 1.57E+03 is equivalent to 1,570 nautical miles; 1.47E+04 is equivalent to 14,700 nautical miles

DWT = Deadweight Tonnage
TEUs = Twenty-foot Equivalent Units
RoRo = Roll-on / roll-off vessel

Table 2-4 shows that Container Ships (Vessel Types 1 and 2) and Bulk Carriers (Vessel Types 3 and 4) navigate the greatest number of vessel-miles within the AIRA study area. Together, Vessel Types 1-4 contribute 67% of the total traffic defined. The next largest contributor is Fishing Vessels (Vessel Type 14). The sum of the five largest contributors represents 82% of all vessel-miles. The remaining Vessel Types contribute only 18% of the vessel-miles in the study area. This observation identifies Vessel Types 1 – 5 as the likely greatest contributors to accident frequency for the study area.

2.6.1 Shipping Lane Data Traffic Plots

In order to develop traffic plots, each vessel lane shown in Figure 2-3 was defined with vessel density characteristics. These characteristics were defined for each Vessel Type transiting each lane:

- Vessel frequency across the individual lane
- Vessel's laden / ballast distribution
- Vessel's hull design distribution
- Vessel's Deadweight tonnage distribution
- Vessel's probable location across the lane width given an assigned probability distribution across the lane

Table 2-4 illustrates the contribution of each Vessel Type through quantifying how many vessel-miles each Vessel Type transits across each lane throughout the study area. Transit Frequency is illustrated in each traffic plot through a gradient color code scheme found in Table 2-4.

Table 2-5 Key to Vessel Transit Plots

Color	Transit Frequency (ship movements per day within each calculation location)
	0.0 to 0.1
	0.1 to 0.5
	0.5 to 1
	1 to 5
	5 to 10
	> 10

Figure 2-4 Traffic Plot for All Vessel Types for Base Year (2008/2009) is an illustration generated by MARCS which displays the traffic input data based upon the frequency of all vessel transits per traffic lane. Figure 2-4 was generated using the MARCS model and traffic data described in the AIRA Preliminary Risk Assessment - Task 1 Semi-Quantitative Traffic Study. Figure 2-4 illustrates that during base year (2008/2009) the heaviest amount of traffic (illustrated in red) occurred in Unimak Pass, the traffic lane to the Southeast of Unimak Pass, and the traffic lane to the Northwest from the Unalaska area.

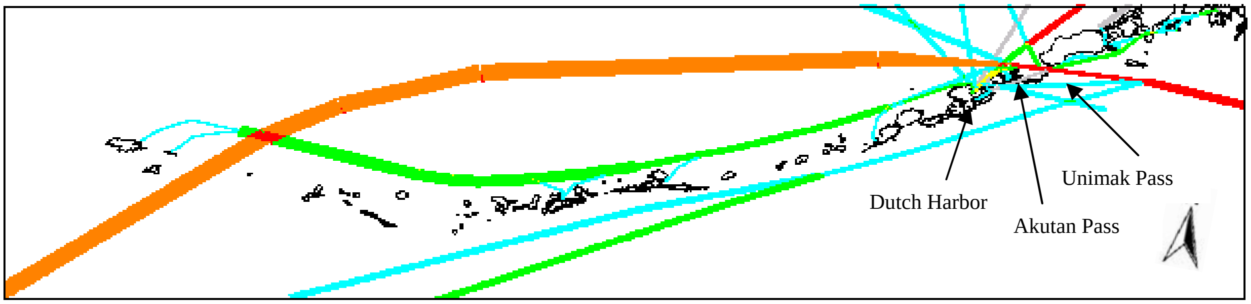

Figure 2-4 Traffic Plot for All Vessel Types for Base Year (2008/2009)

Vessel Traffic Plots for all Vessel Types for base year (2008/2009) are shown in Section 12.

2.6.2 Conclusions from the Traffic Data for Base Year (2008/2009)

Figure 2-4 Traffic Plot for All Vessel Types is an illustration generated by MARCS which displays the traffic input data based upon the frequency of all ship transits per traffic lane.

The vast majority of the traffic is located on the Great Circle Route as expected and the MARCS input data for this traffic is reasonable for the initial baseline spill study based upon comparative historical studies as described in the AIRA Preliminary Risk Assessment Task 1 Semi-Quantitative Traffic Study. The greatest average traffic frequencies are calculated at about 14 movements per day through Unimak Pass. Seasonal variations not represented in the input data might increase this traffic frequency at certain times of the year. This traffic frequency is not very high by international standards, but it is also not insignificant. For comparison purposes, there are over 100 longitudinal movements per day through the Bosphorus (Istanbul, Turkey), in addition to many transverse ferry crossings.

The area close to Dutch Harbor is relatively densely trafficked due to a combination of movements to and from Dutch Harbor and the passing traffic on the Great Circle Route. There are many fishing vessels that use Dutch Harbor.

A smaller proportion of passing traffic types navigates the area to the south of the Aleutian Islands. These vessels may be on weather routing (avoiding the worst of the heavy weather) or they may be heading for ports that are located further to the south compared to traffic on the Great Circle Route.

A number of Vessel Types (mainly fishing vessels, Tank barges and tugs) navigate very close to land (inshore routes) at the eastern end of the study area. Some of these routes use very narrow channels between small islands. This traffic, and its effect on the risk results, will be discussed further below.

The average traffic speeds assumed for each Vessel Type are based on previous DNV traffic studies and are applied throughout the study area. It is assumed that 20% of all ships travel 20% faster than average and 20% of all ships travel 20% slower than average (e.g. out of 100 tugs heading at an average of 10 knots, 20 tugs travel at 8 knots and 20 travel at 12 knots). Thus, some collision risk will be due to ships overtaking within a single lane.

2.7 Traffic Data for the Future Year (2034)

Table 2-6 shows the distance travelled per year within the study area as a function of Vessel Type and for each size range for each Vessel Type for the future year (2034).

Table 2-6 Number of Vessel-Miles for each Vessel Type and Vessel Size Category in the AIRA Study Area for the Future Year 2034

Vessel Type		Ship Size [1] and Vessel Miles								Total Vessel Miles[2]
		0k-2k DWT	2k-6 DWT	6k-14k DWT	14k-30k DWT	30k-50k DWT	50k-90k DWT	90k-130k DWT	130k->130 DWT	
1	Cont. <4500 TEUs	0	0	0	7.37E+04	7.30E+05	2.30E+05	0	0	1.03E+06
2	Cont. >4500 TEUs	0	0	0	0	9.81E+03	2.99E+06	4.25E+05	0	3.42E+06
3	Bulk <60kDWT	0	0	0	4.21E+05	4.02E+05	2.13E+05	0	0	1.04E+06
4	Bulk >60kDWT	0	0	0	0	0	7.29E+05	3.32E+04	1.14E+05	8.76E+05
5	Gen. cargo	0	0	0	4.08E+05	6.14E+05	1.01E+05	0	0	1.24E+06
6	Gas tanker	0	0	0	0	1.90E+05	4.81E+03	0	0	1.95E+05
7	RoRo	0	0	3.94E+04	1.74E+05	0	0	0	0	2.13E+05
8	Cruise	3.59E+03	4.31E+03	4.27E+03	0	0	0	0	0	1.22E+04
9	Oil tanker	0	0	0	0	1.62E+03	0	8.23E+03	0	9.85E+03
10	Product tanker	0	0	1.42E+04	8.21E+04	3.97E+04	0	0	0	1.36E+05
11	Chemical tanker	0	0	0	9.24E+04	0	0	0	0	9.24E+04
12	Tank barge	4.40E+03	1.31E+04	8.29E+04	4.40E+03	0	0	0	0	1.05E+05
13	Cargo barge	0	0	0	0	0	0	0	0	0.00E+00
14	Fishing Vessel	4.05E+05	4.05E+05	0	0	0	0	0	0	8.10E+05
15	Tug	1.49E+05	0	0	0	0	0	0	0	1.49E+05
16	Gov. Vessel	2.35E+04	5.87E+03	0	0	0	0	0	0	2.93E+04
17	Reefer	5.39E+03	2.87E+04	7.40E+03	0	0	0	0	0	4.15E+04
18	Other	3.09E+04	2.55E+03	2.55E+03	2.55E+03	2.55E+03	0	0	0	4.11E+04
Sum		**6.22E+05**	**4.67E+05**	**2.64E+05**	**1.26E+06**	**1.99E+06**	**4.27E+06**	**4.67E+05**	**1.14E+05**	**9.45E+06**

[1]. Although the ship size categories are specified in terms of deadweight, the concept of deadweight is difficult to apply to some Vessel Types (e.g. cruise ships) and in this case the different ship size categories should be interpreted as different relative ship sizes.
[2]. 1.57E+03 is equivalent to 1,570 nautical miles; 1.47E+04 is equivalent to 14,700 nautical miles
DWT = Deadweight Tonnage
TEUs = Twenty-foot Equivalent Units
RoRo = Roll-on / roll-off vessel

Table 2-6 shows that Container ships (Vessel Types 1 and 2) and Bulk Carriers (Vessel Types 3 and 4) navigate the greatest number of vessel-miles within the AIRA study area. Together, Vessel Types 1-4 contribute 67% of the total traffic defined (same proportion as in the base year). The next largest contributors are general cargo (Vessel Type 5) and fishing vessels (Vessel Type 14).

2.8 Base Year vs. Future Year Traffic

Figure 2-5 shows how the ratio of number of vessel miles for each Vessel Type varies between the predicted traffic for the future year (2034) compared to the base year (2008/2009). For example, the ratio for Container ships (>4500 TEUs) of total vessel miles of base year (1.23E+06) under total vessel miles for year 2034 (3.42E+06) is 2.9, indicating a 290% increase in vessel miles for large Container ships. Where the ratio is equal to 1.000 it has not been possible to determine with any degree of certainty how traffic levels might change in the future compared to the base year.

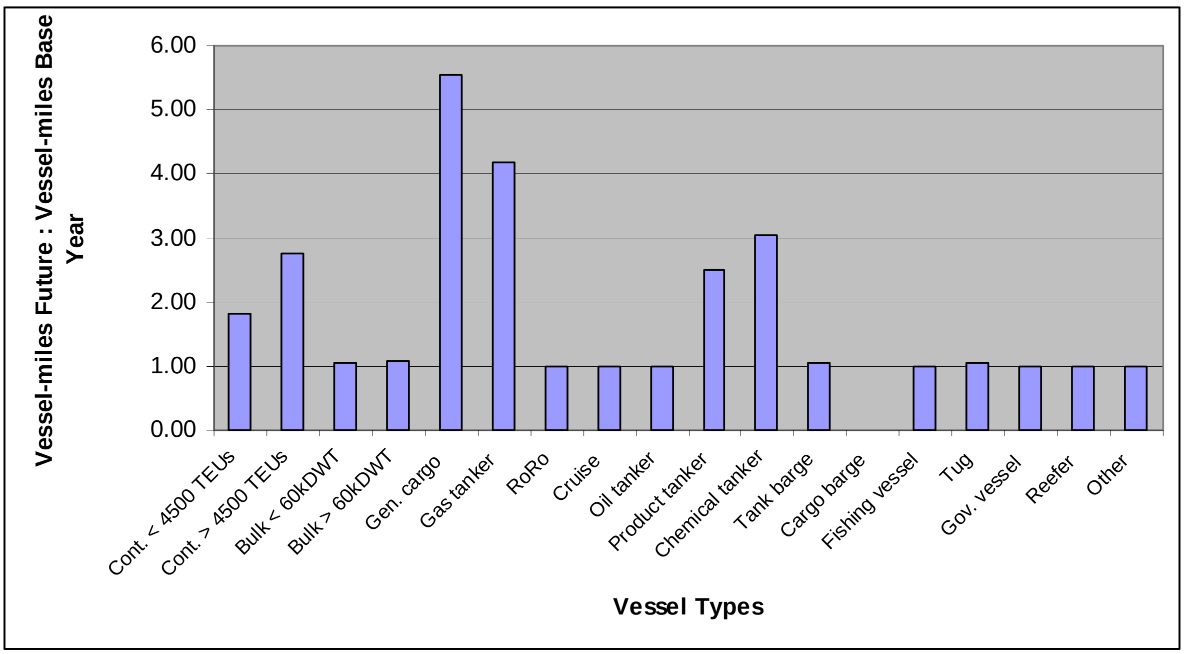

Figure 2-5 Vessel Miles Future (2034) ratio to Vessel Miles Base Year (2008/2009)

Figure 2-5 shows that the largest increases in relative Vessel Type traffic (percentage increase) are predicted for: General Cargo (Vessel Type 5); LNG & Gas Carriers (Vessel Type 7); Chemical tankers (Vessel Type 12); large container ships (Vessel Type 2) and Product tankers (Vessel Type 10) respectively.

Figure 2-6 Traffic Plot for All Vessel Types for Future Year (2034) is an illustration generated by MARCS which displays the traffic input data based upon the frequency of all vessel transits per traffic lane. Figure 2-6 was generated using the MARCS model and traffic data described in the AIRA Preliminary Risk Assessment Task 1 Semi-Quantitative Traffic Study. Figure 2-6 illustrates that during future year (2034) the heaviest amount of traffic (illustrated in red) is forecasted to occur along the Great Circle Route and the traffic lane to the Northwest from the Unalaska area.

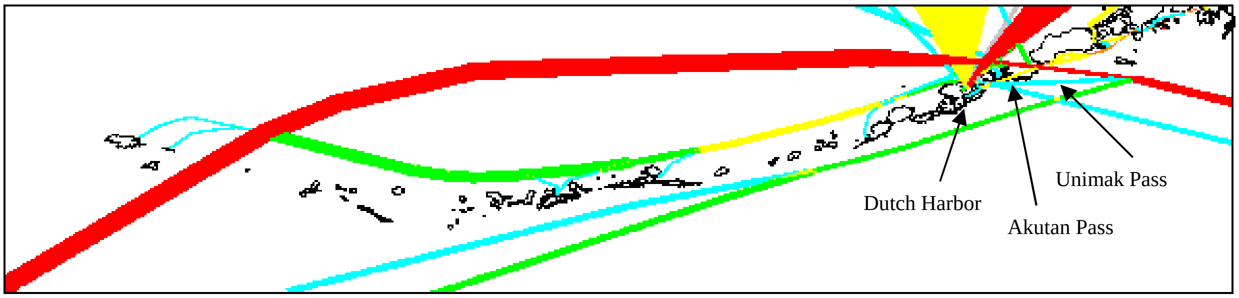

Figure 2-6 Traffic Plot for All Vessel Types for Future Year (2034)

Vessel traffic plots for all the different Vessel Types for future year (2034) are shown in Section 12.

2.8.1 Conclusions from the Traffic Data Future Year (2034)

Similar comments to those made above for the base year traffic data apply to the future year traffic data. That is, the vast majority of the traffic is forecasted to transit along the Great Circle Route.

The area close to Dutch Harbor will remain densely trafficked due to a combination of movements to and from Dutch Harbor and the passing traffic on the Great Circle Route.

A smaller proportion of passing traffic types will navigate the area to the south of the Aleutian Islands; however, as indicated by the traffic plot, this traffic is forecasted to increase.

The main reason for the similarity of the base year and future traffic data is that it is extremely difficult to confidently predict new routes 25 years into the future with sufficient detail to define a new lane in MARCS. Such routes need to be specified in terms of:

- Waypoints for a new shipping lane (Longitude / Latitude vertexes of a shipping route);
- Lane widths;
- Traffic types which would transverse the lane and how often; and
- Cargo types which the vessels would carry.

It is easier to confidently predict relative changes in trading volumes, and these factors are included in the future traffic data presented above.

2.9 Environmental Input Data

The wind rose data shown in Table 2-7 was deduced from NOAA sea buoy station 46073 in the Southeast Bering Sea using data from 2007 and 2008. It was applied over the entire study area as this is a semi-quantitative risk assessment. A single dataset was judged to be sufficient because of the current semi-quantitative nature of the task, the study area would have required pre-defined sub-sets (which were not provided) and minor variations of weather data do not affect the risk assessment models sensitivity.

A wind rose is a standard meteorological term for a time-based probability distribution of a specified wind speed and wind direction. Thus in Table 2-4, the time-based probability of a wind from the east of between 0 and 20 knots is 9.93%, and the sum of all the probabilities shown is 100%.

Table 2-7 Annual Average Wind Rose Data from Station 46073 Calculated from Data for 2007 and 2008

Wind	Knots	N	NE	E	SE	S	SW	W	NW
Calm	0-20	0.0744	0.0940	0.0993	0.0633	0.0696	0.0907	0.1016	0.0714
Fresh	20-30	0.0345	0.0288	0.0431	0.0302	0.0262	0.0320	0.0317	0.0294
Gale	30-45	0.0066	0.0141	0.0225	0.0086	0.0070	0.0099	0.0076	0.0029
Storm	>45	0.0001	0.0001	0.0001	0.0003	0.0000	0.0000	0.0000	0.0001

Sea state data is derived from the wind rose data assuming the entire study area is characterized as open ocean.

Visibility data was taken from the United States Coast Pilot 9: Pacific and Arctic Coasts Alaska: Cape Spencer to Beaufort Sea. 2009 (27th) Edition (Ref. /1/). Based on the data provided in the reference, the probability (time basis) that the visibility is less than 2NM is 45%.

Average drift currents (speed and direction) have not been identified as significant and are not included in the input data to MARCS. Inclusion of tidal currents in marine simulations is complex and beyond the scope of the Phase A assessment.

It is assumed that environmental data, such as visibility and wind rose data, is unchanged between the base year and the future year. The tidal currents, visibility and wind rose data represent best estimates for this semi-quantitative assessment.

2.10 Fault Tree / Event Tree Input Data

Standard risk analysis parameters (e.g. probabilities of collision given an encounter between two ships) were selected by DNV for all ships on the basis of previous marine risk work and on the assumption that no additional risk controls are implemented compared to normal international water navigation are applied in the study area.

Examination of navigational charts of the study area indicates that taking control of a drifting vessel using its anchoring systems will be difficult due to the water depth, rate of reduction of water depth as the shore line is approached and the probable sea bottom type. It is assumed that anchoring is completely ineffective for all Vessel Types for the base year and the future year. This assumption is a best estimate and does not under predict the risk results.

No other risk controls have been identified or assumed for the base year or the future year. Thus, the following factors are not included in the risk estimates:

- There are no compulsory pilotage areas and so pilots are assumed to be absent from the study area (there may be some pilotage in harbor approaches, but these are expected to be short duration and are not represented in the risk model at this stage).
- There are no vessel traffic service or vessel traffic management areas applied.
- There are no traffic separation schemes in the study area.

2.11 Input Data Additional Assumptions

The following additional assumptions were applied to the analysis:

- Tank and cargo barge data was not included within the AIS data; supplemental data was gathered from additional resources and included.
- Ship size data is based on fleet averages in individual lanes.
- All laden ships are assumed fully laden (no partial cargoes carried).
- 50% of all ship movements identified are assumed to be laden and 50% are in-ballast.
- Bunker spill models derived for tankers and other deep sea trading vessels have been assumed to apply to all Vessel Types.
- Cargo spill models derived for oil tankers are assumed to apply to oil tankers, product tankers and chemical tankers.
- Traffic data for only the base year (2008-2009) has been used.
- Wind, visibility and other environmental data is assumed to be identical over the entire study area.

3 BASE YEAR (2008/2009) ACCIDENT FREQUENCY AND RISK RESULTS

The total predicted frequency of accidents is 8.67 accidents per year. This prediction is almost certainly too high and on closer examination of the results it is found that over 80% of the predicted accident frequency is due to tug and fishing vessel grounding accidents (drift grounding plus powered grounding). As noted above, there are a number of inshore routes used by fishing vessels and tugs where the amount of sea room is very restricted. These shipping lanes are expected to generate high grounding accident frequency for the following reasons:

- The distance to shore is very short. Any vessels that breakdown have very little time available to regain control before they drift to ground.
- The more sheltered conditions of these inshore routes (wind and sea state) have not been represented in the input data.

Furthermore it is almost impossible to correctly represent these lanes in a study area as large as that required by the specified scope of work. MARCS calculates risk on a location by location basis. In this study each location is roughly 0.5 x 0.5 nautical miles; however, these inshore channels are relatively narrow compared to this location size. To correctly represent these inshore lanes it would be necessary to set up another smaller study area (e.g. 168 West to 160 West and 53 North to 55.5 North) with a smaller location size. This level of quantitative analysis is beyond the current scope of work but could be performed under future activities.

3.1 Distribution of Accident Type and Vessel Type

The distribution across all accident types is shown in Figure 3-1. As shown, powered grounding and drift grounding comprise 96% of the predicted accident types.

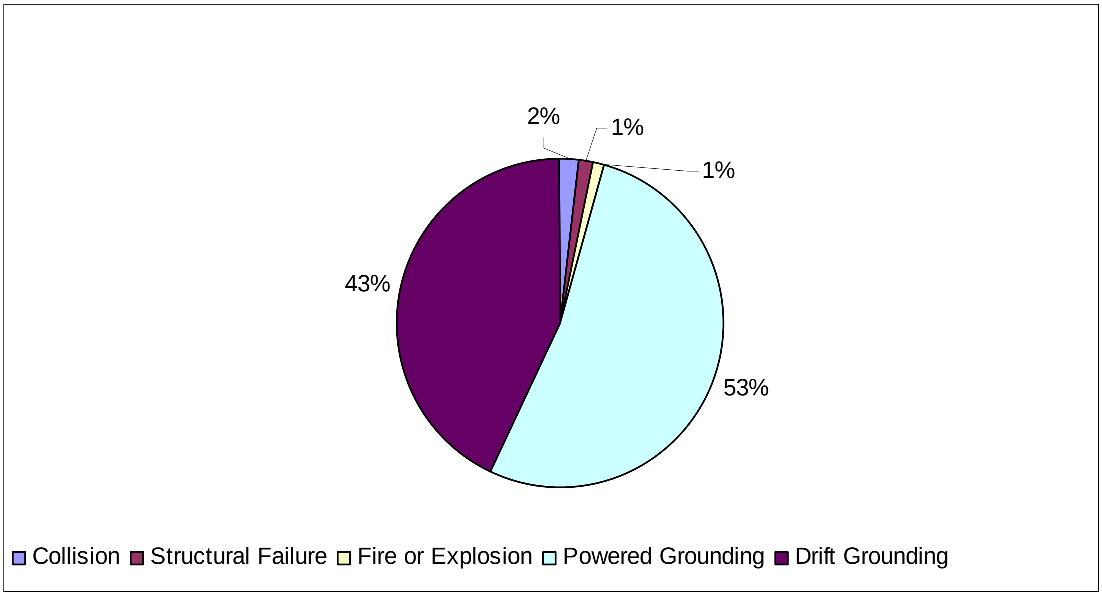

Figure 3-1 Base Year Distribution of Accident Frequency by Accident Type

Figure 3-2 shows the risk model results for distribution of accident frequency by Vessel Type. It indicates that the greatest accident frequencies are associated with Fishing Vessels (72%), Tugs (10%), and Tank Barges (4%).

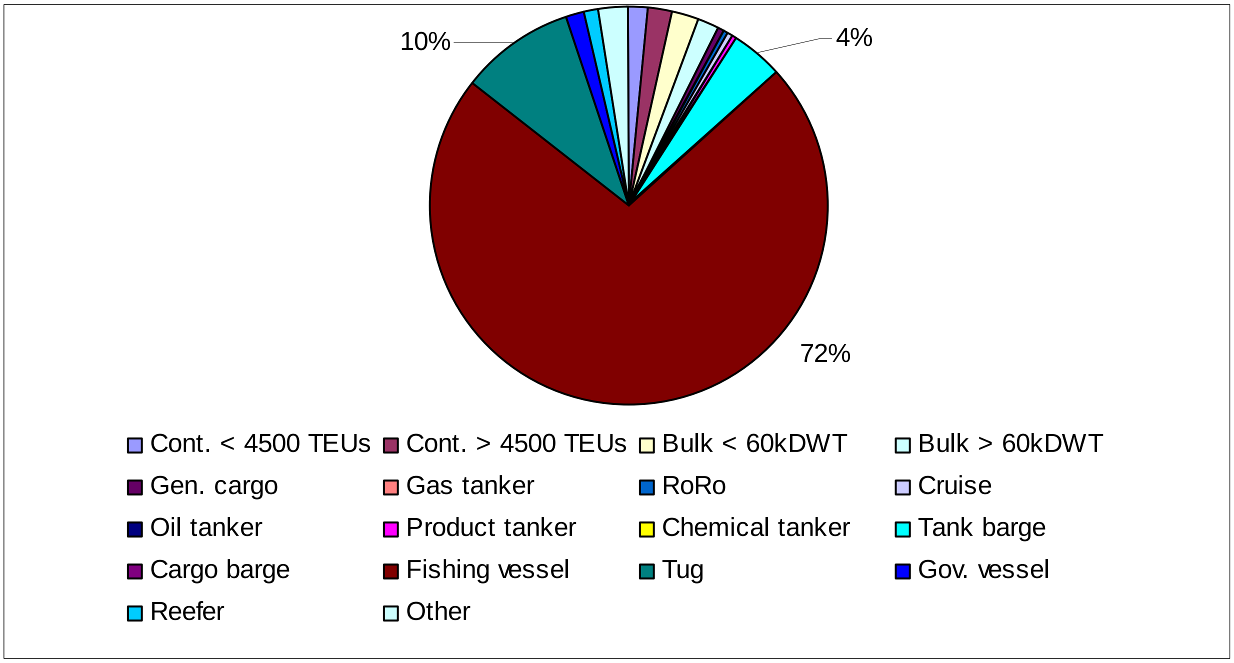

Figure 3-2 Distribution of Accident Frequency by Vessel Type

Figure 3-3 shows the geographical distribution of accident frequency results. The key for Figure 3-3 is shown in Table 3-1.

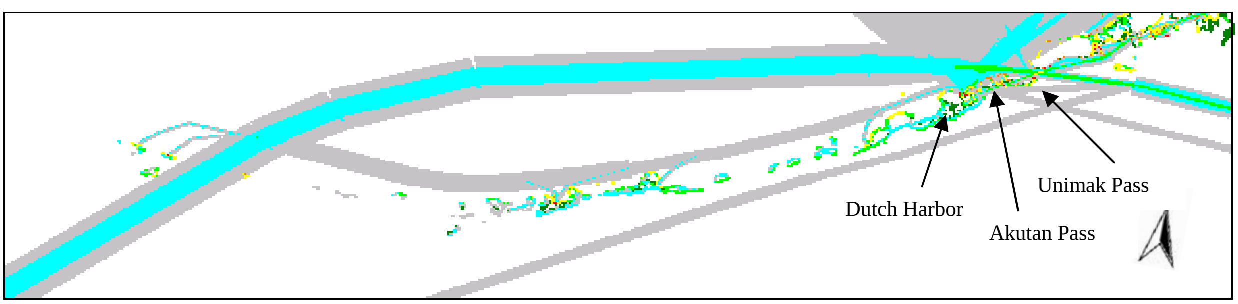

Figure 3-3 Geographical Distribution of Accident Frequency Results

Table 3-1 Key to Accident Frequency Plots

Color	Accident Frequency (accidents per year within each calculation location)
(grey)	1.0 E-08 - 1.0 E-06
(cyan)	1.0 E-06 - 1.0 E-05
(green)	1.0 E-05 - 1.0 E-04
(yellow)	1.0 E-04 - 1.0 E-03
(orange)	1.0 E-03 - 1.0 E-02
(red)	> 1.0 E-02

*e.g. 1.0E-08 = 0.00000001 accident per year or once in a hundred million years; 1.0 E-02 = 0.01 accidents per year or once in a hundred years

Regional Historical Accident Data Analysis

Figure 3-4 USCG Regional Accident Data depicts the results found after analyzing USCG data of historical accidents tracked in the Aleutians Area. Accident types utilized in the USCG database were categorized similarly to the accident types that MARCS utilizes in order to compare findings with accident rates actually experienced in the region.

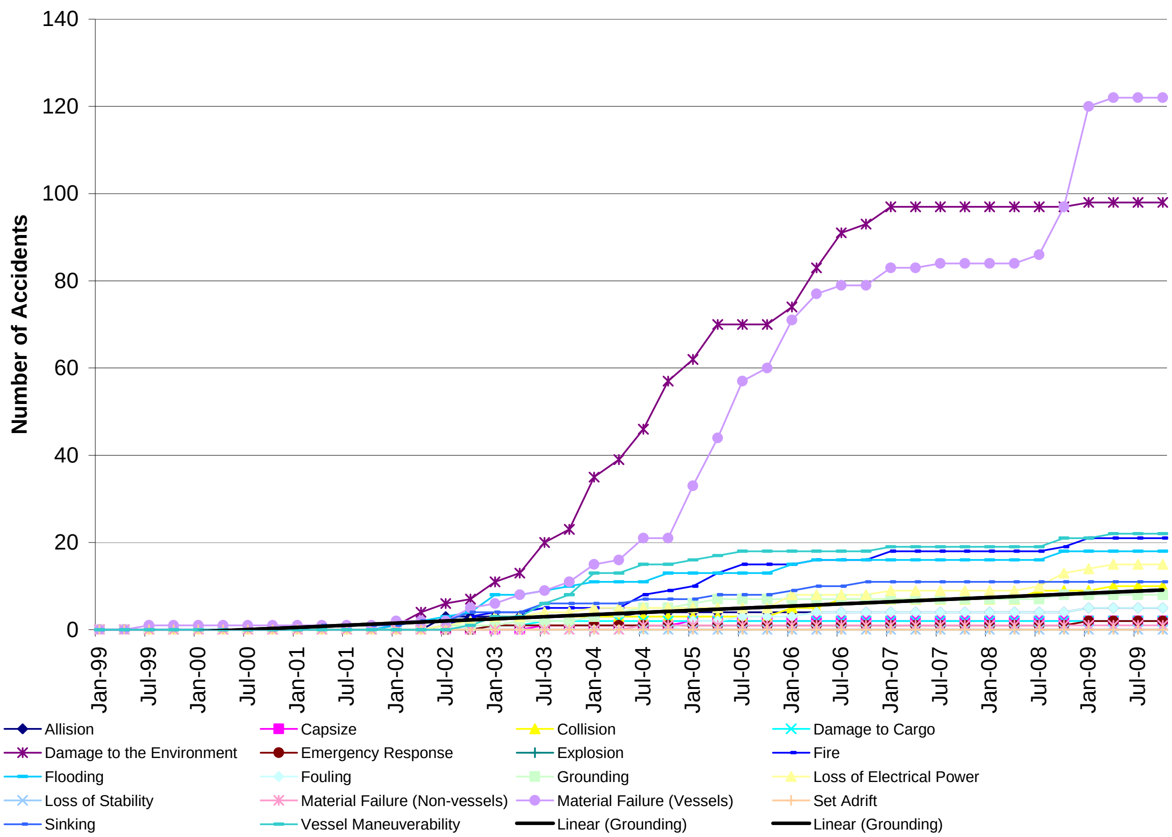

Figure 3-4 USCG Regional Accident Data

Figure 3-4 USCG Regional Accident Data displays the data as a cumulative curve. Based on this graph the following conclusions are determined for the approximate previous 10-year period:

- 21 fire accidents occur over about 10 years (2.1 per year)
- 15 collision accidents over about 10 years (1.5 per year)
- 19 powered grounding (1.9 per year)
- 8 drift grounding (0.8 per year)
- Structural failure is very high (about 16 per year)

If structural failure is excluded (which is almost certainly not reported on a consistent basis with the rest) then total accident frequency is 6.3 per year. As a total this looks consistent with the MARCS results (agreement of risk results, without calibration, within a factor of 2 is generally considered to be very good).

Table 3-2 provides a comparison of the above historical analysis from the USCG data to the MARCS results:

Table 3-2 Comparison of historical vessel accident data with MARCS results data

Accident Data Comparison	Historical Accident Data	MARCS	Factors
Collision	1.5	0.17	8.69
Structural Failure	16	0.10	152.70
Fire or Explosion	2.1	0.12	19.59
Powered Grounding	1.9	4.54	0.42
Drift Grounding	0.8	3.74	0.21
Total Excluding Structural	**6.3**	**8.57**	**0.73**
Total Including Structural	**22.3**	**8.67**	**2.57**

Marine casualty data captured in the USCG marine casualty database is generally similar but not equal to the global marine casualty database utilized by MARCS. A single event is routinely entered in multiple categories in the USCG database and almost always structural failure is entered whenever damage is reported (i.e. collision, fire, grounding), which explains the high incidence of structural failure cases.

The total accidents predicted by MARCS per year are 8.67 and the total results found historically per year are 6.3 excluding structural failure and 22.3 including structural failure accidents. DNV determines any agreement within a factor of 2 is to be an excellent comparison and an agreement within a factor of 5 is considered good. With this in mind, the two respective factors (excluding structural and including structural) are 0.73 and 2.57.

The range of failures which the USCG records regarding structure failure is considered to be more inclusive than the definition of a MARCS structural failure. Therefore, the addition of additional scenario representation in the data is expected. With all of this in mind, this comparison is deemed sufficient.

3.2 Conclusions for the Accident Frequency Results for the Base Year (2008/2009)

The main conclusions for the accident frequency results for the base year traffic data are summarized as follows:

- MARCS results show that the dominant accident type is powered grounding followed by drift grounding. Although MARCS is known to generally over-estimate the frequency of groundings (for reasons which are managed in this study and listed below), this initial conclusion is reasonable because of the long coastline of the Aleutian Islands, the assumed positioning of traffic lanes close to the Aleutian Islands (where smaller ships can shelter from the severe sea states that can exist), and the difficulty of taking a ship into tow in remote areas with difficult environmental conditions.
- The distribution of accident frequency by Vessel Type generally follows the annual number of vessel-miles defined in Table 2-4.
- The greatest accident frequencies are predicted in the area through Unimak Pass, Akutan Pass and the approach to Dutch Harbor. Additional work could refine the input traffic data in these areas (more precise waypoints and lane widths) to obtain more refined results but, on balance, this result is both reasonable and expected.
- The MARCS frequency results are comparable to and validated by the analysis of historical accident data.

The reasons why MARCS can over-predict grounding frequencies are:

- MARCS assumes a straight line drift trajectory from the breakdown location to the grounding location. In practice, ships normally drift in many different directions prior to grounding (or recovery of control) and this reduces the average drift velocity compared to that assumed by MARCS. Thus, in operations, ships usually have more time to recover control by making repairs.
- MARCS is designed to perform open-water navigational risk. Ship lanes that approach harbors are interpreted by MARCS as dangerous courses and these in turn generate unrealistically high powered grounding frequencies.

The lane width is represented by a Gaussian probability function. For inshore lanes this may mean that the “tails” of the lane width functions may overlap with ground locations. Under these distribution conditions, the proportion of the lane is immediately counted as grounded for both powered and drift grounding accidents.

4 FUTURE YEAR (2034) ACCIDENT FREQUENCY AND RISK RESULTS

The total predicted accident frequency (see results for base year) is 9.61 accidents per year. The majority of the future accidents does not result in any spill of cargo or bunker fuel oil (see below).

4.1 Distribution by Accident Type and Vessel Type

The distribution of these accidents by accident type and Vessel Type is shown in Figure 4-1 and Figure 4-1, respectively. As indicated in figures below, powered and drift grounding account for 91% of the accident types and large Container ships account for 65% of accidents by Vessel Type.

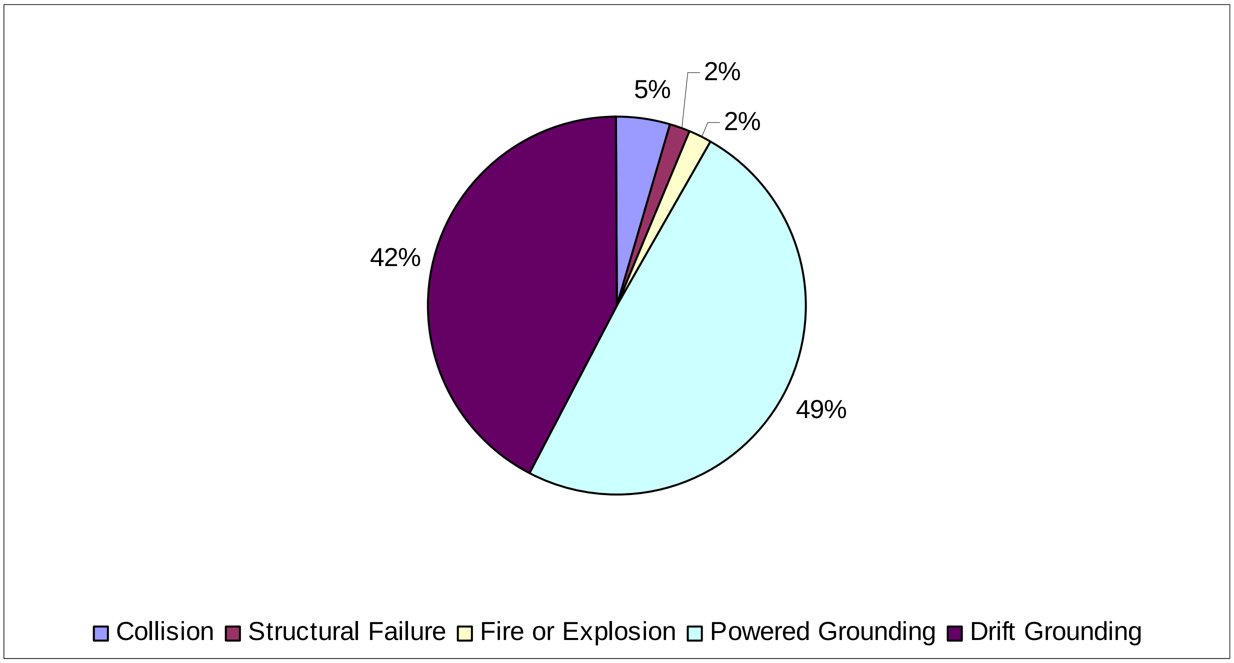

Figure 4-1 Future Year (2034) Distribution of Accident Frequency by Accident Type

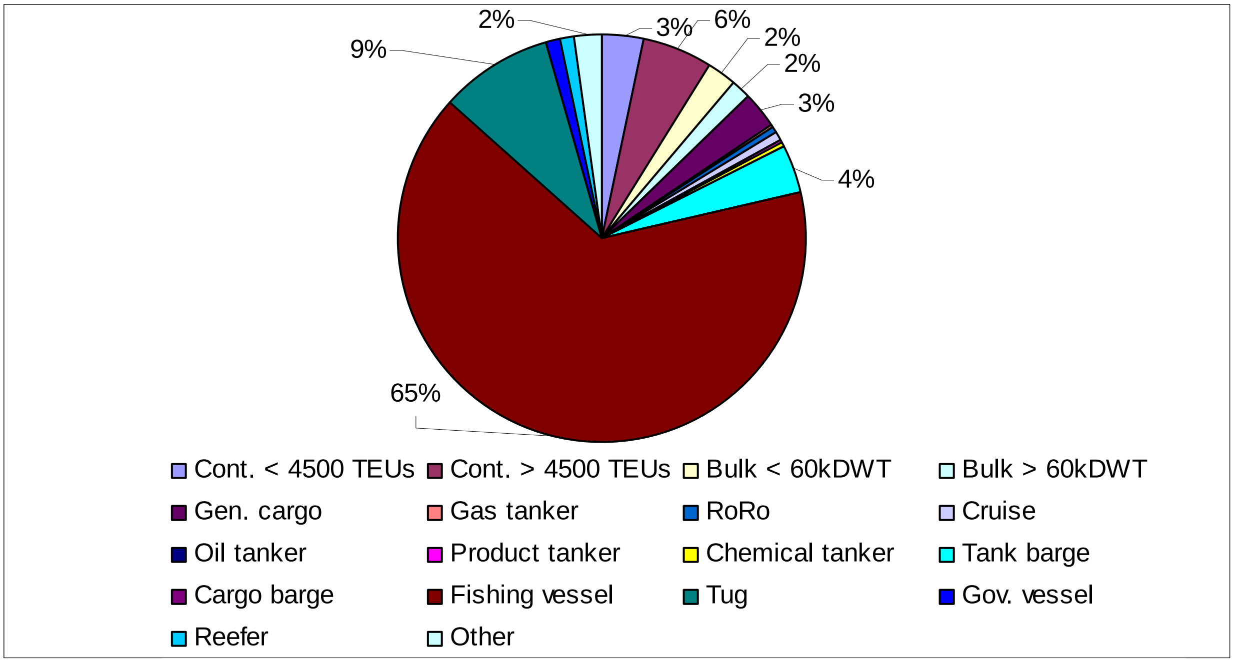

Figure 4-2 Future Year (2034) Distribution of Accident Frequency by Vessel Type

Figure 4-3 shows the future year (2034) geographical distribution of accident frequency.

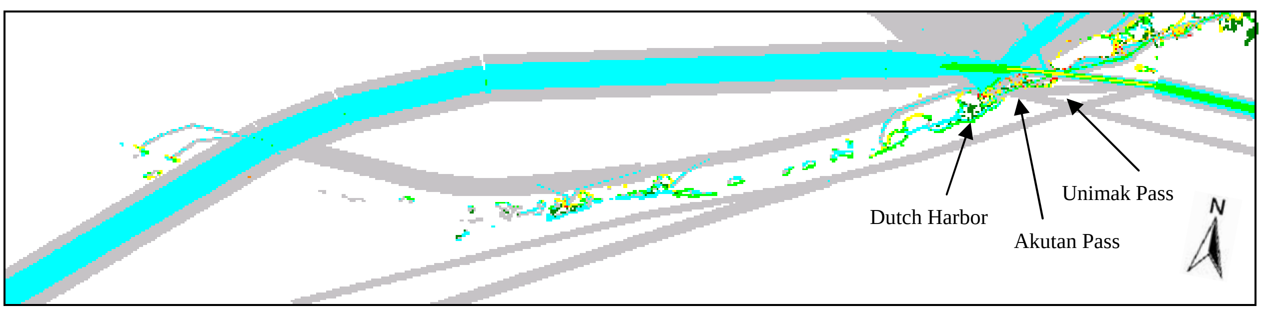

Figure 4-3 Future Year (2034) Geographical Distribution of Accident Frequency

4.2 Conclusions from Accident Frequency Results for the Future Year (2034)

The summary and conclusions for the future year accident frequency results are similar to those for the base year.

The frequency of accidents during base year is 8.67, whereas as the future year is 9.61. Thus, the frequency of accidents is predicted to increase by 11% (future year: base year = 1: 1.11). This increase is as expected because there is an increase in traffic in the future year, but there are no risk controls that might reduce the frequency of accidents defined for 2034. However, there are risk controls that reduce the cargo and bunker spill consequence and these are discussed in the sections below.

5 BUNKER AND CARGO SPILL RISK EVALUATION

In the oil industry, hydrocarbons are normally measured either by volume in gallons and US barrels, or by weight in tons or tonnes. The relationship between volume and weight is usually measured by liquid density. Liquid density varies between oil types, and hence the volumes in bbl from tons can be different for different oil types. MARCS calculations are conducted in metric tons. For this study, an average of fuel oils density is applied for conversion to bbl which corresponds to approximately 6.6 bbl per metric ton. LNG and hazardous materials figures are only presented in tons as bbl conversion do not apply.

Risk can be calculated as the sum over all events of the frequency of an event multiplied by the consequence of the event. Some events may have multiple consequences with different probabilities. In this case, a probability weighted sum of consequences is used to calculate the consequence. The "risk" therefore is a predicted expectation value of loss per frequency unit (usually per operation or per unit time). In this study, risk numbers are quoted as the expected (or long-term average) amounts of cargo or bunker oil or both spilled per year. For example, it might be concluded that the risk of cargo spill is 660 bbl or 100 tons per year. This could mean that 660 bbl or 100 tons is likely to be spilled every year, or it could mean that 66,000 bbl or 10,000 tons is spilled 1 year in 100 and there is no spill for the remaining 99 years. MARCS is capable of calculating risks from specific ship size ranges, or in specified spill ranges. However, these types of calculation were not evaluated within the scope of this task. Some qualitative statements are, however, made to help the interpretation of the average risk results quoted.

MARCS calculates cargo spill and bunker oil spill separately for each Vessel Type, each ship size, each accident type, each lane and each geographical location. All of these small risks are summed to provide the aggregated overview of the risk results presented below.

5.1 Bunker (Ship's Fuel Oil) Spill Risk Results for the Base Year (2008/2009)

The risk results indicate a total bunker spill risk of 1,584 bbl of fuel oil per year (or 240 tons per year). As stated above, the potential risk of a spill of 1,584 bbl of oil in a year is equivalent to a spill risk of 15,840 bbl in a 10 year period or 158,400 bbl in a 100 year period. Only 8% of all accidents result in a bunker spill. This is a consequence of the fact that the majority of marine accidents will not cause damage in the vicinity of bunker tanks (see discussion of probabilistic spill models below).

The bunker fuel oil capacity of ships included in the risk modeling range from 264 bbl (40 tons) to 68,640 bbl (10,400 tons), thus the largest possible spill of bunker fuel oil in the calculated risk results is 48,048 bbl (7,280 tons.) This would occur if an average large container ship is involved in a total loss accident (because it is assumed that fuel tanks are 70% full at the time of accident).

Regional historical data analysis shows between the years 1995 – 2007 there were 9 accidents which spilled approximately 84.45 bbl (3,547 gallons) of fuel oil per year. The largest driver for this high historical spill rate was the M/V Selendang Ayu accident. Without the consideration of the M/V Selendang Ayu accident, the historical rate would be 990 bbl of fuel oil per year, which is a good comparison. Therefore, the historical fuel oil spill data supports our bunker spill risk results.

5.1.1 Distribution by Accident Type and Vessel Type

The distribution of bunker spill risk across all accident types is shown in Figure 5-1. As indicated in Figure 5-1, Drift Grounding is the accident type associated with the greatest percentage of bunker spills. The distribution for each Vessel Type is shown in Figure 5-2. The Vessel Types with the greatest likelihood of bunker spill risk for the base year are Container Ship Vessel Types combined (48%).

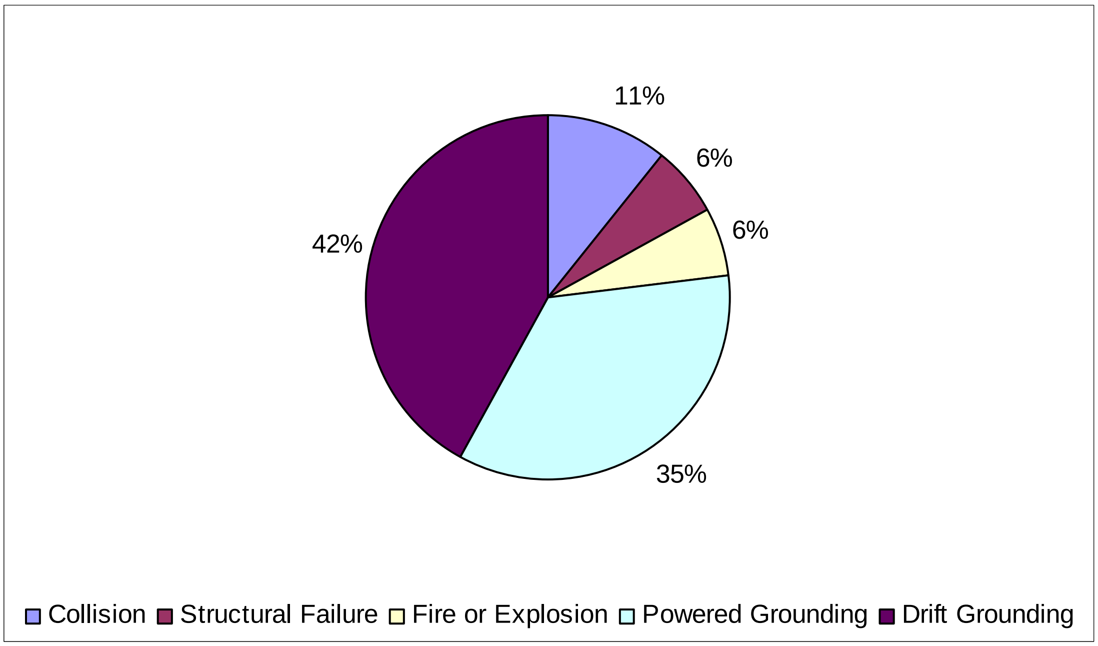

Figure 5-1 Distribution of Bunker Spill Risk by Accident Type for the Base Year (2008/2009)

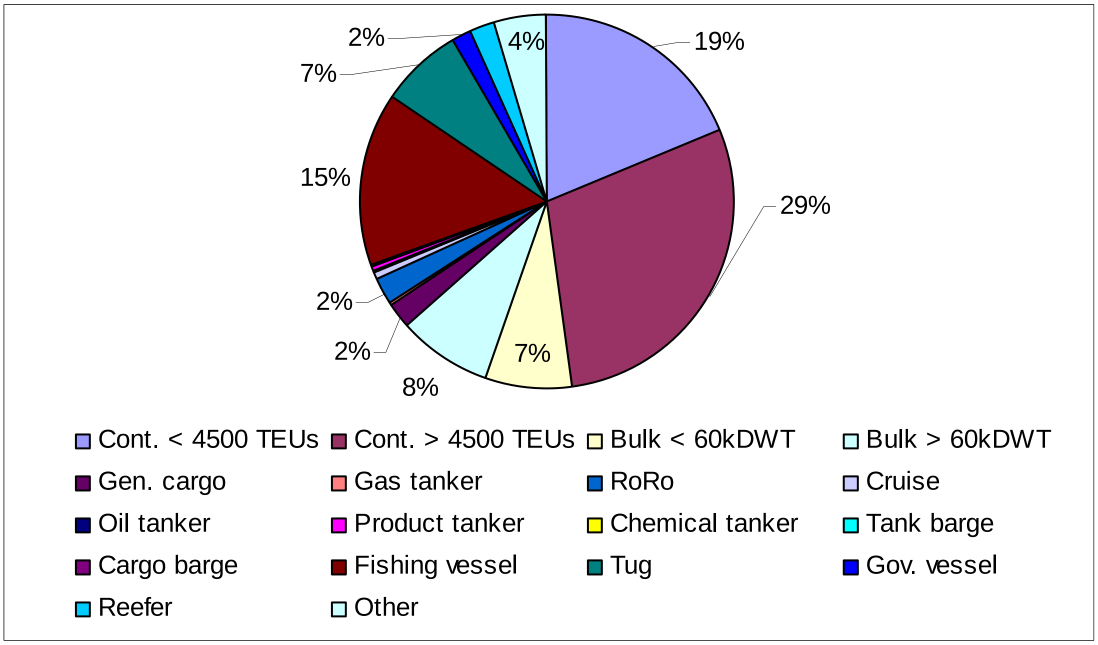

Figure 5-2 Distribution of Bunker Spill Risk by Vessel Type for the Base Year (2008/2009)

Figure 5-3 shows the geographical distribution of bunker spill risk results. The key for Figure 5-3 is shown in Table 5-1.

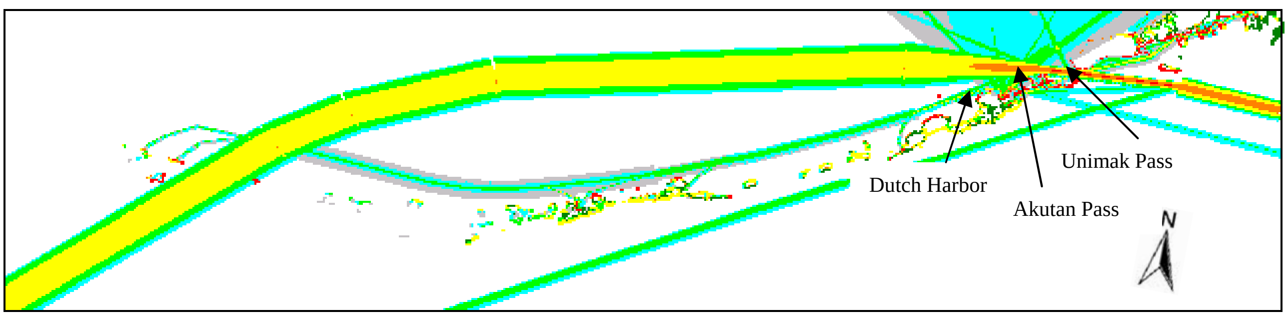

Figure 5-3 Geographical Distribution of Bunker Spill Risk Results for the Base Year (2008/2009)

Table 5-1 Key to Bunker and Cargo Spill Risk Plots

Color	Spill Risk (Tons of bunker or cargo oil spilled per year within each calculation location)
(grey)	1.0 E-08 – 1.0 E-06
(cyan)	1.0 E-06 – 1.0 E-05
(green)	1.0 E-05 – 1.0 E-04
(yellow)	1.0 E-04 – 1.0 E-03
(orange)	1.0 E-03 – 1.0 E-02
(red)	> 1.0 E-02

*e.g. 1.0E-08 = 0.00000001 tons of bunker fuel or cargo oil spilled per year or one ton in a hundred million years; 1.0 E-02 = 0.01 tons of bunker fuel per year or one ton in a hundred years

The spill risk in Table 5-1 is defined as the tons of bunker or cargo oil spilled per year within each calculation location.

Based on the geographical distribution of bunker spill risk, the locations of greatest frequency of accidents are predominately located near Unimak Pass, Akutan Pass and the approach to Dutch Harbor.

5.1.2 Conclusions for the Bunker Spill Risk Results for the Base Year (2008/2009)

The primary conclusions for the bunker spill risk for the base year results are:

- Drift Grounding dominates the bunker spill risk results (42% of all accidents).
- Nearly 29% of the total bunker spill risk is attributed to Category 2, Large Container Ships >4500 TEU.
- The distribution of bunker spill risk by Vessel Type generally follows the annual number of vessel-miles defined (see Table 2-4 above). However, bunker spill risk from container ships is increased relative to that expected because container ships have larger bunker cargo oil tanks than most other Vessel Types. This is discussed in the section on the probabilistic spill models below.
- The greatest bunker spill risks are predicted in the area through Unimak Pass, Akutan Pass, and the approach to Dutch Harbor. In addition, there are high bunker spill risks on the inshore routes.

5.2 Bunker Spill Risk Results for Future Year (2034)

The total average annual bunker spill risk is predicted to be 2,904 bbl of fuel oil per year (or 440 tons per year). The proportion of all accidents that result in a bunker spill is not changed compared to the base year. This is because 20% of all vessels are assumed to still have only single hull protection for their bunker fuel tanks in 2034. However, the amount of bunker oil spilled per accident is reduced by the double hulled protection assumed to be present for 80% of the bunker tanks in 2034.

5.2.1 Distribution by Accident Type and Vessel Type

The distribution of bunker spill risk across all accident types is shown in Figure 5-4. As indicated, Drift Grounding remains the accident type associated with the greatest percentage of bunker spills. The distribution for each Vessel Type is shown in Figure 5-5**.**

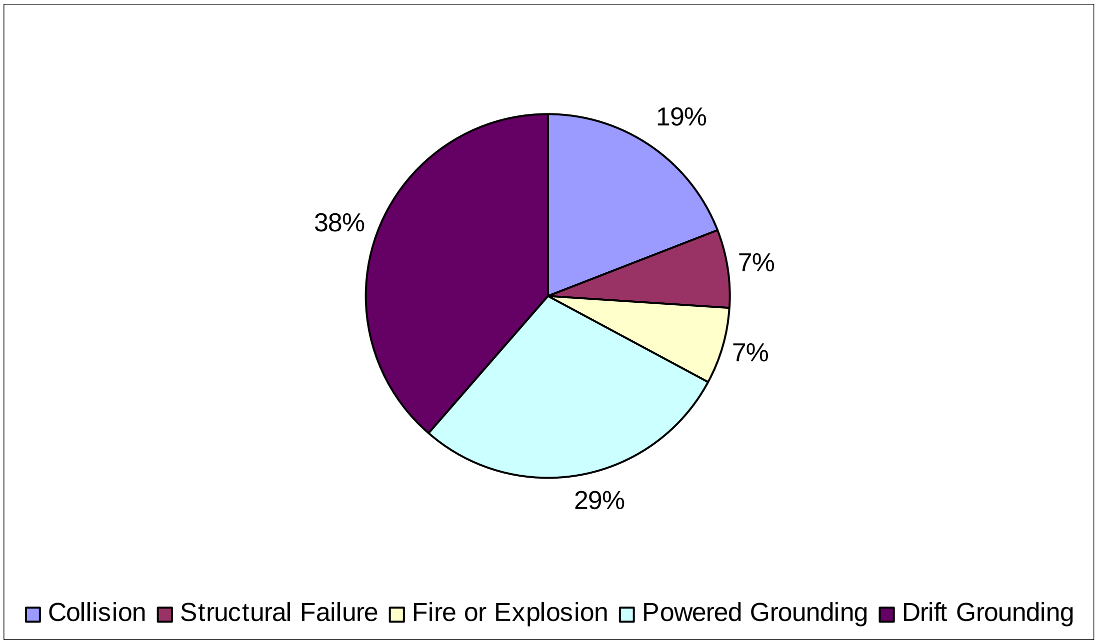

Figure 5-4 Distribution of Bunker Spill Risk by Accident Type for Future Year (2034)

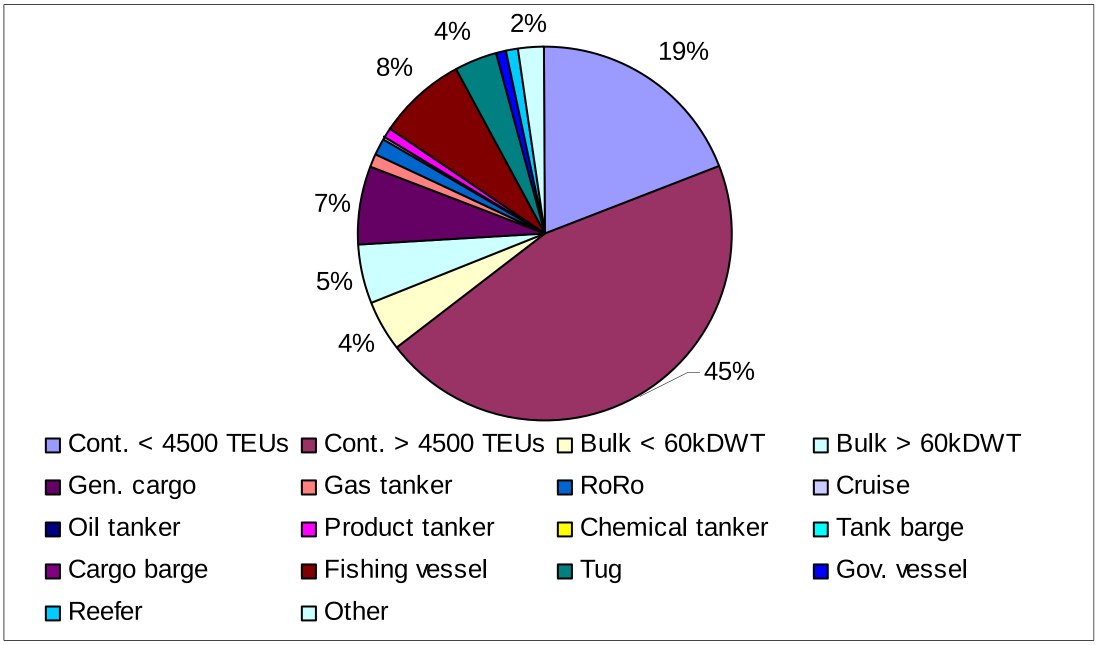

Figure 5-5 Distribution of Bunker Spill Risk by Vessel Type for Future Year (2034)

As indicated in the above figure, Container ships are the Vessel Type associated with the greatest risk of occurrence of a bunker spill risk (64% total).

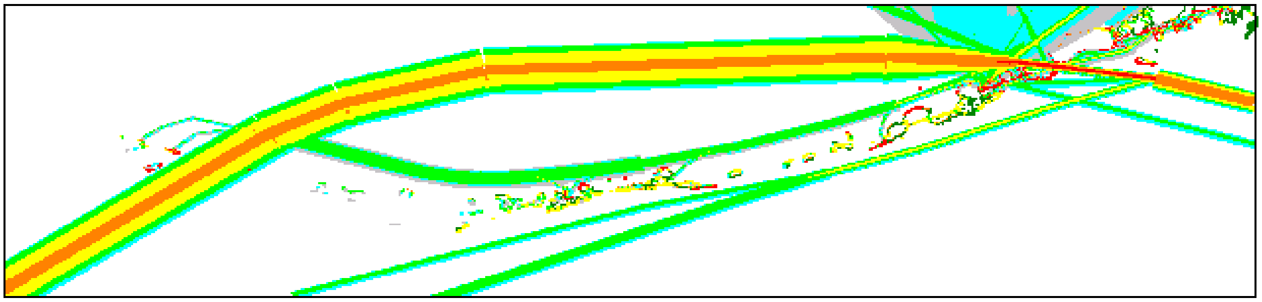

Figure 5-6 Geographical Distribution of Bunker Spill Risk for Future Year (2034)

Figure 5-6 shows the geographical distribution of bunker spill risk results. The key for Figure 5-6 is the same as shown in Table 5-1.

Based on the geographical distribution of bunker spill risk, the locations of greatest frequency of accidents for future year (2034) are predominately along the Great Circle Route.

5.2.2 Conclusions from Bunker Spill Risk Results for the Future Year (2034)

The future year bunker spill risk results are similar to those for the base year. The predicted growth in large container ship traffic in 2034 combined with the relatively large bunker tanks on container ships results in large container ships becoming the dominant contributor to bunker spill risk in 2034.

5.3 Cargo Spill Risk Results

Table 2-1 indicates the Vessel Types that contribute to cargo spill risk. This section presents the calculated quantity of cargo spilled as a result of navigational accidents. It should be noted that for container ships (Vessel Types 1, 2) and general cargo ships (Vessel Type 5) it is estimated that no more than 10% of the total cargo carried is hazardous cargo, so the figures quoted below should be reduced by a factor of 10 for these Vessel Types for strict inter-comparability of results. The cargo spill risk is presented by the volume of cargo release over a year's time. This volume is a probabilistic amount deduced by analyzing the probability of cargo release for each accident type. This is further explained in the MARCS Methodology document included in Attachment 1.

5.3.1 Cargo Spill Risk Results for the Base Year (2008/2009)

The total cargo spill risk is 4,045 bbl (or 613 tons per year for all cargo types.) Different cargo types have very different potential environmental and socioeconomic impacts. These different effects will be evaluated in subsequent project tasks.

The distributions of cargo spill risk by accident type and Vessel Type for the base year (2008/2009) are shown in Figure 5-7 and Figure 5-8 respectively. As indicated in Figure 5-7, Powered Grounding remains the accident type associated with greatest percentage of cargo spills

(45%). Figure 5-8 shows that Tank barges account for the greatest frequency of cargo spill risks (72%) by Vessel Type.

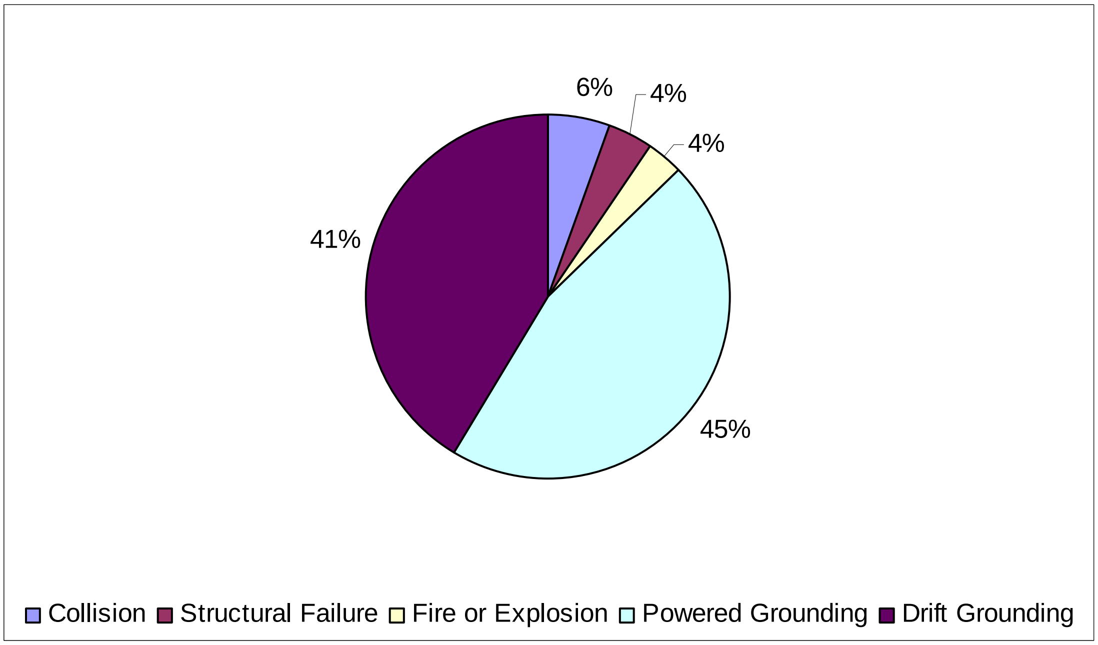

Figure 5-7 Distribution of Cargo Spill Risk by Accident Type for Base Year (2008/2009)

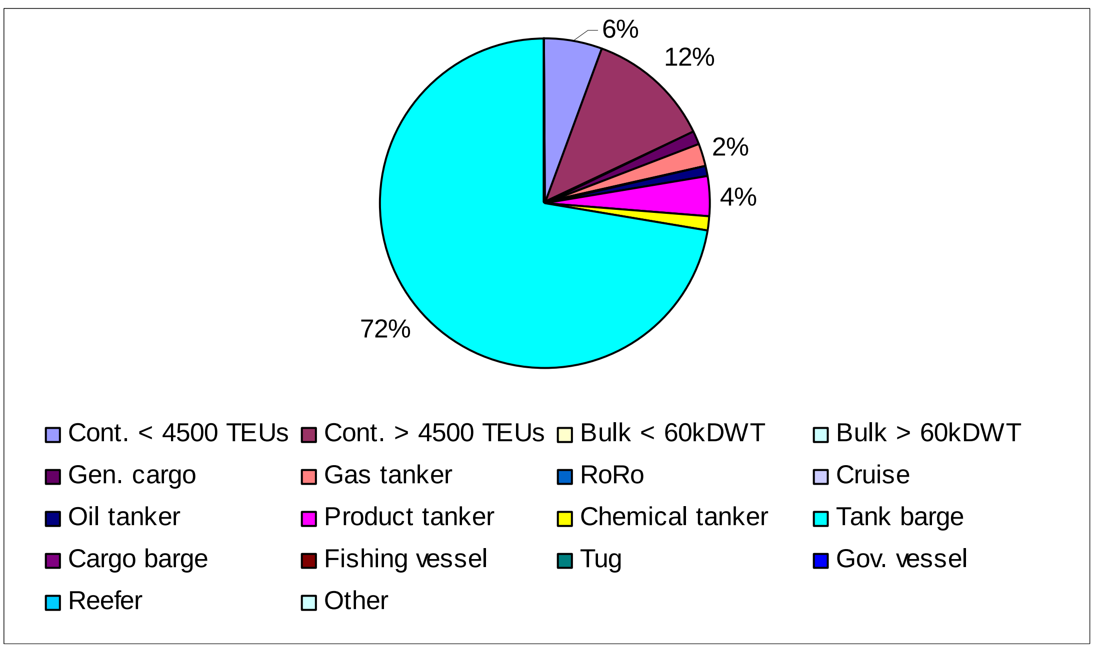

Figure 5-8 Distribution of Cargo Spill Risk by Vessel Type for Base Year (2008/2009)

In the MARCS input data, the quantity of cargo (dry or liquid) carried by all vessel types ranges from 0 tons to 150,000 tons. The largest quantity of hazardous cargo (oil or chemical) included in the input data is 130,000 tons (8,580,000 bbl) of crude oil (Vessel Type 9). In a total loss event all cargo is assumed to enter the water.

The graphics of the geographical distributions of cargo spill risk by Vessel Type for Base Year are found in Section 12. Base Year distributions by Vessel Type are found on Figures 12-37 through 12-44.

Conclusions from Cargo Spill Risk Results for the Base Year (2008/2009)

The conclusions of the base year cargo spill risk results indicate the following:

- The dominant accident types contributing to cargo spill risk are powered grounding followed by drift grounding.
- The distribution of cargo spill risk by Vessel Type is dominated by cargo spill risk from Tank barges. The following Tank barge assumptions were applied:
  - Tank barges carry substantial amounts of cargo (the largest barges are in the size range of 14kDWT to 30kDWT).
  - Tank barges are always loaded and 80% fully laden. This assumption may be conservative (research shows a number of barges operating in the AIRA study area, service multiple locations, offloading a portion of their cargo at each location).
  - Tank barges are always single hulled. (Research shows that double hull barges service the AIRA study area; however, the assumption considers the OPA 90 exemptions for double hull requirement for Tank barges operating in the AIRA study area).
  - Tank barges often navigate on the inshore routes discussed above.
- The geographical distribution of cargo spill plots show that the greatest cargo spill risks are predicted in the area through Unimak Pass, Akutan Pass and the approach to Dutch Harbor. In addition, there are high cargo spill risks on the inshore routes, especially for the Tank barges.

5.3.2 Cargo Spill Risk Results for the Future Year (2034)

The total cargo spill risk is 6,006 bbl (or 910 tons per year for all cargo types). Different cargo types have very different environmental impacts (See baseline oil spill study). These different effects will be evaluated in subsequent project tasks.

The distribution of cargo spill risk by accident type and Vessel Type for the Future Year (2034) is shown in Figure 5-9 and Figure 5-10, respectively. As indicated in Figure 5-9, drift grounding is the accident type associated with the greatest percentage of cargo spills (40%). Figure 5-10 shows that tank barges account for the greatest frequency of cargo spill risks (39%).

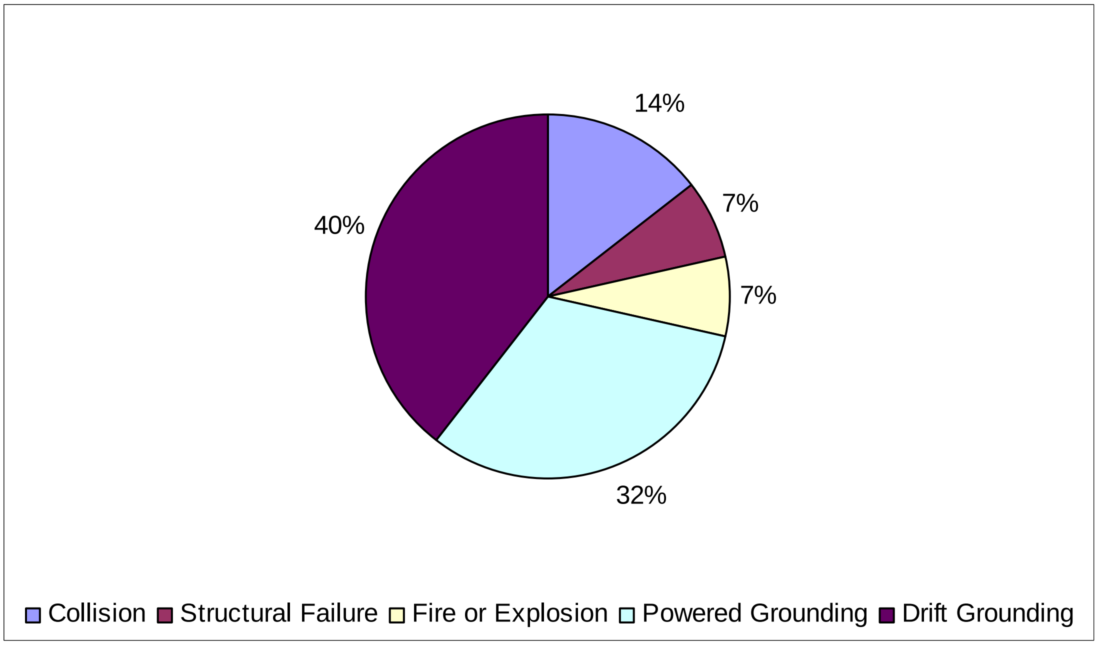

Figure 5-9 Distribution of Cargo Spill Risk by Accident Type for Future Year (2034)

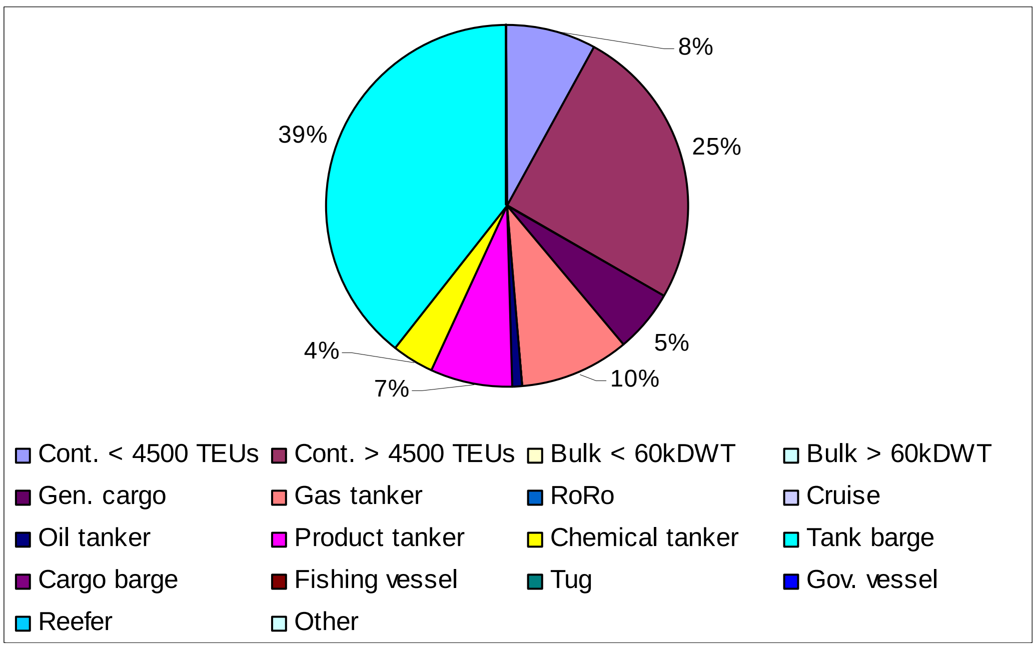

Figure 5-10 Distribution of Cargo Spill Risk by Vessel Type for Future Year (2034)

The graphics of the geographical distributions of cargo spill risk by Vessel Type for Future Year (2034) are found in Section 12. Future Year distributions by Vessel Type are found on Figures 12-45 through 12-52.

Conclusions from Cargo Spill Risk Results for the Future Year (2034)

The conclusions of the future year cargo spill risk results indicate the following:

- The dominant accident types contributing to cargo spill risk are drift grounding followed by powered grounding.
- The distribution of cargo spill risk by Vessel Type is dominated by cargo spill risk from Tank barges. Both the proportion and the absolute total of cargo spill risk from Tank barges in the future year are reduced compared to the base year because of the introduction of double hulled barges by 2034.
- The geographical distribution of cargo spill plots show that the greatest cargo spill risks are predicted in the area through Unimak Pass, Akutan Pass and the approached to Dutch Harbor. In addition, there are high cargo spill risks on the inshore routes, especially for the Tank barges.

6 DESCRIPTION OF PROBABILISTIC SPILL MODELS

The generic approach to spill risk modeling in MARCS is described in Attachment 1 - MARCS Model Methodology. This section describes new probabilistic spill models that were derived for this spill frequency and size task.

6.1 General Principles

Analysis of worldwide historical accident data indicates that about 5% of all serious accidents result in the total loss of the ship. In this case, it is assumed that all liquid cargo and bunker fuel oil is lost into the water. This is a conservative assumption because in some accidents some cargo and/or bunker oil can be recovered from the wrecked ship. However, the data is not available to quantify the degree of conservatism in this assumption.

Analysis of worldwide historical accident data has enabled DNV to derive probabilistic spill models for liquid oil cargo spills that take into account the accident type (such as collision, grounding) and the hull type (single hull, double hull). These models include probabilities of no-spill given an accident to a laden ship, as well as probabilities of small spills, medium spills and total loss spills (all as a function of ship size).

This analysis has been used as the reference basis to generate probabilistic bunker fuel oil spills for conventional single hulled bunker tanks, as well as cargo spills from gas tankers.

6.2 Bunker Spill Models

The bunker spill models as a function of Vessel Type and hull protection are described below.

Bunker Spill Models as a function of Vessel Type

The traffic data compiled by DNV for the study area included estimates of the average amount of bunker fuel oil carried by each Vessel Type. These average amounts were incorporated into

DNV's generic bunker oil spill models to make the bunker spill models specific to the AIRA study area. In general, DNV's generic models were good representations of some Vessel Types (e.g. gas, oil, product and chemical tankers, as well as bulk carriers), but the model underrepresented the amount of bunker fuel oil carrier by some other Vessel Types (e.g. container ships). The reason for this is that Container ships typically travel at greater velocities than other Vessel Types because of the nature of their cargo (which is usually high value and may be perishable), which increases fuel consumption.

Bunker Spill Models with Double Hull Protection

DNV has previously developed bunker fuel spill models for single hulled bunker fuel tanks. However, the bunker spill model was amended to represent double hulled bunker tank protection by taking account of the following:

- Bunker tanks are relatively small compared to the ship's size, thus it is assumed that 90% of accidents do not cause damage to the bunker tanks.
- Analysis of worldwide historical accident data indicates that double hulls reduce the probability of cargo spill given a serious accident by about a factor of 4.
- Engineering judgment indicates that if a spill occurs the amount spilled will not change and the probability of total loss of the ship will not be reduced by the double hull protection.

6.3 Cargo Spill Risk Models

The cargo spill risk models as a function of Vessel Type are described below.

Cargo Spill Risk Models for Container Ships (1, 2)

Industry estimates of the number of containers lost into the sea worldwide varies from less than 2000 per year (Ref. /2/), or 0.005% of all containers transported per year, to less than 10,000 per year (expert judgment). The majority of containers lost are due to storm conditions rather than navigation accidents.

There is no data available on the loss of containers from ships during accidents, thus expert judgment is applied. It is assumed that some accidents will not result in loss of any containers, some accidents will result in a few containers lost, and a few accidents will result in about 10 or about 100 containers lost from the container ship. It is not considered credible that all containers will be lost from a container ship. It is assumed that on average one container may contain 40 tons of cargo. On this basis, the assumptions shown in Table 6-1 were used to generate the mass of cargo (not hazardous cargo) lost from the container ship during marine accidents.

Table 6-1 Basic Assumptions for Container Spill Models

	No Container Loss	Few Containers Lost	Some Containers Lost	Many Containers Lost
Probability Distribution of Contain Loss Severity	25%	40%	25%	10%
	Tons of Cargo Lost (not hazardous cargo)			
Smallest container ship	0	44	220	880
	0	80	400	1600
	0	140	700	2800
Largest container ship	0	220	1100	4400
	Number of containers lost			
Smallest container ship	0	1.1	5.5	22
	0	2	10	40
	0	3.5	17.5	70
Largest container ship	0	5.5	27.5	110

The shipping data for the study area indicates that no more than 10% of the cargo carried in containers is hazardous cargo, and this figure will normally be lower.

When a container is lost into the water it will normally float initially (unless it is heavier than the weight of water it displaces). Containers will continue to float until they are washed onto the shore or until enough water enters the container to force it to sink. The rate of sinking will be increased by rough sea states which will either cause containers to collide, or may induce internal load movements leading to mechanical damage of the container and water ingress.

Hazardous cargo inside the container will normally be packaged in plastic or metal drums. These drums are designed to withstand a degree of rough handling. Hazardous chemicals that are sealed within their drums when the container sinks are not expected to produce a sudden, rapid and large release of chemicals at a single location, thus the environmental impacts may be relatively small compared with the loss of perhaps thousands of tons of bunker oil from a damaged bunker tank in a period of one to two days.

To summarize:

- There is a low probability that containers enter the water following a container ship navigational accident.
- There is a low probability that the container contains hazardous cargo.
- There is a low probability that a large number of hazardous cargo drums will be damaged at the same time leading to a large release of hazardous cargo over a short period of time in a single location.

For these reasons, it is concluded that the reasonable worst case spill scenario for container ships is that a single container is 50% filled with packaged hazardous chemicals (total 20 tons of hazardous chemicals) and the entire contents is released into the sea within a few hours.

Cargo Spill Risk Models for Bulk Carriers (Vessel Types 3, 4)

Bulk carriers typically transport materials like ore, coal, cement or grain. These materials are normally considered non-hazardous to the environment. They might, however, be considered hazardous to the environment if very large quantities were released quickly in some locations.

Bulk carriers are typically sub-divided into between 4 and 8 full-width holds. Nearly all bulk carriers have double bottoms and newer ships have double hulls.

The extent of cargo loss during a marine accident will depend on:

- The size of the hole in the hull and its location relative to the water line.
- The density and solubility of the cargo. Materials that are insoluble and denser than water are unlikely to be washed out of the damaged hull by wave action in significant quantity.
- If the cargo will flow or stick when wet.

DNV is not aware of any analysis of cargo loss from bulk carriers during accidents. Our judgment, based on the factors stated above, is that the loss of solid, denser than water, insoluble cargo from bulk carriers in accidents will be almost negligible and thus, was not included in the assessment.

Cargo Spill Risk Models for General Cargo Ships (Vessel Type 5)

General cargo ships are like bulk carriers in that they are typically divided into full-width holds, but they are like container ships in the types of cargo that they carry. For this scope of analysis, it is reasonable to assume that cargo spill models for general cargo ships are the same as those for container ships.

Cargo Spill Risk Models for Tank Barges (Vessel Type 12)

DNV has previously developed cargo spill models for cargo spills from single hulled and double hulled tankers. It is assumed that these are sufficient to represent spills from Tank barges to a first approximation.

7 BASELINE SPILL SCENARIOS

By examination of the traffic study results, preliminary output results from MARCS, and concerns addressed by AIRA Advisory Panel members during project kickoff meeting, the Risk Analysis Team used professional judgment and identified six spill scenarios to develop the data input required for the baseline oil spill modeling elements of Task 2B. The example scenarios, which are described in more detail below, include a container ship, LNG tanker, product tanker, crude oil tanker, and car carrier. Each example scenario assumes a specific geographical location based on those areas identified by the modeling results as being the greatest risk areas for accidents. The type of accident selected is also based on the most frequent accident types identified from the modeling results. Assumptions used regarding fuel capacity and percentage full and ship construction were obtained from the traffic study results presented in the Task 1 Semi-quantitative Traffic Study Report.

It should be noted that a spill is not the most likely consequence of a shipping accident (see discussion in Section 5). The probability of no-spill, especially for tankers with double hulls, is significant.

7.1 Example Scenario 1

An Eastbound 50,000 DWT container ship, laden with containers filled with mostly non-hazardous cargo, but also including some hazardous cargo, lost power in the winter off the coast of Unalaska. In the winter storms, it drifted onto the shoreline between Cape Sarichef and Scotch Cap (about 165W, 54.5N) and punctured one of its two fuel tanks. The ship has a total fuel capacity of 22,000 bbl, but the fuel tanks were about 70% full at the time of the accident. The grounding resulted in a tank puncture below the water line. Consequently, the rate of release of the fuel in the one damaged tank (7705 bbl) was relatively low at an average of 125 bbl per hour. Emergency response was prompt and effective, helped by an abatement of the storm conditions. After 18 hours, the ship was re-floated using the high tide and local tugs. After 22 hours, the leak of fuel was stopped by pumping out the remaining contents of the damaged tank. Total loss of fuel was about 2,760 bbl, 25% of the contents of the damaged tank, or nearly 13% of the total bunker oil capacity.

During the grounding, 15 containers were lost over the side of the ship. One container contained 20 tons of hazardous cargo (phorate and linoleic acid) in 30 separate drums. Fortunately, none of this secondary packaging was broken before the drums were recovered. Unfortunately, another container that contained another 20 tons of hazardous cargo in 30 separate drums was smashed by wave action and the entire contents of the drums were spilled into the sea over a period of 4 hours. The other 13 containers only contained non-hazardous cargo.

7.2 Example Scenario 2

A Westbound, laden 80,000 DWT LNG tanker was struck in the side by another vessel during summer fog while exiting the Unimak Pass (about 165.5W, 54.3 N). The tanker consisted of five cargo tanks and one cargo tank was punctured in the accident above the water line. Approximately 25% of the tank contents (that portion of the tank above the puncture) spilled rapidly onto the water in the first 20 minutes (4,000 tons in 20 minutes = 12,000 tons per hour). The remaining portion of the damaged tank (12,000 tons) was spilled over 24 hours by a combination of evaporation and sea water entry into the tank through wave action. Fire or explosion did not occur. Thus the total loss of cargo was 24,000 tons.

7.3 Example Scenario 3

A 10,000 DWT product tanker, laden with diesel fuel, failed to make a critical course change due to a combination of summer fog and crew distraction. The tanker went aground (powered grounding) on the coast of Sanak Island (about 163W, 54.3N). The initial grounding caused limited damage to the tanker (only the bow was damaged and no cargo tanks were penetrated), but the tanker remained on the rocks and was subsequently further damaged by efforts to re-float the tanker and the action of sea swell on the exposed coast. Over a period of five days, a total of three tanks out of a total of eight were punctured before the tanker could be re-floated. The entire contents of the damaged tanks were gradually released into the water by the action of wave pumping. Thus, a total of 23,589 bbl of diesel was released over five days at an average release rate of about 195 bbl per hour.

7.4 Example Scenario 4

A laden 50,000 DWT crude oil tanker lost main power as it navigated past Agattu Island in the early spring. It was forced onto the rocks at Agattu Island (about 174E, 52.5N) and over a period of two days, the tanker broke up in the heavy swell before any salvage could be attempted. A total of 315,000 bbl of crude oil plus 23,500 bbl of bunker fuel were released into the sea at an average rate of 6,875 bbl per hour.

7.5 Example Scenario 5

A large car carrier was struck (collision) by another vessel in open water (about 179W, 54.2N) in the fall. A single bunker tank was damaged above the water line. The bunker tank had a capacity of 33,025 bbl and contained 23,100 bbl at the time of the accident. About 10% of the damaged tank's contents were spilled in the first hour (2,310 bbl per hour). The damaged ship was unable to immediately transfer the contents of the damaged fuel tank to a secure storage tank, so the car carrier continued to leak bunker oil at a rate of 63 bbl per hour for a further 48 hours, at which point response work prevented further spills. A total of 5,334 bbl of bunker fuel was spilled.

7.6 Example Scenario 6

An Eastbound 50 kDWT container ship, laden with containers filled with mostly non-hazardous cargo, but also including some hazardous cargo, lost power in the winter off the coast of Unalaska. In the winter storms, it drifted onto the shoreline between Cape Sarichef and Scotch Cap (about 165 °W, 54.5 °N). Emergency response was prompt and effective, helped by an abatement of the storm conditions. After 18 hours, the ship was refloated using the high tide and local tugs. During the grounding 15containers were lost over the side of the ship. One container contained 20 tons of hazardous cargo in 30 separate drums. None of this secondary packaging was broken before the drums were recovered. However, another container that contained another 20 tons of hazardous cargo in 30 separate drums was smashed by wave action and the entire contents of the drums were spilled into the sea over a period of 4 hours. The other 13 containers only contained non-hazardous cargo.

It is to be noted that Scenario 6 is same as Scenario 1 except that Scenario 6 was focused on a cargo spill of hazardous chemicals and Scenario 1 was focused on Bunker C fuel spill.

8 MODEL DEPENDENCIES, SENSITIVITIES AND UNCERTAINTIES, AND MODEL CORRELATION EFFECTS

8.1 Model Dependencies

This section summarizes how the MARCS results are likely to vary with plausible changes to input assumptions. Almost all the comments provided below can be derived from reading the Attachment 1 that describes the MARCS model.

8.1.1 Variation of Accident Frequencies

All the accident frequency models vary linearly with traffic frequency except for the ship-ship collision model, which increases with the product of the pair-wise traffic frequency.

The powered grounding and collision models give increased accident frequency with increased probability of poor visibility.

The drift grounding and the structural failure model give increased accident frequency with increased probability of higher wind speed states (since sea state is assumed to correlate with wind speed, see Section 8.4 below).

8.1.2 Variation of Accident Consequences

There are two types of accident consequence models used: cargo spill models and bunker fuel oil models.

All spill models do not currently represent correlation effects, though MARCS is capable of representing such effects if the data is available to derive secure parameters. That is, the severity of the accident that could be determined from the accident frequency calculator does not affect the magnitude of the accident consequence calculated from the spill model. Instead, MARCS calculates the frequency of all serious accidents and then applies a probabilistic spill model per serious accident. The spill model defines the probability of different outflows, including no outflow and all cargo lost from containment.

The cargo spill models for double hulled tankers generally define a significant probability of no spill given a serious accident. Then they usually consider two additional damage events and a total loss event. The two damage events consider damage to 1 tank and to 2 tanks. Different outflows arise for different types of accident (e.g. grounding outflows are different from collision outflows because the damage generally occurs at different heights relative to the keel and the waterline). The average cargo spill risk is generally dominated by the total loss events which occur for fewer than 90% of all accidents.

The bunker spill models result in no spill for 90% or more of all accidents. This is because of the location of bunker spill tanks on the ship. A total of four events are considered: no spill, spill from 1 bunker tank, spill from 2 bunker tanks and total loss. The historical spill data for bunker spills is not sufficient to support different consequence models for different accident types.

8.2 Sensitivities and Uncertainties

The principal sources of uncertainty in the risk assessment results arise from the following types of uncertainties:

- Uncertainties due to input data (e.g., AIS traffic data);
- Uncertainties due to the representation of input data into the risk models (type, spatial and temporal granularity);
- Uncertainties due to the way the risk models represent reality; and
- Uncertainties in the risk parameters that are used to populate the risk models.

Each of these sources of uncertainty is discussed further below.

8.2.1 Input Data Uncertainties

DNV consider that the main source of uncertainty in the marine risk results for the Aleutian Islands is the uncertainty in the quantity and location of the traffic data. As mentioned in the traffic data report, the traffic data for the base year (August 2008 – July 2009) was derived from AIS data. However, not all ship tracks will be represented in the AIS data because:

- Not all ships will have a fitted and functional AIS system. DNV estimate that the IMO requires that at least 95% of ships in the study area should carry an AIS transponder and that 99% of these transponders will be functioning at any one time. Thus DNV estimate that the traffic registered by AIS may be under-estimated by about 5% based on this source of error.

- The Marine Exchange of Alaska (MXAK) reported that during the period from October 1, 2008 through September 30, 2009 the AIS system reliability was approximately 94% (cumulative down time of 22 days for the reported period). However, because of overlapping coverage at the Unimak Pass area, the MXAK estimates year round coverage closer to 99%.
- The spatial range of AIS coverage is relatively limited compared to the total size of the Aleutian Islands Risk Assessment study area. DNV estimates that the spatial extent of AIS coverage is limited to not more than 10% of the total study area. While every effort has been made to assess traffic locations outside the AIS coverage area consistent with the project schedule, there must be significant uncertainty about both the position of the ships outside AIS coverage and the quantity of shipping. The effect of this factor is difficult to estimate.

For the estimated traffic data in 2034, the levels of uncertainty in quantity and location is obviously much higher because these traffic levels are based on the base year data and on projections (economic and otherwise) over 25 years. It is not possible to meaningfully quantify this uncertainty, but a factor of 10, or perhaps more, either way does not seem impossible.

The risk results also rely on ship size information and ship cargo type information. Neither of these inputs are directly available from the AIS data. Ship size information was obtained by correlating two data sources (AIS Maritime Mobile Service Identity – MMSI numbers and merchant vessel data from Equasis) and should be precise where the correlation has been found. In some cases (about 20% of the total) where a correlation was not found, DNV made plausible assumptions so that the vessel data could be used and not discarded. The uncertainty in vessel size data may not be very significant in comparison with other sources of uncertainty. DNV estimates up to a factor of two either way for the small proportion of ship sizes that have needed to be estimated.

The data on the type of cargo carried and if the ship is laden, partially laden or in-ballast is very difficult to identify. In some cases, plausible assumptions are possible (e.g. crude oil tankers carry crude oil and tend to be either fully laden or in-ballast). In other cases, for example for bulk carriers or container ships, the level of uncertainty is judged to be high. In particular, we only have an approximate estimate of the worldwide average proportion of containers that contain hazardous cargo. In the AIRA study area we only know where the container ships are located (subject to the uncertainties noted above) and there are no firm data on which routes, if any, carry hazardous cargo. It is estimated that the level of uncertainty could easily be a factor of two, or higher, either way.

8.2.2 Data Representation Uncertainties

An example of a data type issue is that not all ships fit neatly into one of the 17 ship types defined. Such ships may be placed in the 18th ship category “Other” or they may be categorized as a specific ship type even though they are not closely similar to the other ships in that category. For this reason, the “Other” category of ships is likely to have a wider range of characteristics compared to the other ship categories.

Even when an individual ship can be clearly assigned to a ship category, it may be at the large or small size of the ship size range in which it is placed. Thus, the assumption of the average ship size for the ship size range does not accurately represent the specific ship in question.

The MARCS model uses a statistical representation of all input data, so there are other examples of this type of uncertainty which result from "binning" all data into data ranges. Three types of data representation uncertainties are identified and discussed below.

Spatial Uncertainty: An example of data spatial uncertainty is the use of average meteorological data over the entire study area. Clearly this is an approximation, especially for the inshore traffic routes. The alternative is to define sub-areas within the study area and to define meteorological data for each sub area. This is not as straightforward as it might appear. Meteorological data is only measured at discrete locations in the study area. The spatial relationships between the measurement locations are not regular and in any case, climate is strongly influenced by local factors. Thus it becomes a significant task to: establish consensus on the boundaries between each meteorological sub-area; and establish consensus on the data that should be applied within those sub-areas (if the sub-area contains more than one measurement location, or if the sub-area has no measurement location). In the Task 1 / Task 2A results a single, reasonable-worst-case meteorological data set was applied to the entire study area. It is believed that this is the appropriate approach given the stated requirement to develop a semi-quantitative risk assessment.

Temporal uncertainty: An example of data temporal uncertainty is how meteorological data may vary with time, both in terms of seasonal variation within a year and in terms of climatic variation over the next 25 years.

Seasonal Variation: Seasonal variation has not been included in the Task 1 / Task 2A results. Instead annual average meteorological and ship traffic data have been included. The effect of this uncertainty is not considered to be very important to annual average risks results.

Although information on future climatic changes was reviewed, it has not been possible to identify how meteorological data might vary over the next 25 years with much certainty. Thus, it has been assumed that the meteorological data is unchanged.

8.2.3 Risk Model Uncertainties

There are two main parts to the MARCS risk model:

- Accident frequency models; and
- Cargo and bunker (fuel) oil outflow models.

Any model is only a model. It cannot represent all factors that might affect the risk results. Nevertheless, the risk models used in MARCS have been subject to significant review over the last 15 to 20 years and have been found to provide useful insights into how the marine system under study functions.

As an example, all the accident frequency model results depend linearly with ship-hours in the study area, except for the ship to ship collision model. This increases with the product of the ship-hours in the study area for each ship pair. One result of the way that the accident frequency models are defined is that the accident frequencies appear to decrease with increasing ship speed (reduced ship-hours in the study area). However, all ship speeds are defined to be between 10 and 22 knots, so this effect is considered to be acceptable. The alternative requires the definition of different ship accident probabilities as a function of ship speed. Not only does this greatly increase the complexity of the modeling process, but such parameters cannot be defined based on the worldwide data alone; they would require additional assumptions that can be challenged.

8.2.4 Risk Model Parameter Uncertainties

The ship collision model defines the probability of a collision given that two ships have an encounter (navigate to within 0.5NM of each other). The worldwide data supports the derivation of average values for these probabilities.

Logically, these collision probabilities should vary with the local traffic density. Previous work has clearly shown that the average collision probabilities are too large for densely trafficked waters (the collision risk model over-predicts the risk results for such areas). In effect, in densely traffic waters navigators pay more attention, compared to lower density waters, and this has the effect of reducing the average collision probability per encounter that should be applied. Again, there is insufficient data to represent this effect without making assumptions that are open to challenge.

8.3 Sensitivities and Uncertainties Conclusions

While it is clear there are uncertainties in the Task 1 and Task 2A risk model outputs, the risk analysis team considers that these uncertainties are consistent with the stated aim of the Phase A risk assessment. The requirement stated is to "conduct a semi-quantitative risk assessment." This has been achieved, consistent with the resources and schedule allocated to the work. Thus, the traffic study and initial marine risk assessment results provide an applicable and sufficient basis for conducting the remaining tasks of the Phase A risk assessment.

9 DEFINITIONS

Accident	An event where normal safety margins have been lost and some form of harm has actually occurred, though maybe not in all harm categories (e.g. no fatality but minor damage to the ship's hull).
Bunker	Fuel, such as fuel oil, used in ships.
Consequence	The outcome that results from an accident. Consequences may vary in severity from little or no harm in an impact category to an accident resulting in severe harm (e.g. multiple fatalities) in multiple harm categories (e.g. human fatality and environmental impact).
Frequency	A measure of how often something happens. It could be per year or per operational cycle.
Harm	An adverse consequence of an accident. Harm can occur in multiple harm categories (e.g. fatality, pollution, asset loss, reputation damage, etc.)
Hazard	A hazard can be defined as an event or circumstance that may lead to some form of harm.
Incident	An event or condition where normal safety margins have not been fully maintained. Often called a "near miss".
Risk	The estimated average harm. Risks are normally compared within a harm category (e.g. one level of average human fatality compared to another), but sometimes risks between harm categories need to be balanced.

10 ACRONYMS AND ABBREVIATIONS

ADEC	Alaska Department of Environmental Conservation
AIRA	Aleutian Islands Risk Assessment
AIS	Automatic Identification System
BBL	Barrels
DGPS	Differential Global Positioning System
DNV	Det Norske Veritas
DW	Deep Water
DWT	Deadweight Tonnage
ECDIS	Electronic Chart Display and Information System
ERM	Environmental Resources Management (ERM-West, Inc.)
ERV	Emergency Response Vessel
GPS	Global Positioning System
GRT	Gross Registered Ton
HP	Horsepower
IMO	International Maritime Organization
KDWT	One-thousand Deadweight Tons
MARCS	Marine Accident Risk Calculation System
NFWF	National Fish and Wildlife Foundation
NM	Nautical Miles
SOLAS	Safety of Life at Sea
TEU	Twenty Foot Equivalents Unit
TSS	Traffic Separation Scheme
USCG	United States Coast Guard
VTS	Vessel Traffic Service
VTMIS	Vessel Traffic Monitoring and Information System

11 REFERENCES

/1/ United States Coast Pilot 9: Pacific and Arctic Coasts Alaska: Cape Spencer to Beaufort Sea. 2009 (27th)

/2/ Vero Marine Insurance Containers Overboard Discussion (http://www.veromarine.co.nz/dirvz/marine/marine.nsf/Content/PhotoFeature0007)

12 GEOGRAPHICAL DISTRIBUTION FIGURES

This section presents the Traffic Plot and geographical distributions of cargo spill risk by Vessel Type for the Base Year (2008/2009) and future year (2034).

The graphics illustrate the contribution by each Vessel Type through quantifying how many vessel-miles each Vessel Type transits across each lane throughout the study area. Transit Frequency is illustrated in each traffic plot through a gradient color code scheme found in Table 12-1 Key to Vessel Transit Plots.

Table 12-1 Key to Vessel Transit Plots

Color	Transit Frequency (ship movements per day within each calculation location)
Grey	0.0 to 0.1
Cyan	0.1 to 0.5
Green	0.5 to 1
Yellow	1 to 5
Orange	5 to 10
Red	> 10

The graphics were generated using the MARCS model and traffic data described in the AIRA Preliminary Risk Assessment Task 1 Semi-Quantitative Traffic Study.

12.1 List of Traffic Plot and Geographical Distributions of Cargo Spill Risk by Vessel Type for the Base Year (2008/2009) and Future Year (2034)

Data for Vessel Type 13 – Cargo Barges was not defined

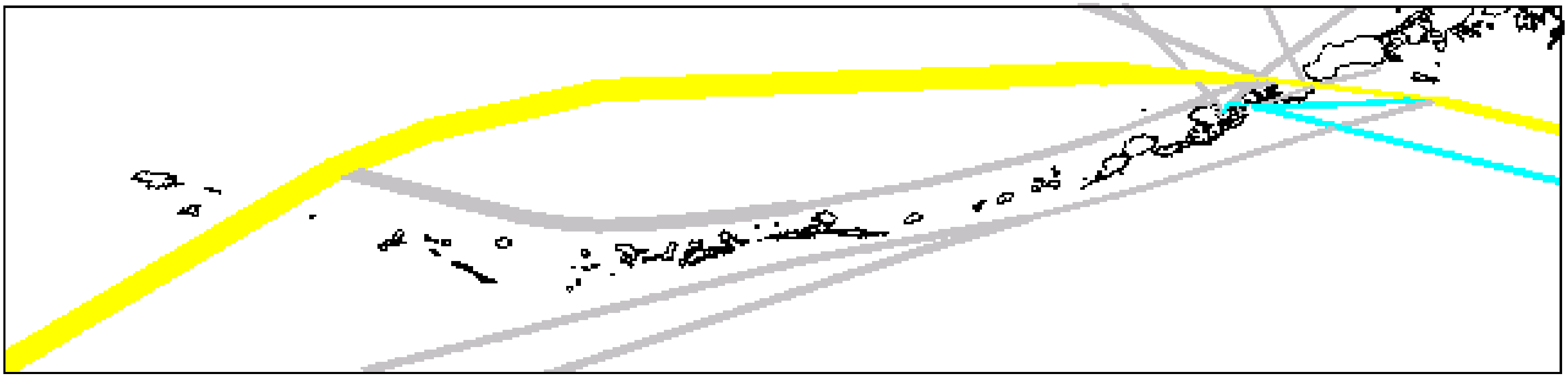

Figure 12-1 Base Year (2008/2009) Traffic Plot for Vessel Type 1 – Small Container Ships

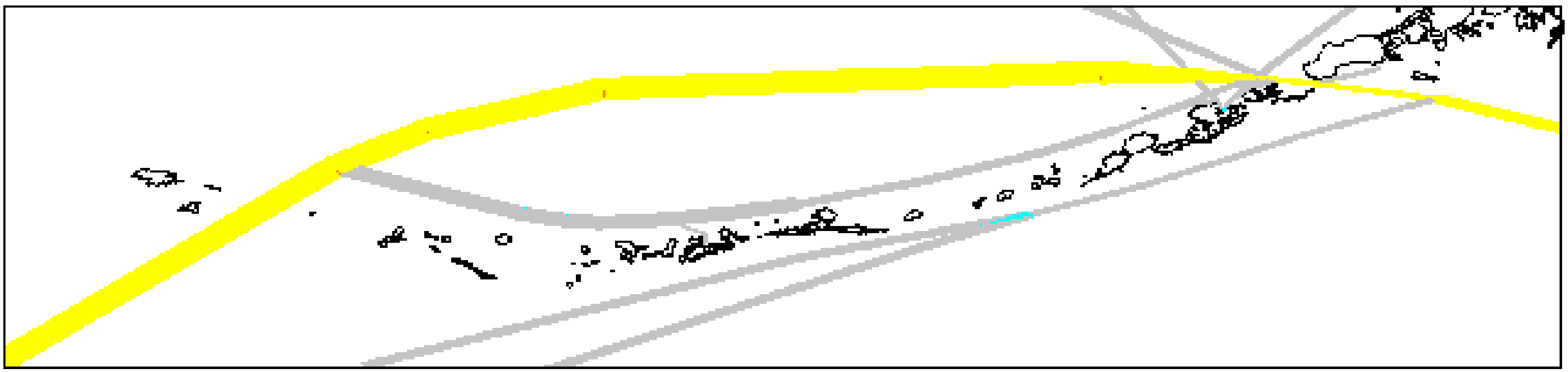

Figure 12-2 Base Year (2008/2009) Traffic Plot for Vessel Type 2 – Large Container Ships

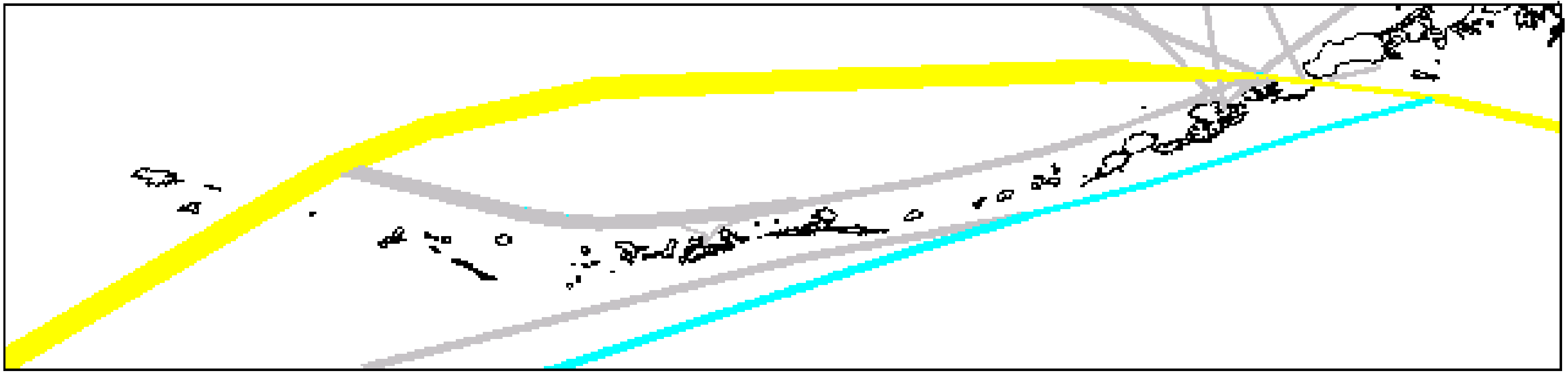

Figure 12-3 Base Year (2008/2009) Traffic Plot for Vessel Type 3 – Small Bulk Carrier Ships

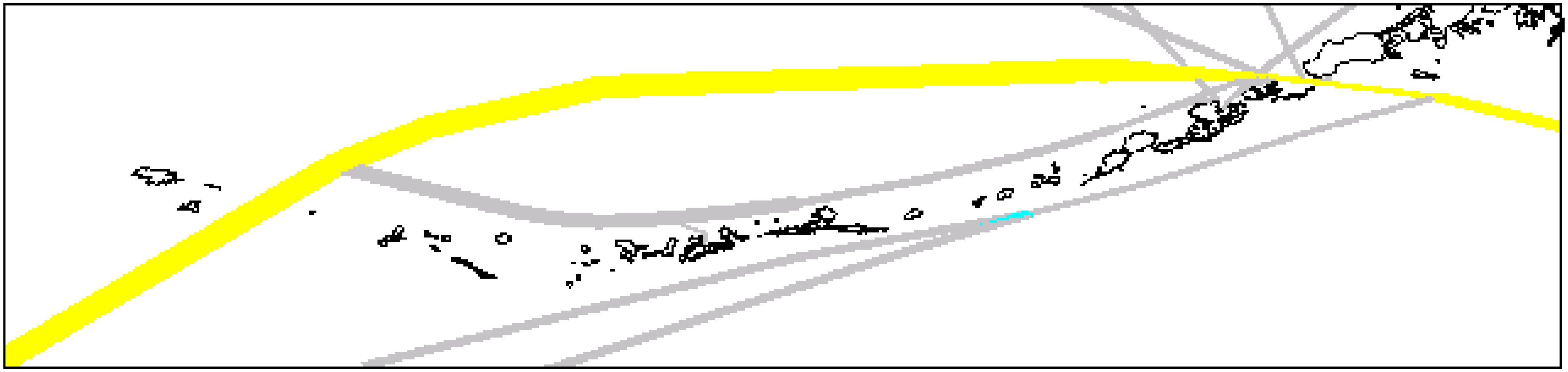

Figure 12-4 Base (2008/2009) Year Traffic Plot for Vessel Type 4 – Large Bulk Carrier Ships

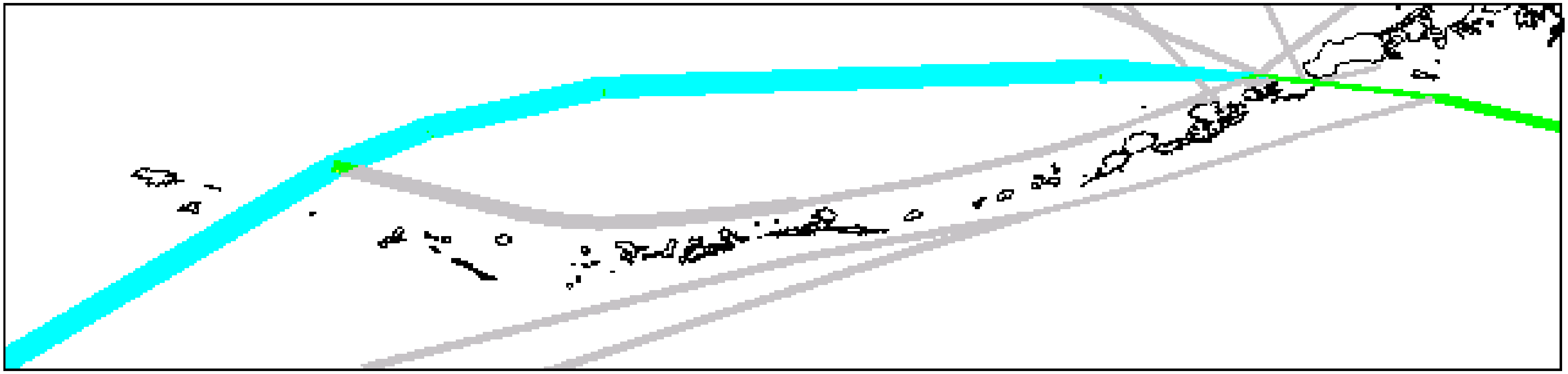

Figure 12-5 Base (2008/2009) Year Traffic Plot for Vessel Type 5 – General Cargo Ships

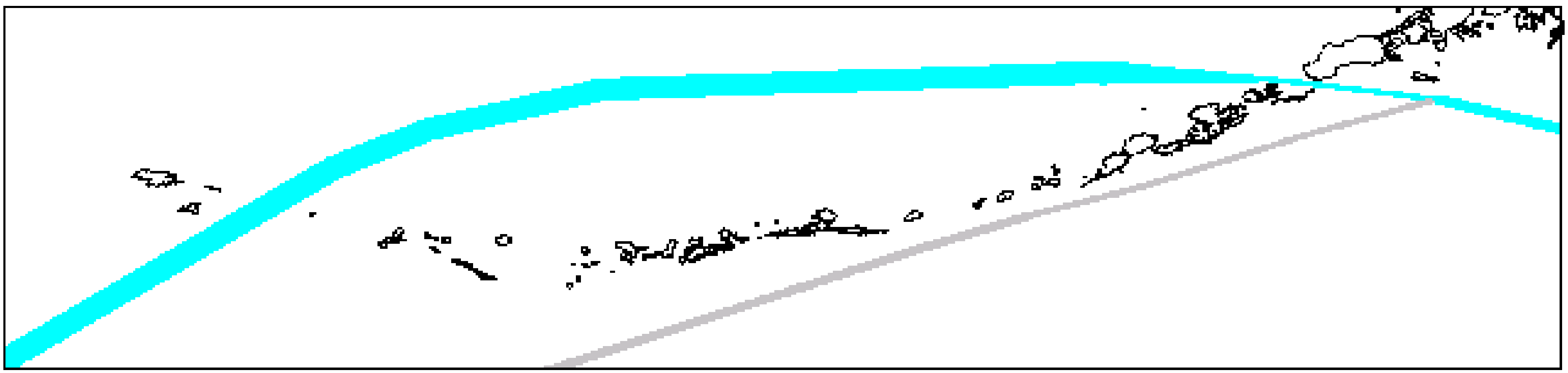

Figure 12-6 Base (2008/2009) Year Traffic Plot for Vessel Type 6 – LNG and Gas Ships

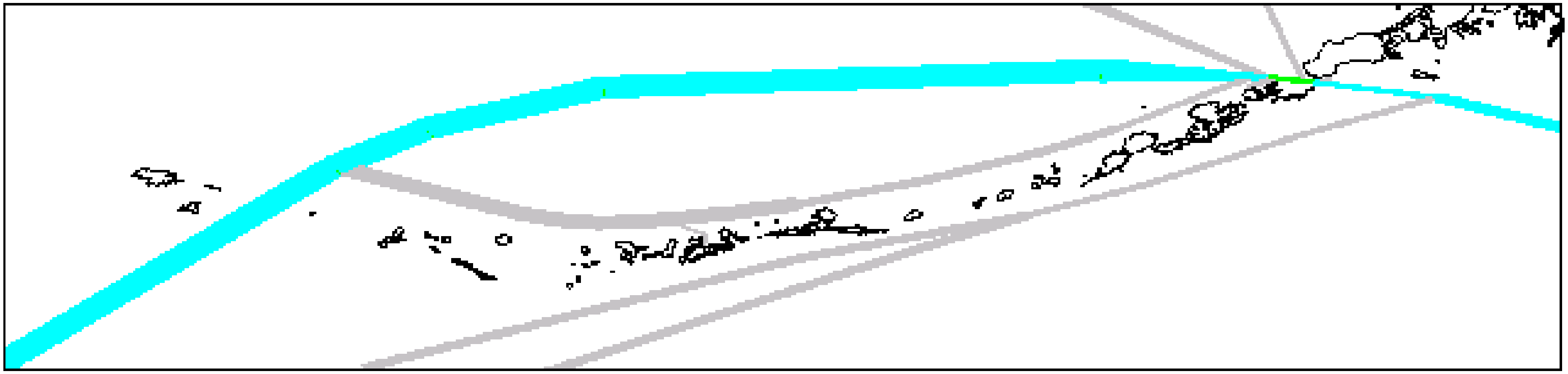

Figure 12-7 Base Year (2008/2009) Traffic Plot for Vessel Type 7 – RoRo and Car Carrier Ships

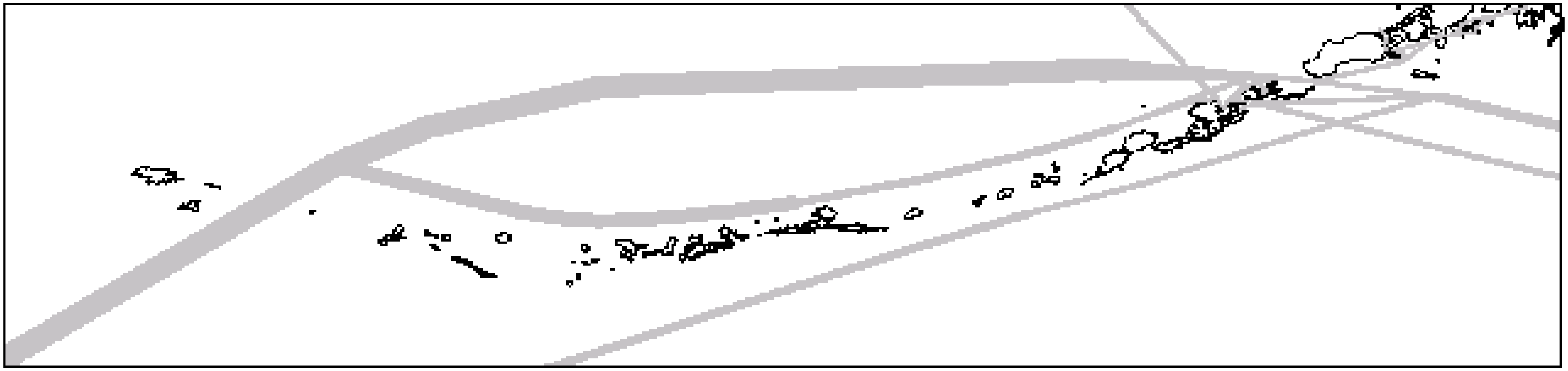

Figure 12-8 Base Year (2008/2009) Traffic Plot for Vessel Type 8 – Cruise Ships

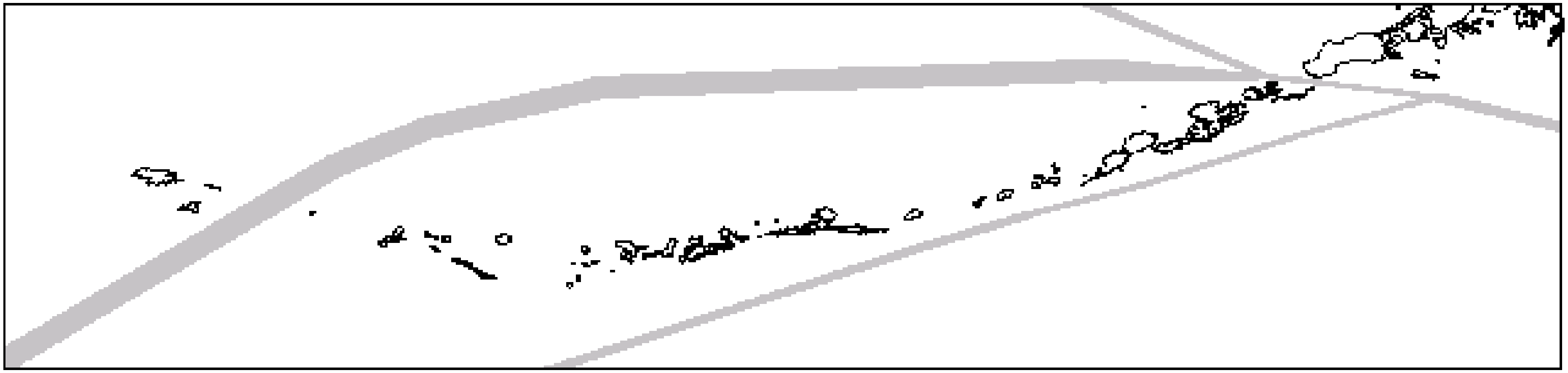

Figure 12-9 Base Year (2008/2009) Traffic Plot for Vessel Type 9 – Crude Oil Ships

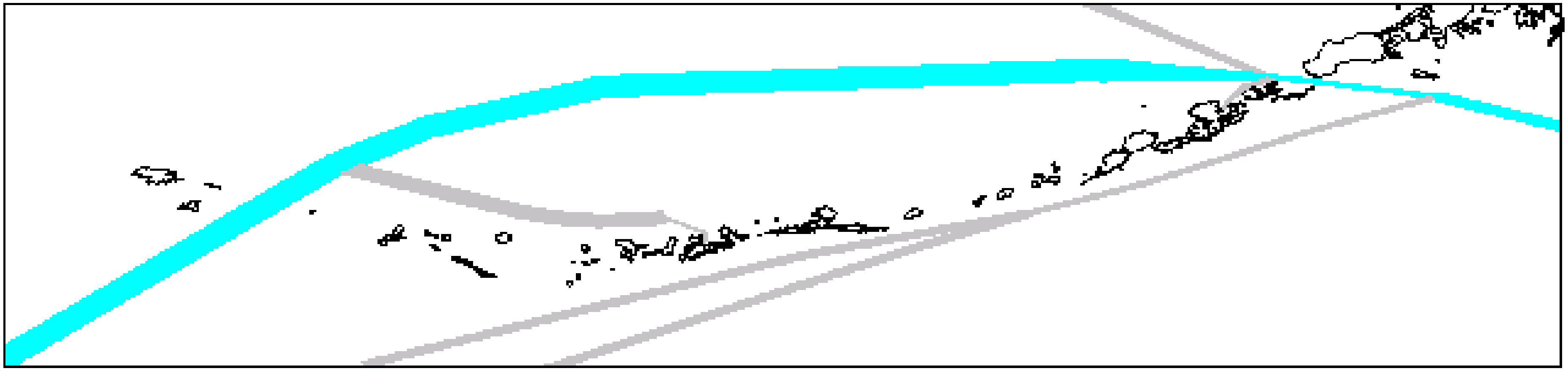

Figure 12-10 Base Year (2008/2009) Traffic Plot for Vessel Type 10 – Product Tanker Ships

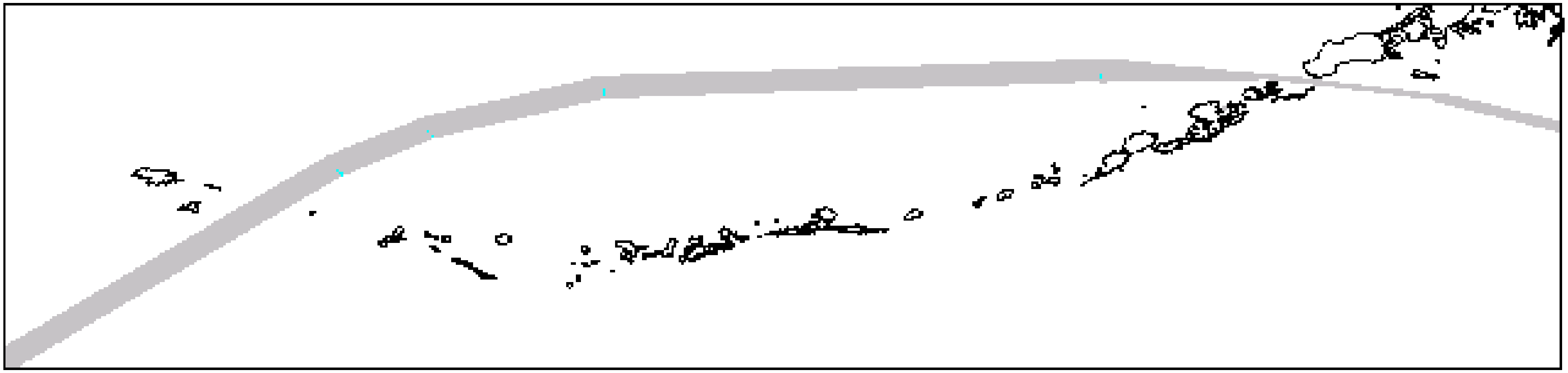

Figure 12-11 Base Year (2008/2009) Traffic Plot for Vessel Type 11 – Chemical Tanker Ships

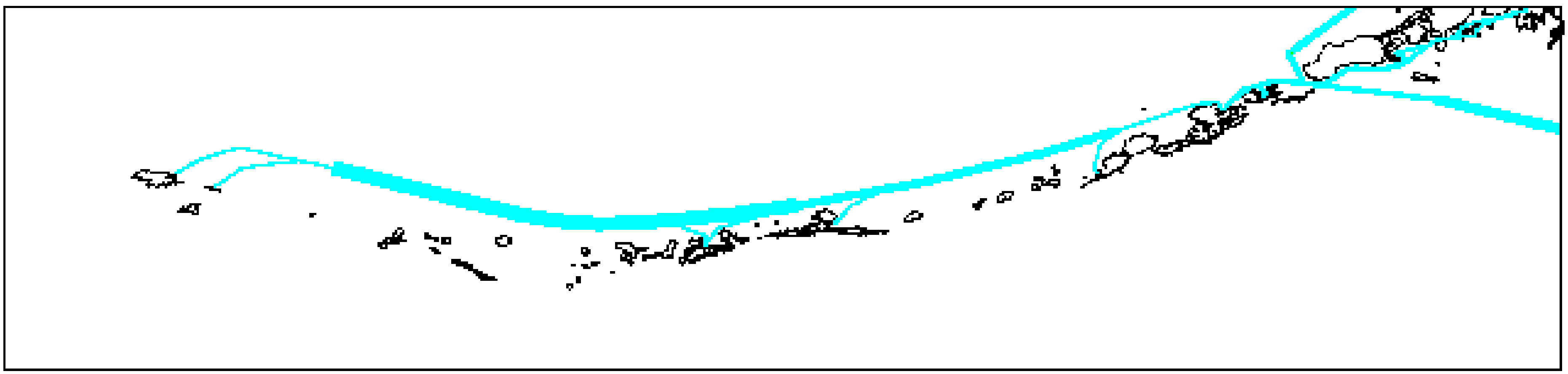

Figure 12-12 Base Year (2008/2009) Traffic Plot for Vessel Type 12 – Tank Barges

Figure 12-13 Base Year (2008/2009) Traffic Plot for Vessel Type 14 – Fishing Ships

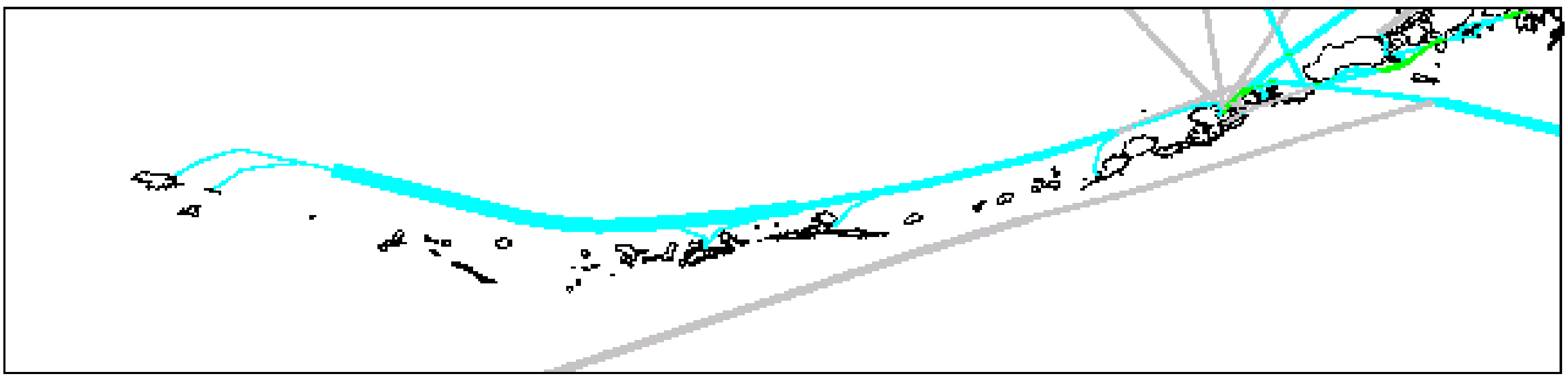

Figure 12-14 Base Year (2008/2009) Traffic Plot for Vessel Type 15 – Tug Ships

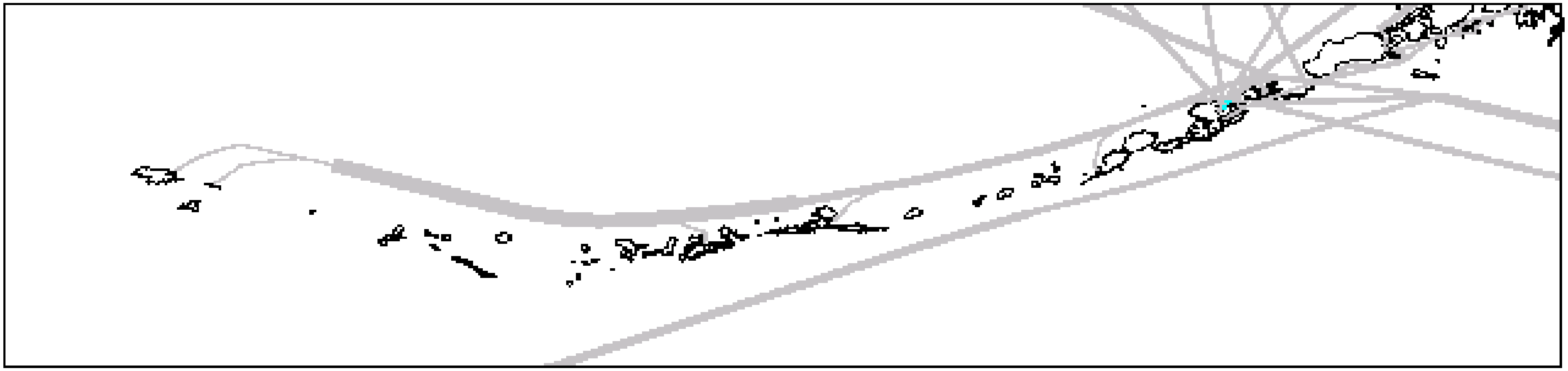

Figure 12-15 Base Year (2008/2009) Traffic Plot for Vessel Type 16 – Government Vessels

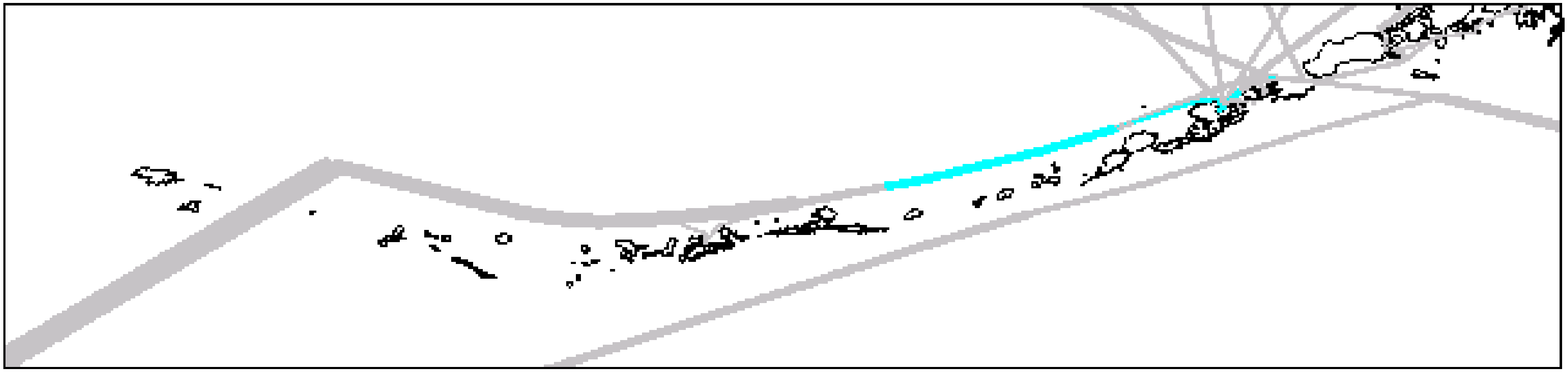

Figure 12-16 Base Year (2008/2009) Traffic Plot for Vessel Type 17 – Refrigerated (Tramp) Ships

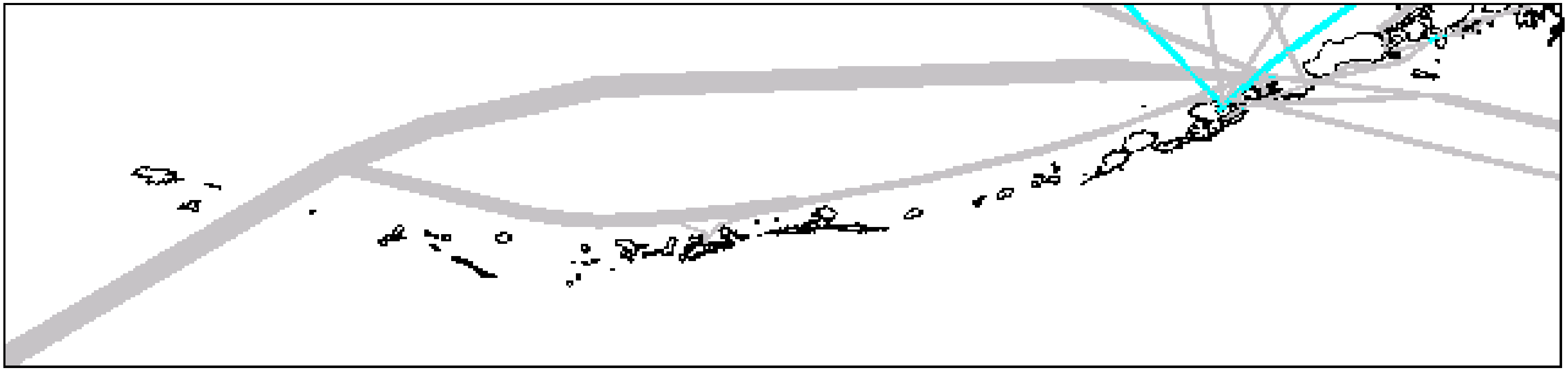

Figure 12-17 Base Year (2008/2009) Traffic Plot for Vessel Type 18 – Other Ships

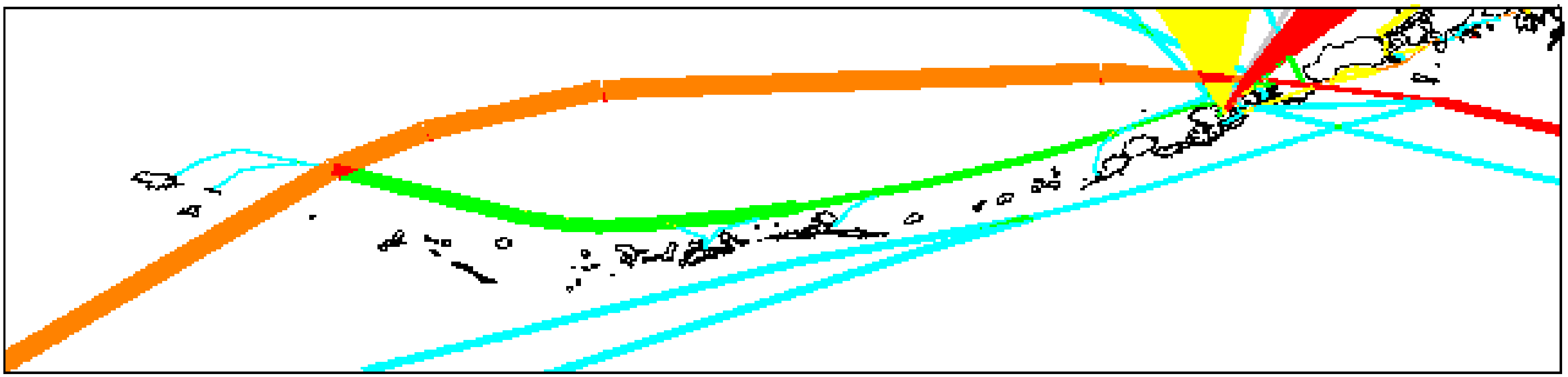

Figure 12-18 Base Year (2008/2009) Traffic Plot for All Vessel Types

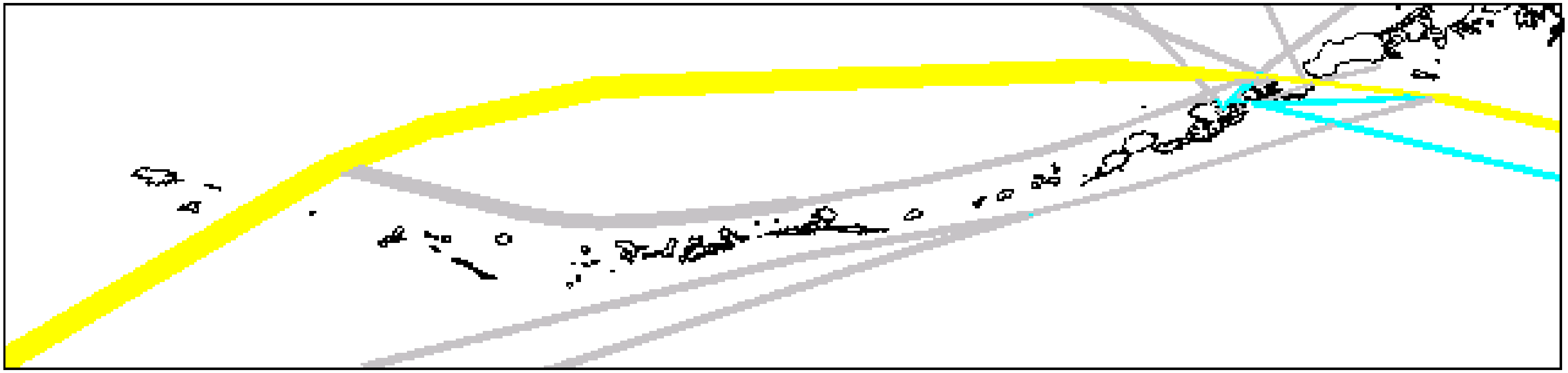

Figure 12-19 Future Year (2034) Traffic Plot for Vessel Type 1 – Small Container Ships

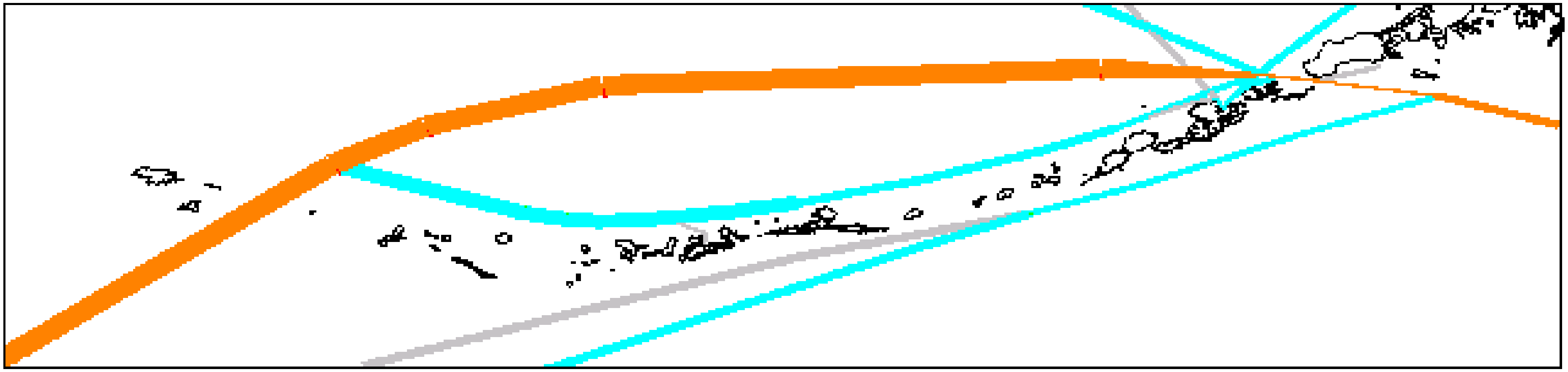

Figure 12-20 Future Year (2034) Traffic Plot for Vessel Type 2 – Large Container Ships

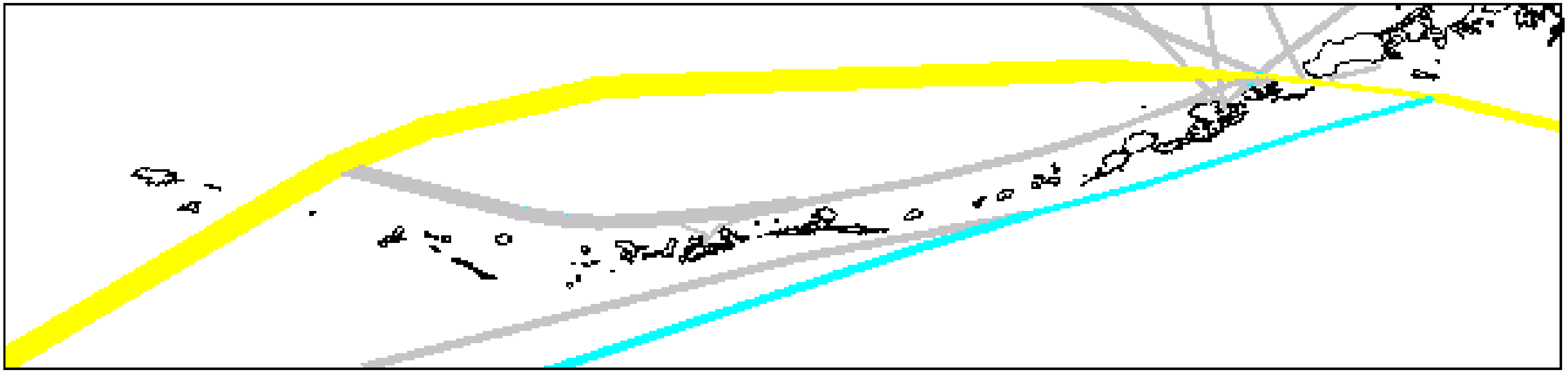

Figure 12-21 Future Year (2034) Traffic Plot for Vessel Type 3 – Small Bulk Carrier Ships

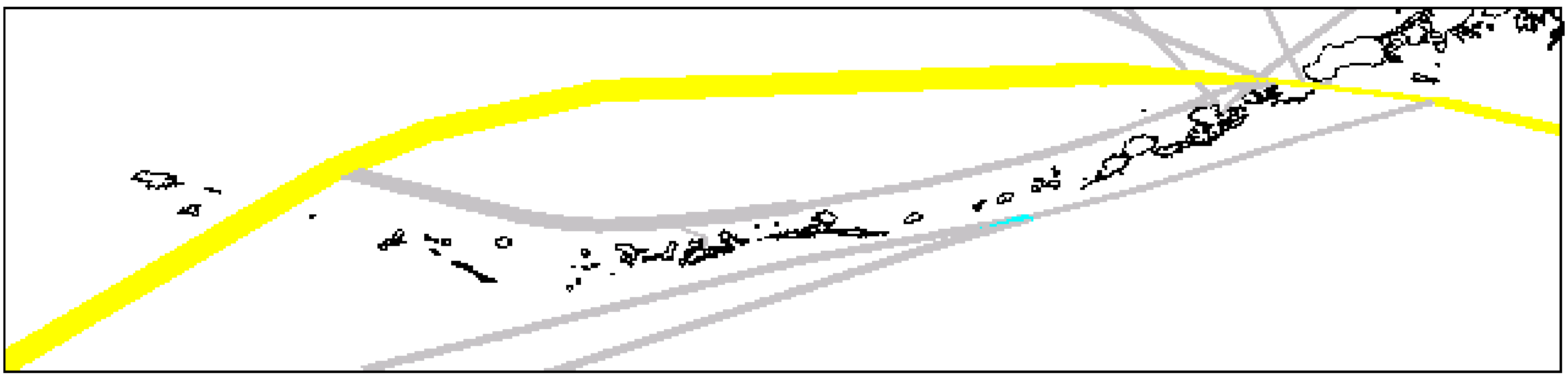

Figure 12-22 Future Year (2034) Traffic Plot for Vessel Type 4 – Large Bulk Carrier Ships

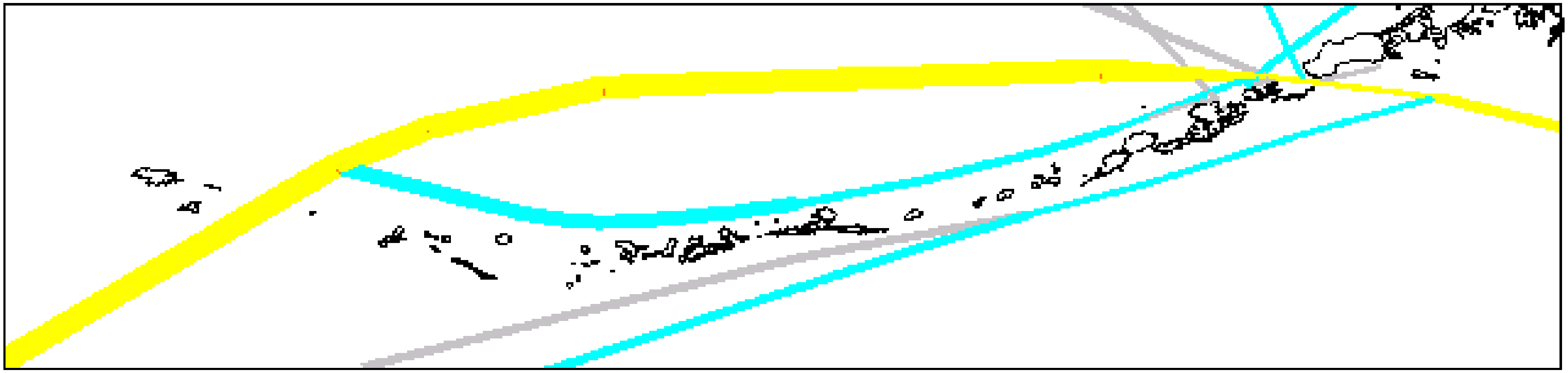

Figure 12-23 Future Year (2034) Traffic Plot for Vessel Type 5 – General Cargo Ships

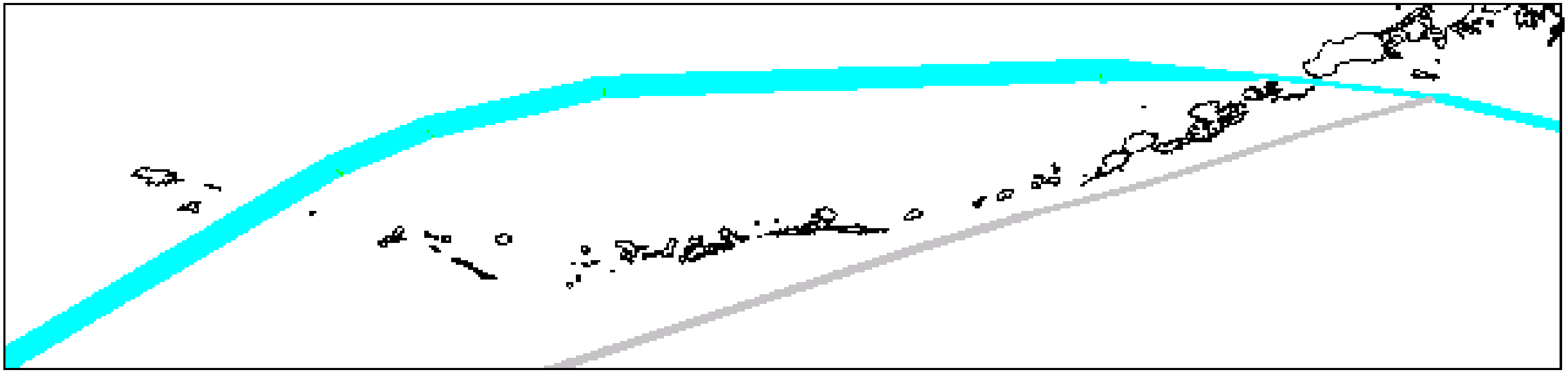

Figure 12-24 Future Year (2034) Traffic Plot for Vessel Type 6 – LNG and Gas Ships

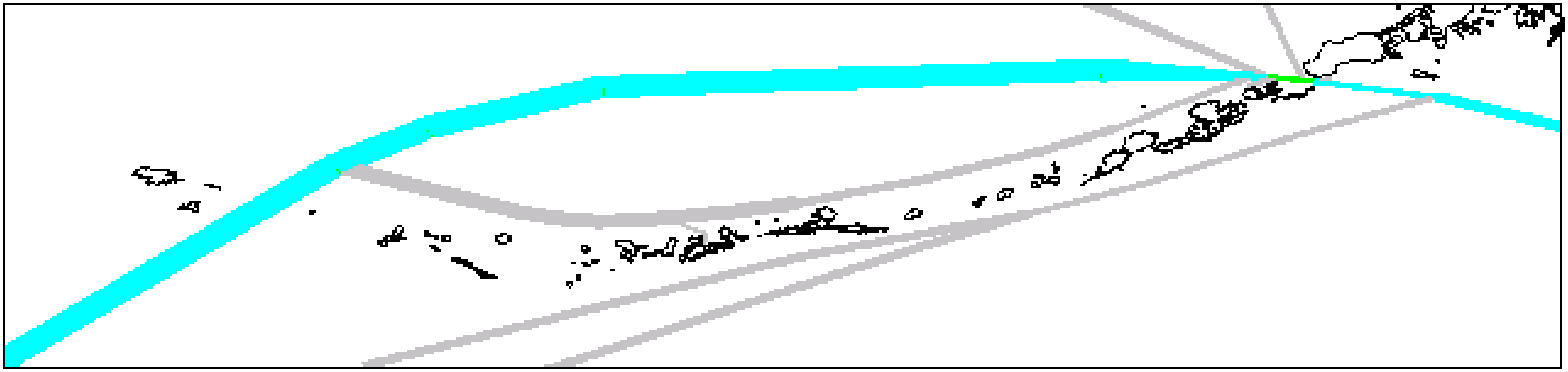

Figure 12-25 Future Year (2034) Traffic Plot for Vessel Type 7 – RoRo and Car Carrier Ships

Figure 12-26 Future Year (2034) Traffic Plot for Vessel Type 8 – Cruise Ships

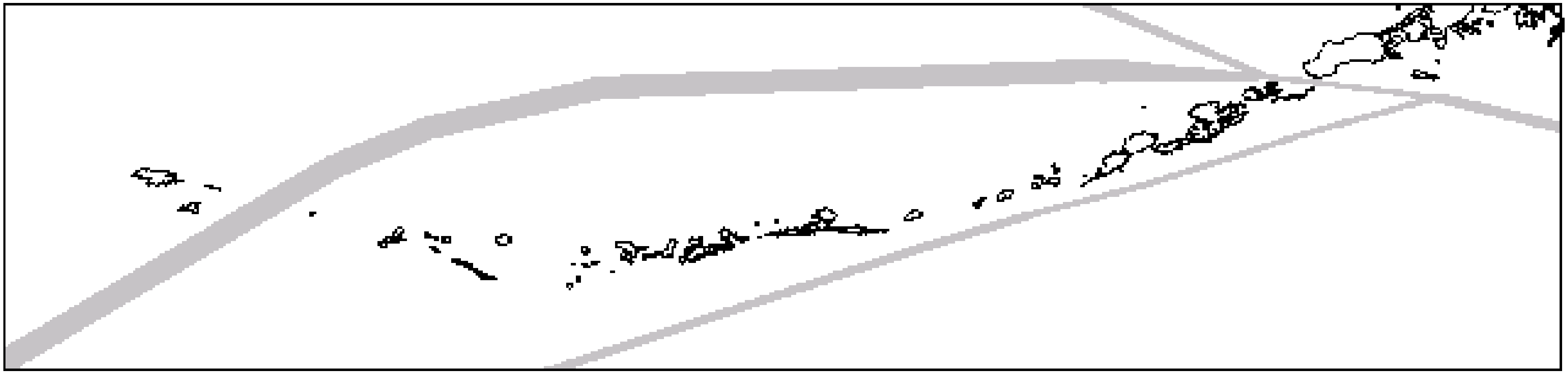

Figure 12-27 Future Year (2034) Traffic Plot for Vessel Type 9 – Crude Oil Ships

Figure 12-28 Future Year (2034) Traffic Plot for Vessel Type 10 – Product Tanker Ships

Figure 12-29 Future Year (2034) Traffic Plot for Vessel Type 11 – Chemical Tanker Ships

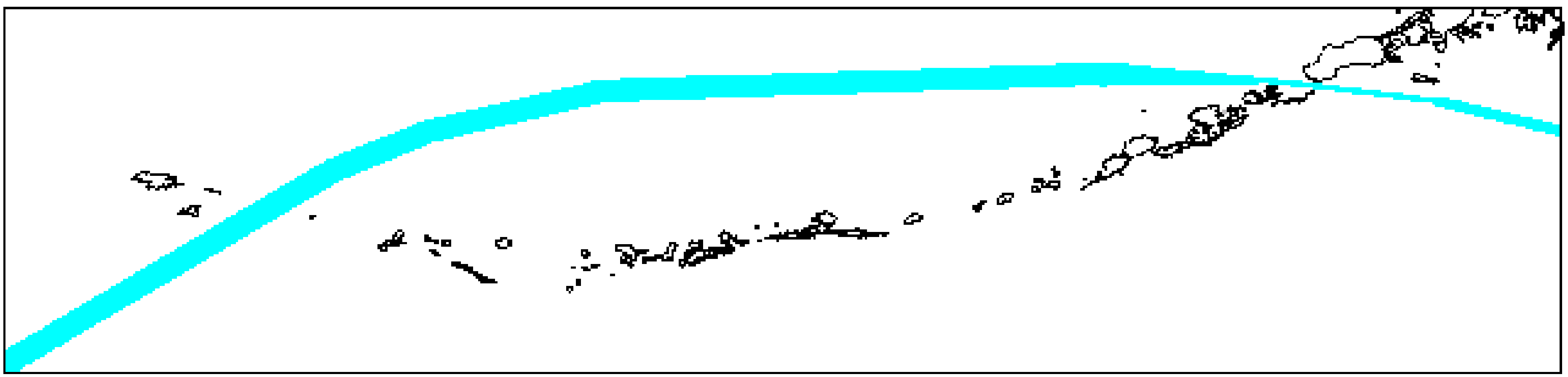

Figure 12-30 Future Year (2034) Traffic Plot for Vessel Type 12 – Tank Barges

Figure 12-31 Future Year (2034) Traffic Plot for Vessel Type 14 – Fishing Ships

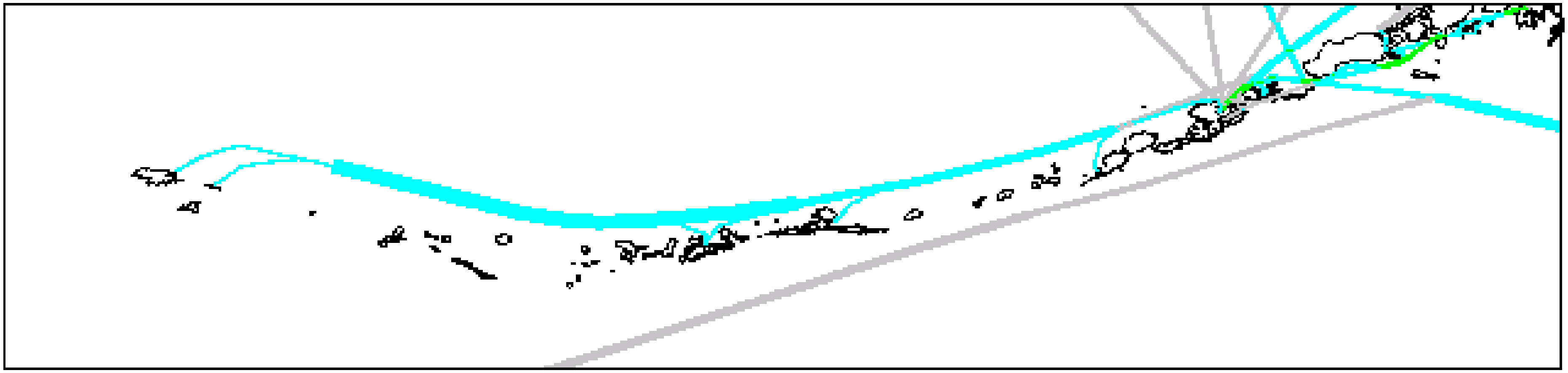

Figure 12-32 Future Year (2034) Traffic Plot for Vessel Type 15 – Tug Ships

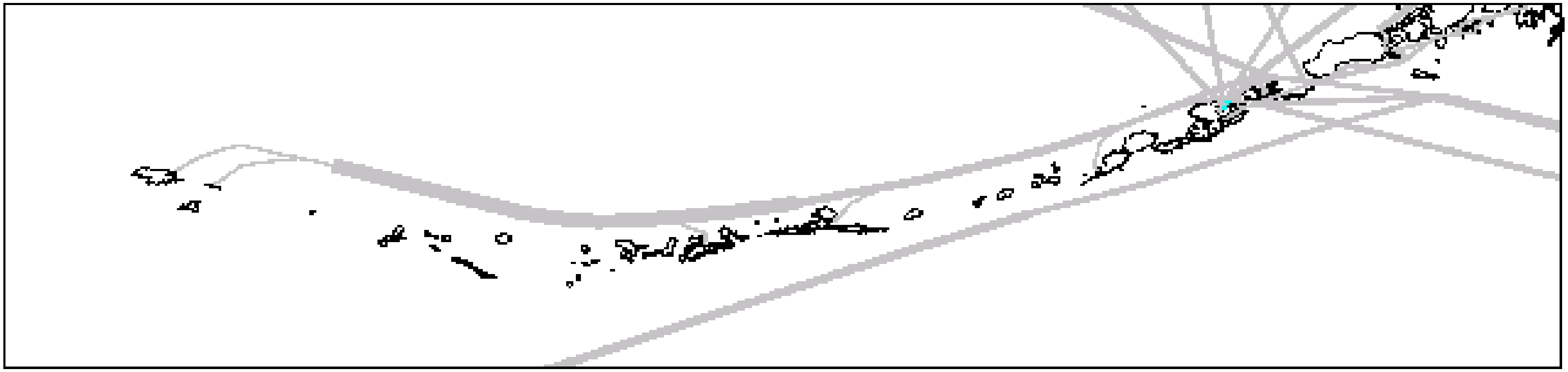

Figure 12-33 Future Year (2034) Traffic Plot for Vessel Type 16 – Government Vessels

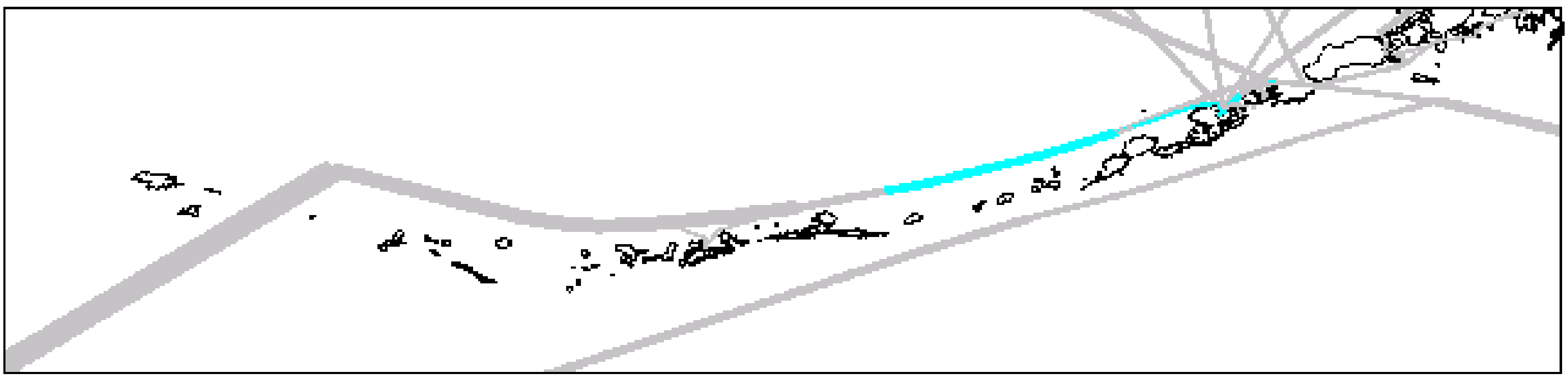

Figure 12-34 Future Year (2034) Traffic Plot for Vessel Type 17 – Refrigerated (Tramp) Ships

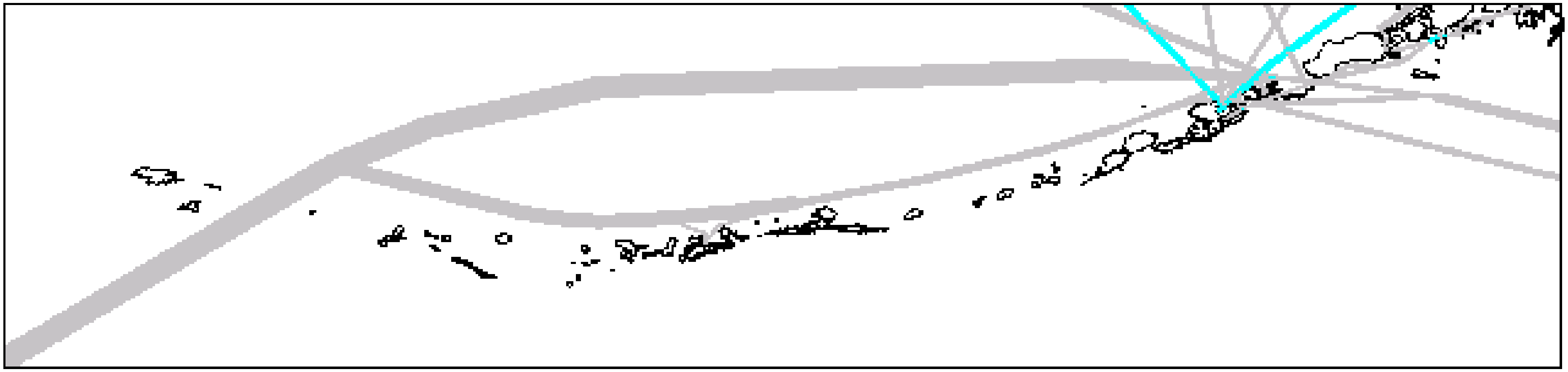

Figure 12-35 Future Year (2034) Traffic Plot for Vessel Type 18 – Other Ships

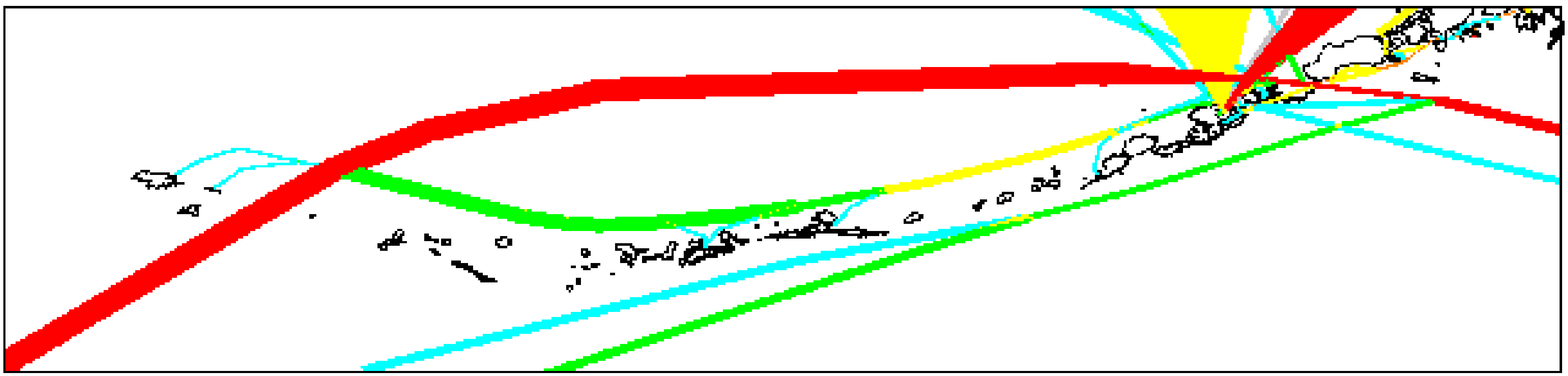

Figure 12-36 Future Year (2034) Traffic Plot for All Vessel Types

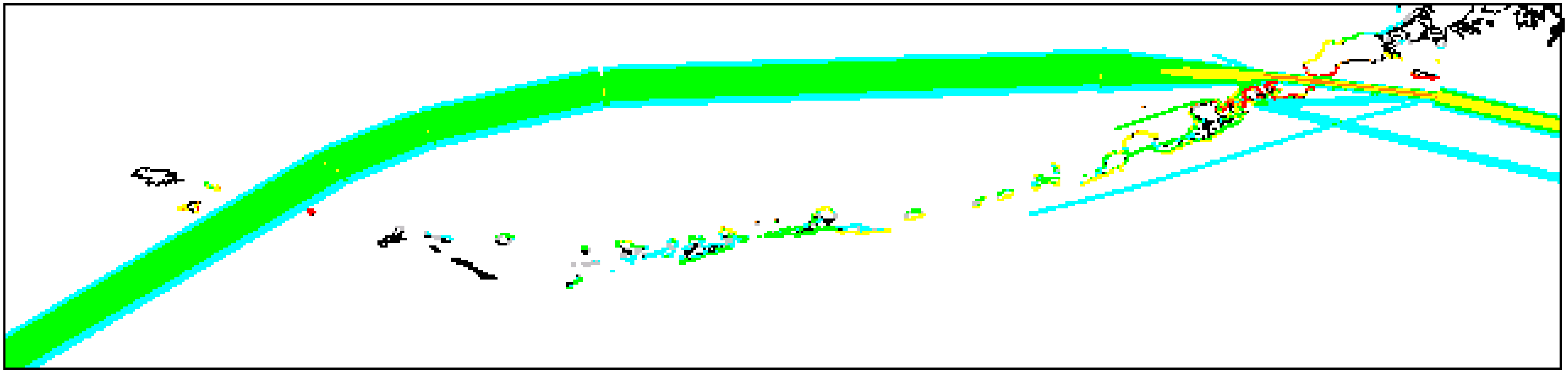

Figure 12-37 Base Year (2008/2009) Geographical Distribution of Cargo Spill Risk for Small Container Ships

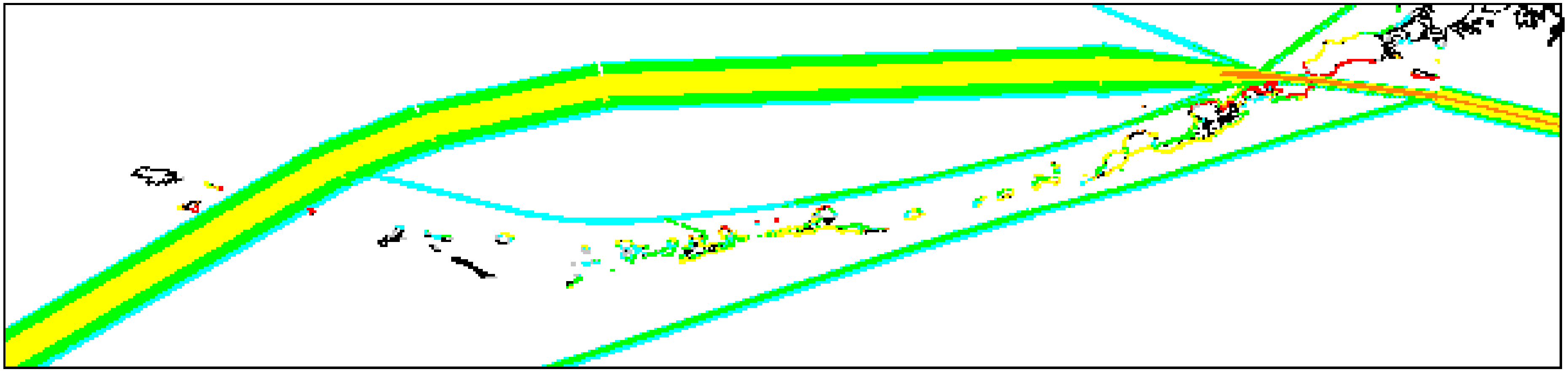

Figure 12-38 Base Year (2008/2009) Geographical Distribution of Cargo Spill Risk for Large Container Ships

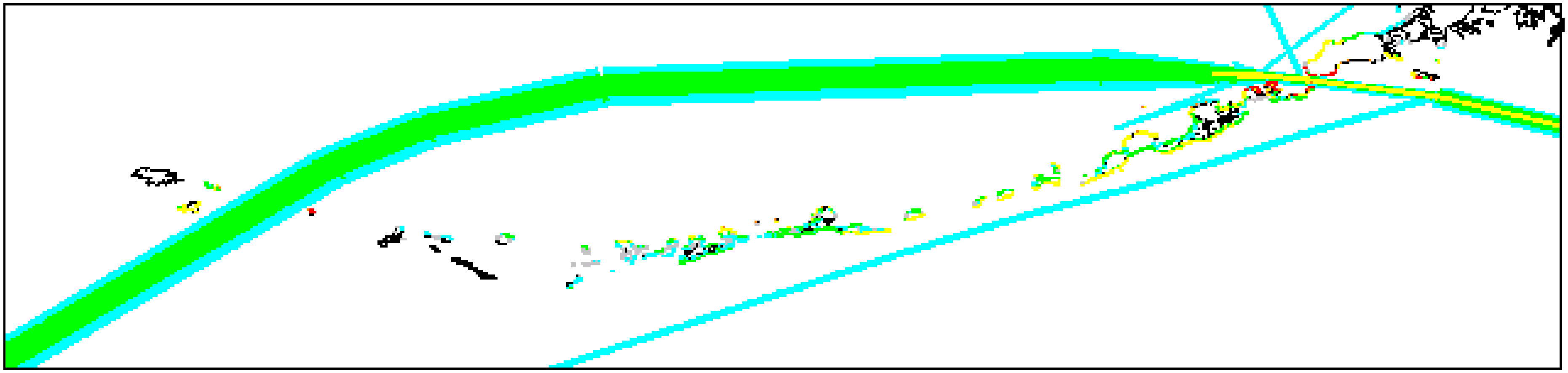

Figure 12-39 Base Year (2008/2009) Geographical Distribution of Cargo Spill Risk for General Cargo Ships

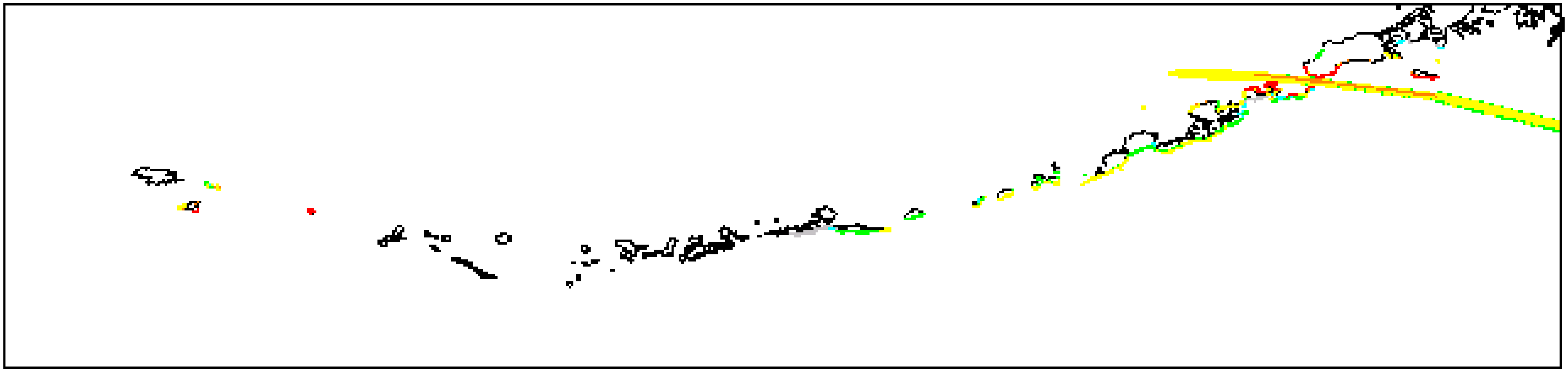

Figure 12-40 Base Year (2008/2009) Geographical Distribution of Cargo Spill Risk for LNG and Gas Ships

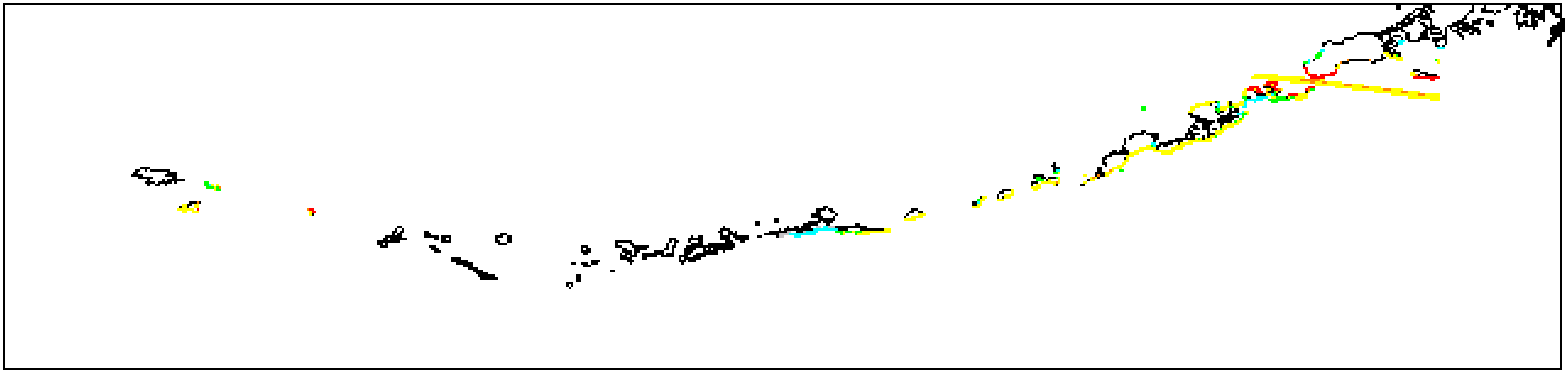

Figure 12-41 Base Year (2008/2009) Geographical Distribution of Cargo Spill Risk for Crude Oil Ships

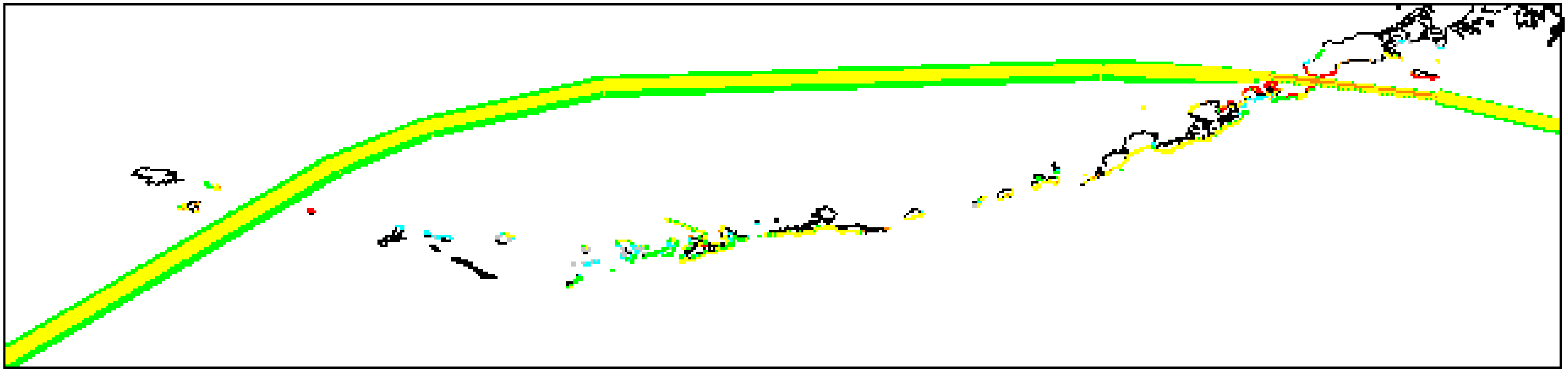

Figure 12-42 Base Year (2008/2009) Geographical Distribution of Cargo Spill Risk for Product Tanker Ships

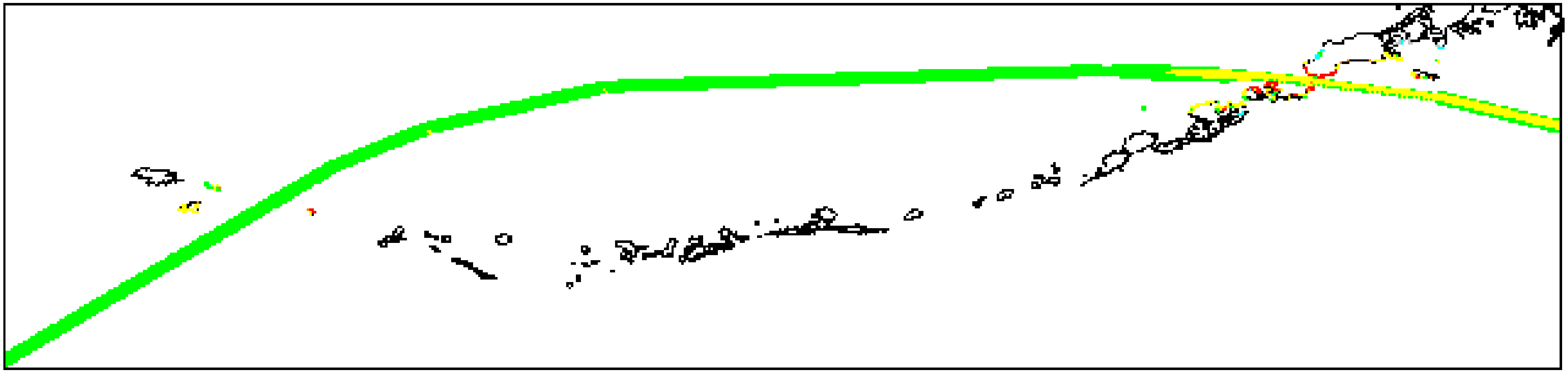

Figure 12-43 Base Year (2008/2009) Geographical Distribution of Cargo Spill Risk for Chemical Tanker Ships

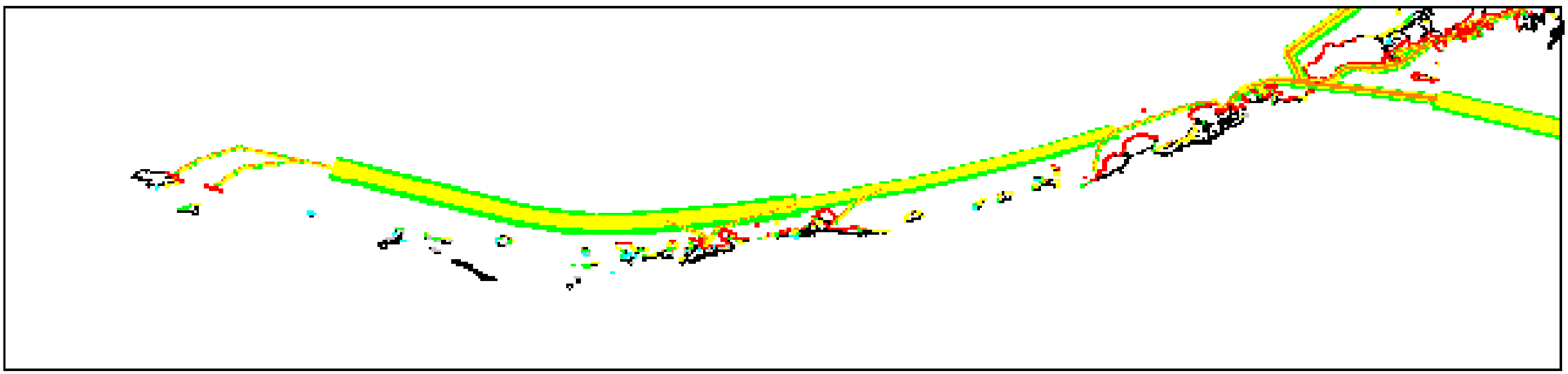

Figure 12-44 Base Year (2008/2009) Geographical Distribution of Cargo Spill Risk for Tank Barges

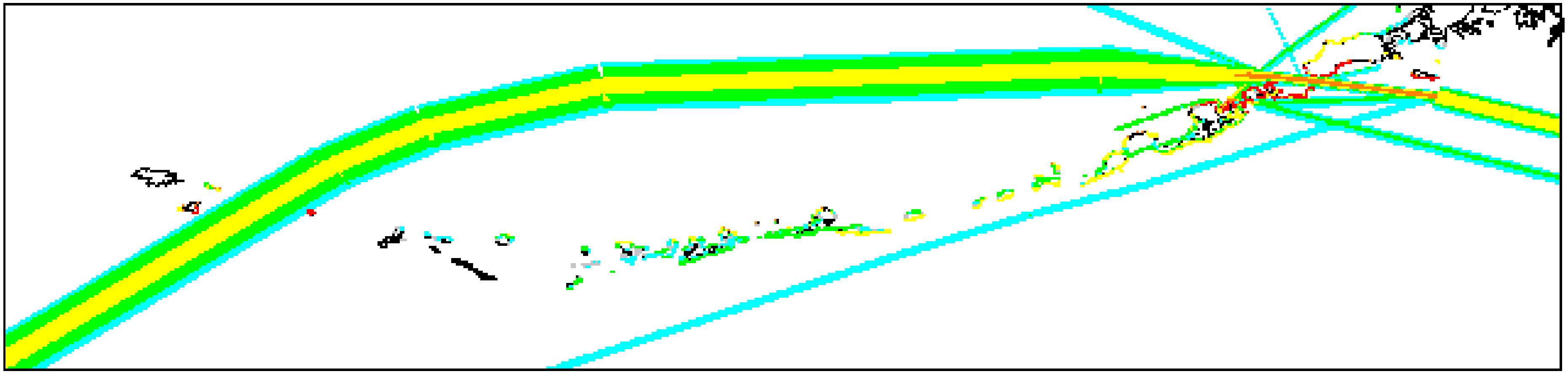

Figure 12-45 Future Year (2034) Geographical Distribution of Cargo Spill Risk for Small Container Ships

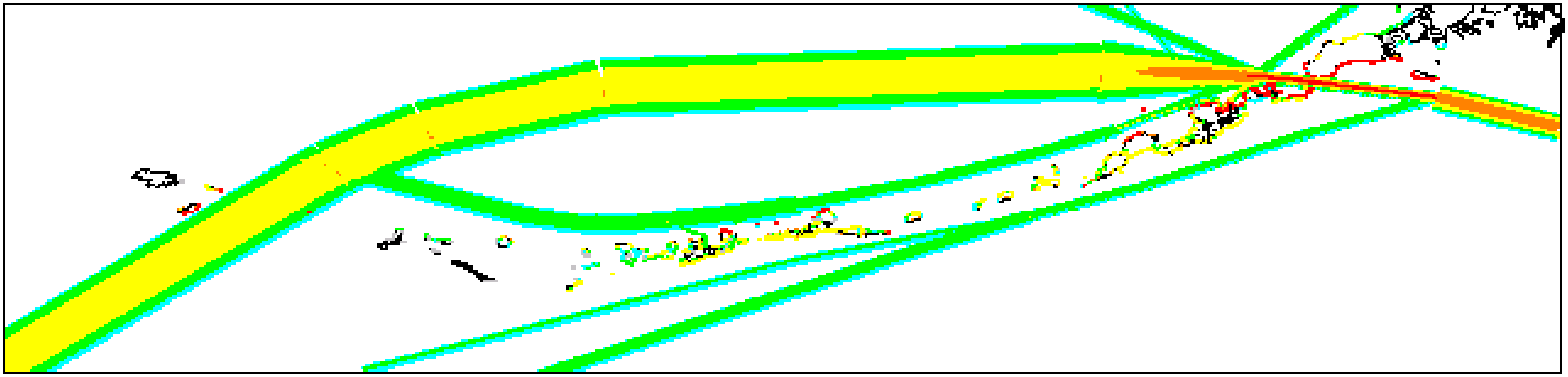

Figure 12-46 Future Year (2034) Geographical Distribution of Cargo Spill Risk for Large Container Ships

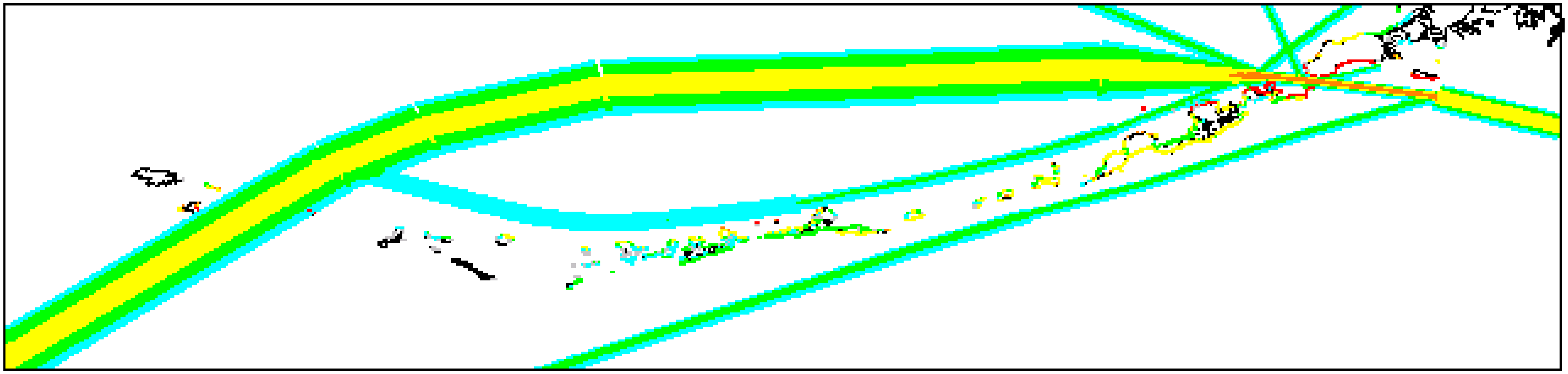

Figure 12-47 Future Year (2034) Geographical Distribution of Cargo Spill Risk for General Cargo Ships

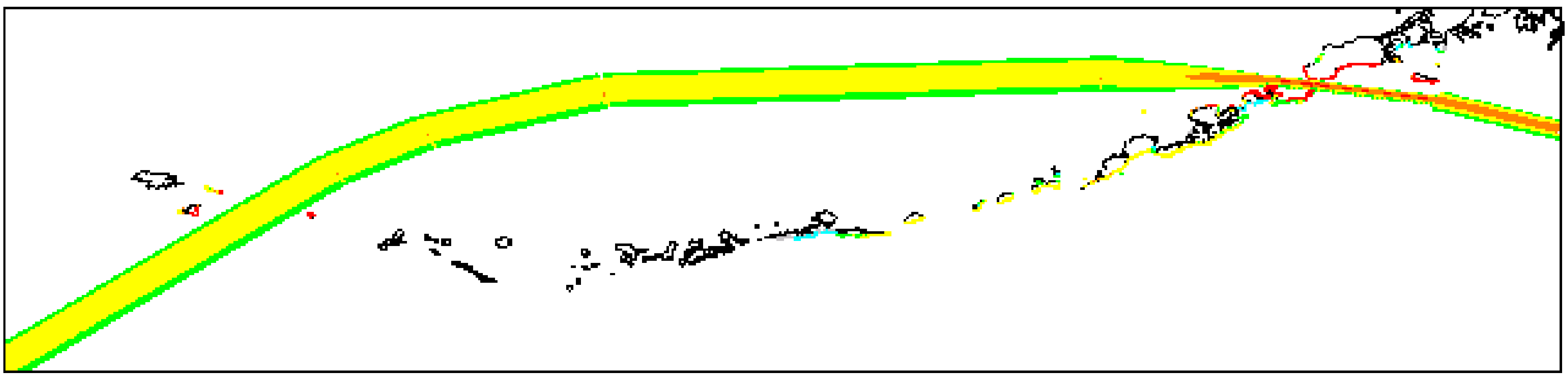

Figure 12-48 Future Year (2034) Geographical Distribution of Cargo Spill Risk for LNG and Gas Ships

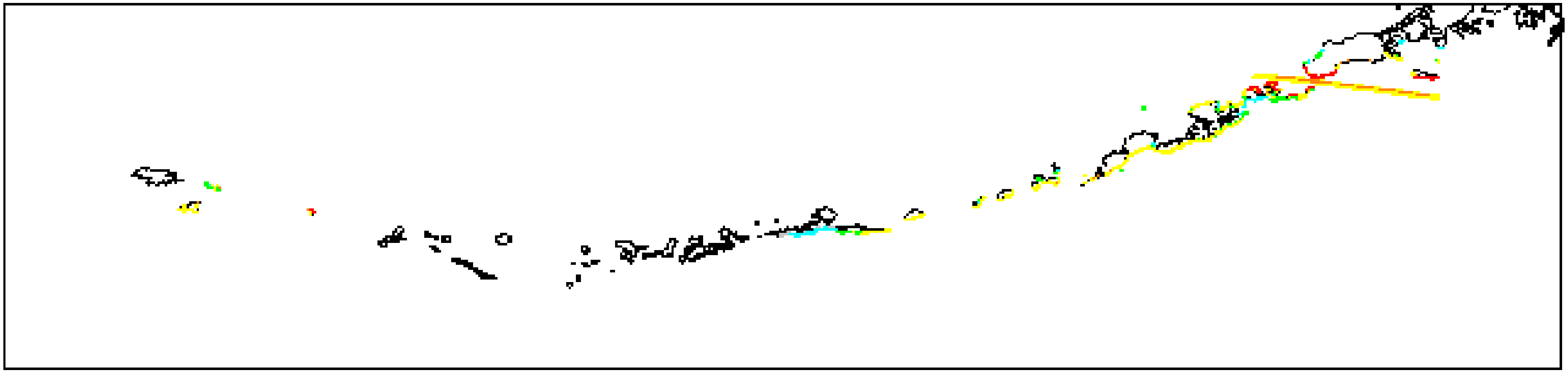

Figure 12-49 Future Year (2034) Geographical Distribution of Cargo Spill Risk for Crude Oil Ships

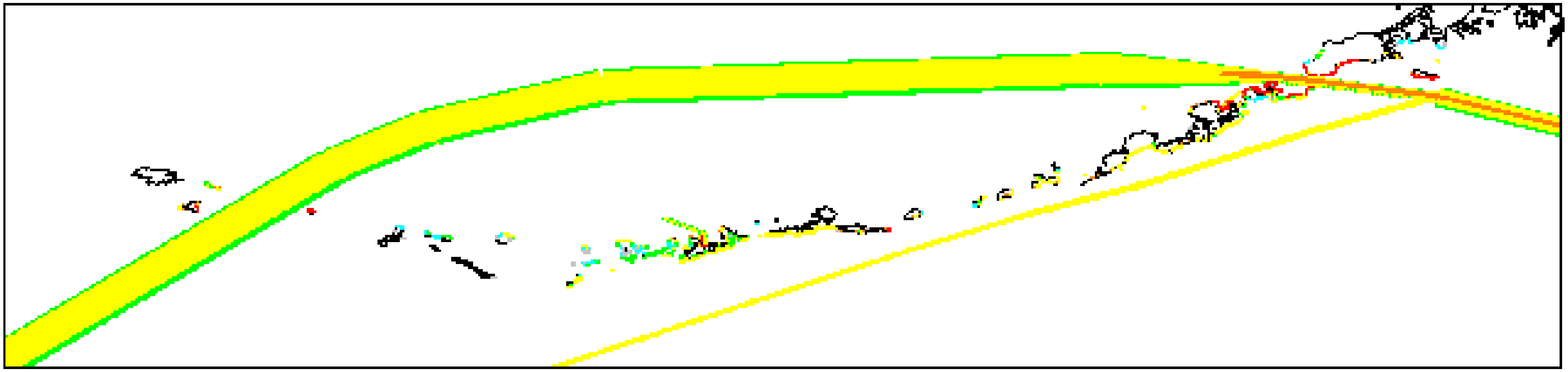

Figure 12-50 Future Year (2034) Geographical Distribution of Cargo Spill Risk for Product Tanker Ships

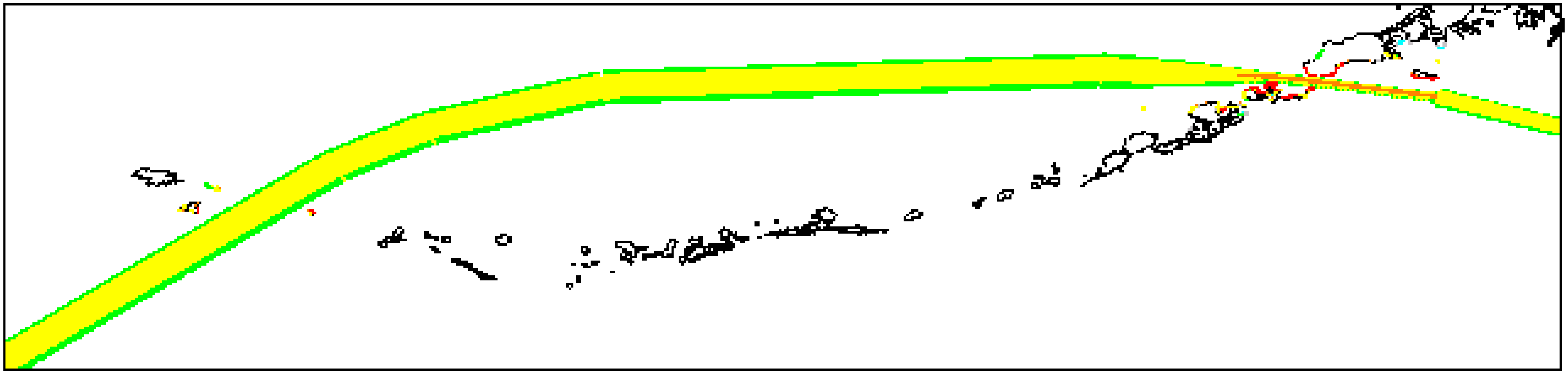

Figure 12-51 Future Year (2034) Geographical Distribution of Cargo Spill Risk for Chemical Tanker Ships

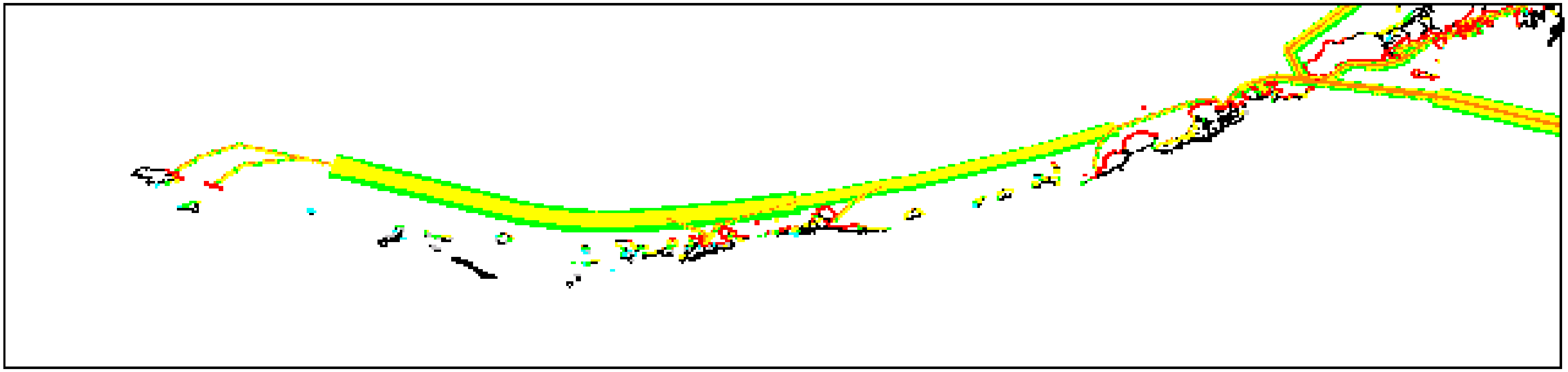

Figure 12-52 Future Year (2034) Geographical Distribution of Cargo Spill Risk for Tank Barges

ATTACHMENT 1

Marine Accident Risk Calculation System (MARCS) Model Methodology

Task 2A Marine Spill Frequency and Size Report
Attachment 1 – MARCS Model Methodology
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I. BACKGROUND

Transportation by sea using conventional shipping operations results in both economic benefits and associated ship accident risks, which can result in safety and environmental impacts. Analysis of historical ship accident data indicates that almost all open-water shipping losses (excepting causes such as war or piracy) can be categorized into the following generic accident types:

- Ship-ship collision;
- Powered grounding (groundings which occur when the ship has the ability to navigate safely yet goes aground, such as the *Exxon Valdez*);
- Drift grounding (groundings which occur when the ship is unable to navigate safely due to mechanical failure, such as the *Braer*);
- Structural failure/foundering whilst underway;
- Fire/explosion whilst underway;
- Powered ship collision with fixed marine structures such as platforms or wind turbines (similar definition to powered grounding); and
- Drifting ship collision with fixed marine structures such as platforms or wind turbines (similar definition to drift grounding).

These generic accident types effectively represent the results of a high level marine transportation hazard identification (HAZID) exercise and are applicable for most marine transportation systems. However, each marine risk analysis should consider if additional locally specific accident modes apply. For example, in Prince William Sound (Alaska), laden oil tankers are tethered to a tug for part of the transit to mitigate grounding accidents. However, the presence of the tug also introduces an extra accident mode (tanker grounds because tug actions are inappropriate). The presence, or absence, of such additional geographically specific accident modes should be verified on a project specific basis.

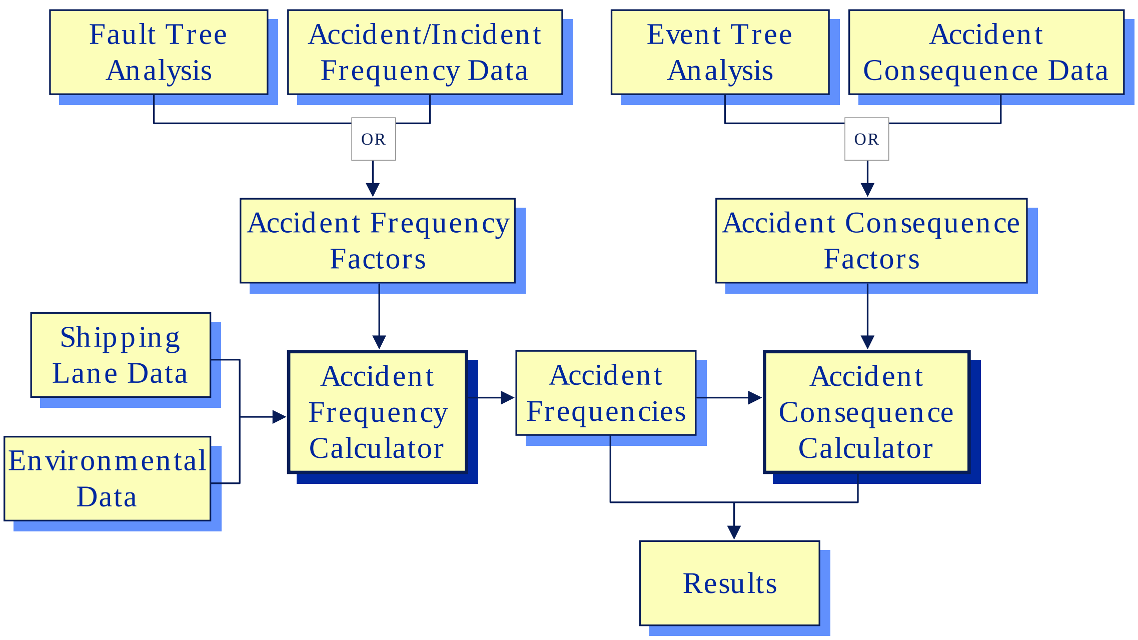
Marine transport risk analysis can be performed by assessing the frequency of the above accident types, followed by an assessment of the accident consequences, typically in terms of cargo spill, lives lost or in financial terms. DNV has developed the MARCS model to perform such marine transport risk analyses in a structured manner. The risk analysis results can then be assessed to determine if the estimated risks are acceptable or if risk mitigation is justified or required (risk assessment).

II. INTRODUCTION TO MARCS

II.1.1 Overview

The Marine Accident Risk Calculation System (MARCS) was developed by DNV to support our marine risk management services. The MARCS model provides a general framework for the performance of marine risk calculations. A block diagram of the model is shown in Figure II.1.

Figure II.1 Block Diagram of MARCS



The MARCS model classifies data into 4 main types:

- Shipping lane data describes the movements of different marine traffic types within the study area;
- Environmental data describes the conditions within the calculation area, including the location of geographical features (land, offshore structures, etc.) and meteorological data (visibility, wind rose, currents and sea state);
- Internal operational data describes operational procedures and equipment installed onboard ship – such data can affect both accident frequency and accident consequence factors;
- External operational data describes factors external to the ship that can affect ship safety, such as VTMS (Vessel Traffic Management Systems), TSS (Traffic Separation Schemes), and the location and performance of emergency tugs – such data can affect both accident frequency and accident consequence factors.

As indicated in Figure II.1, accident frequency and consequence factors can be derived in two ways. If a coarse assessment of accident risk is required, the factors may be taken from worldwide historical accident data. Alternatively, if a more detailed study is required, these factors may be derived from generic fault trees or event trees which have been modified to take account of specific local factors.

II.1.2 Critical Situations

MARCS calculates the accident risk in stages. It first calculates the location dependent frequency of critical situations (the number of situations which could result in an accident – "potential accidents" – at a location per year; a location is defined as a small part of the study area, typically about 1 nautical mile square, but dependent on the chosen calculation resolution). The definition of a critical situation varies with the accident mode, see Section II.4. MARCS then assesses the location dependent frequency of serious accidents for each accident mode via "probability of an accident given a critical situation" parameters. A "serious accident" is defined by Lloyds as any accident where repairs must be made before the ship can continue to trade. Finally, the location dependent accident consequence, and hence risk, is assessed.

Analysis of these results for a specified area or trade enables the derivation of conclusions and recommendations on topics such as risk acceptability, risk reduction measures and cost-benefit analysis of alternative options.

II.1.3 Fault Tree Analysis

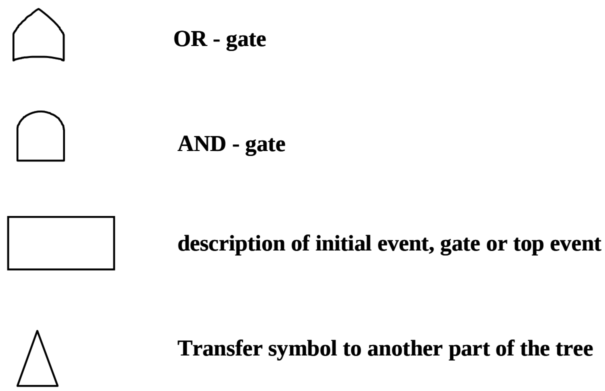
Fault tree analysis (see, for example, Henley E.J. and Kumamoto H., 1981 or Cooke R.M., 1995) can be described as an analytical technique, whereby an undesired state of a system is specified, and the system is then analyzed in the context of its environment and operation to find all credible ways in which the undesired event can occur. This undesired state is referred to as the top event of the fault tree. It expresses the frequency or probability for the occurrence of this event or incident.

The basic events of a fault tree are those events that make up the bottom line of the fault tree structure. To perform calculations of the top frequency or probability of a fault tree, these basic events needs to be quantified.

The fault tree structure is built up by basic events, and logical combinations of these events which are expressed by AND and OR gates. The outputs of these gates are new events, which again may be combined with other events / basic events in new gates. The logic finally results in the top event of the fault tree. For example, fire occurs if combustible material AND air/oxygen AND an ignition source are present.

The different symbols in the fault tree are defined in Figure II.2.

Figure II.2 Fault tree symbols

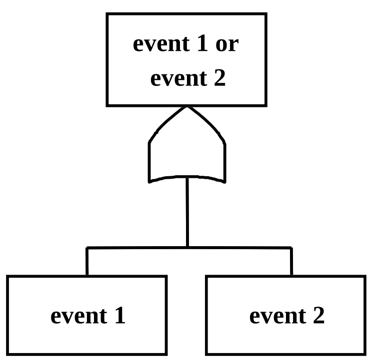


The OR gate, see Figure II.3, expresses the probability of occurrence of event 1 or event 2, and is calculated as the sum minus the intersection of the two events;

P(event 1 OR event 2) = P1 + P2 - P1*P2

Usually the intersection probability can be neglected, as it will be a very small number (if P1 = P2 = 10^{-2}, then P1*P2 = 10^{-4}).

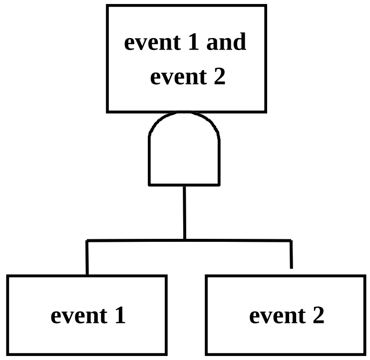
Figure II.3 OR - gate



The AND gate, see Figure II.4, expresses the probability that event 1 and event 2 occur simultaneously, and is calculated as the product of the two events;

P(event 1 AND event 2)= P1*P2

Figure II.4 AND - gate



It should be emphasized that the quality of the results produced by fault tree analysis is dependent on how realistically and comprehensively the fault tree model reflects the causes leading to the top event. Of course, it is never possible to fully represent reality, and therefore the models will always only represent a simplified picture of the situation of interest. The top event frequencies will generally be indicative, and hence relative trends are more secure than the absolute values.

Fault tree models have been constructed to assess a number of parameters within MARCS, including collision per encounter probabilities (collision model) and failure to avoid a powered grounding given a critical situation probabilities (powered grounding model) (SAFECO I; SAFECO II).

II.2 Data used by MARCS

II.2.1 Traffic Image Data

The marine traffic image data used by MARCS is a representation of the actual flows of traffic within the calculation area. Marine traffic data is represented using lane data structures. Different traffic types are divided into separate marine databases in order to facilitate data verification and the computation of different types of risk (for example, crude oil spill risk versus human safety).

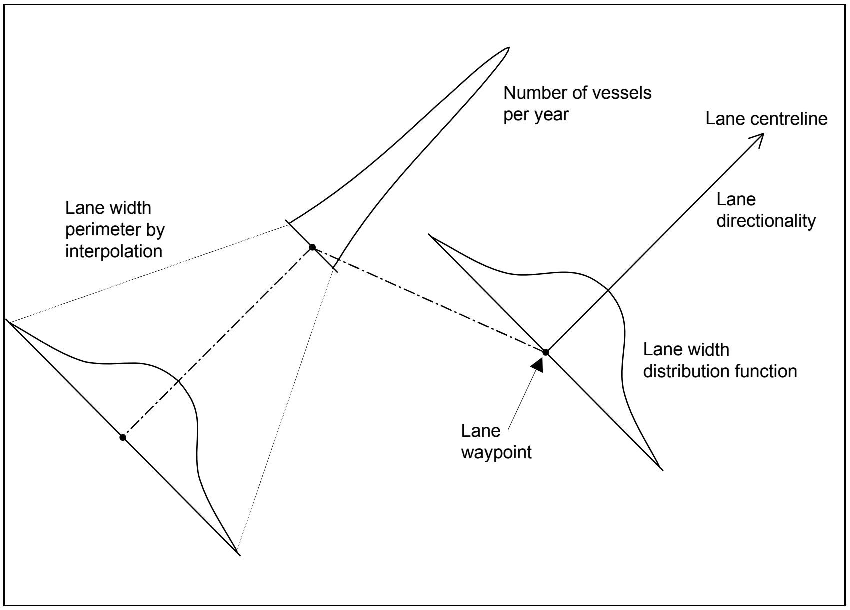
A typical traffic lane is shown in Figure II.5. The following data items are defined for all lanes:

1. The lane number (a unique identifier used as a label for the lane);
2. The lane width distribution function (Gaussian or truncated Gaussian);
3. The lane directionality (one-way or two-way);
4. The annual frequency of ship movements along the lane;
5. A list of waypoints, and an associated lane width parameter at each waypoint; and

6. The vessel size distribution on the lane.

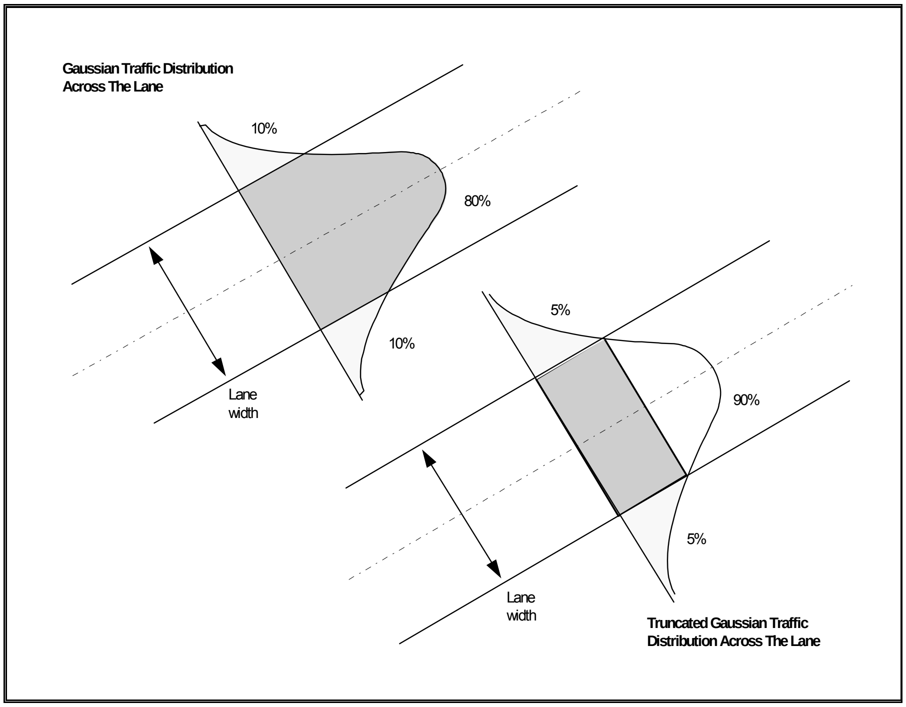
Additional data may be attached to the lane, such as: the hull type distribution (single hull, double hull, etc) for tankers; the loading type (full loading, hydrostatic loading) for tankers; ship type, etc.

Figure II.5 Shipping Lane representation used in MARCS



Detailed surveys of marine traffic in UK waters in the mid 1980s (e.g. HMSO, 1985) concluded that commercial shipping follows fairly well defined shipping lanes, as opposed to mainly random tracks of individual ships. Further detailed analysis of the lanes showed that the lateral distribution across the lane width was approximately Gaussian, or truncated Gaussian for traffic arriving in coastal waters from long haul voyages (e.g. from the US or Canada). The shipping lane distributions used in MARCS are shown in Figure II.6.

Figure II.6 Shipping Lane Width Distribution Functions used in MARCS



The marine traffic description used by MARCS is completed by the definition of four additional parameters for each type of traffic, as follows:

1. Average vessel speed (generally 8 to 18 knots);
2. Speed fraction applied to faster and slower than average vessels (generally plus/minus 20%);
3. Fraction of vessels travelling faster and slower than the average speed (generally plus/minus 20%); and
4. Fraction of vessels that exhibit "rogue" behavior (generally set to 0%, though historical accident data in many geographical areas shows a small proportion of (usually) smaller vessels undergo accidents through lack of watch keeping (bridge personnel absent or incapacitated)).

A rogue vessel is defined as one that fails to adhere (fully or partially) to the Collision Avoidance Rules (Cockcroft, 1982). Such vessels are assumed to represent an enhanced collision hazard. These four parameters can be specified as a function of location within the study area for each traffic type.

The marine traffic image is made up by the superposition of the defined traffic for each contributing traffic type.

II.2.2 Internal Operational Data

Internal operational data is represented within MARCS using either worldwide data or frequency factors obtained from fault tree analysis or location specific survey data. Fault tree parameters take into consideration factors such as crew watch-keeping competence and internal vigilance (where a second crew member, or a monitoring device, checks that the navigating officer is not incapacitated by, for example, a heart attack). Examples of internal operational data include:

1. The probability of a collision given an encounter;
2. The probability of a powered grounding given a ship's course is close to the shoreline; and
3. The frequency (per hour at risk) of fires or explosions.

Internal operational data may be defined for different traffic types and/or the same traffic type on a location specific basis.

II.2.3 External Operational Data

External operational data generally represents controls external to the traffic image, which affect marine risk. In MARCS it relates mainly to the location of VTS zones (which influence the collision and powered grounding frequencies by external vigilance, where external vigilance means that an observer external to the ship may alert the ship to prevent an accident) and the presence and performance of emergency towing vessels (tugs) which can save a ship from drift grounding.

II.2.4 Environment Data

The environment data describes the location of geographical features (land, offshore structures, etc.) and meteorological data (visibility, wind rose, sea currents and sea state).

Poor visibility arises when fog, snow, rain or other phenomena restrict visibility to less than 2 nautical miles. It should be noted that night-time is categorized as good visibility unless fog, for example, is present.

Wind rose data is defined within 8 compass points (north, north-east, east etc) in 4 wind speed categories denoted: calm (0 to 20 knots, Beaufort 0 to 4); fresh (20 to 30 knots, Beaufort 5 to 6); gale (30 to 45 knots, Beaufort 7 to 9); and storm (greater than 45 knots, Beaufort 10 to 12). Sea state (wave height) within MARCS is inferred from the wind speed and the nature of the sea area (classified as sheltered, semi-sheltered or open water).

Sea currents are represented as maximum speeds in a defined direction within an area.

II.3 Description of Accident Frequency Models

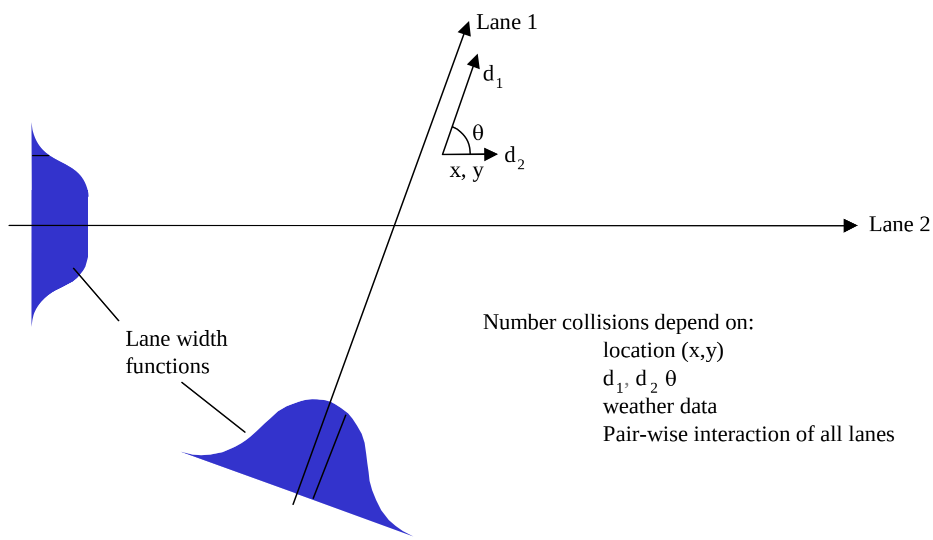
The section describes how MARCS uses the input data (traffic image, internal operational data, external operational data and environment data) to calculate the frequency of serious accidents in the study area.

II.3.1 The Collision Model

The collision model calculates the frequency of serious inter-ship powered collisions at a given geographical location in two stages. The model first estimates the frequency of encounters (critical situations for collision - when two vessels pass within 0.5 nautical miles of each other) from the traffic image data using a pair-wise summation technique, assuming no collision avoiding actions are taken. This enables the calculation of either total encounter frequencies, or encounter frequencies involving specific vessel types.

The model then applies a probability of a collision for each encounter, obtained from fault tree analysis, to give the collision frequency. The collision probability value depends on a number of factors including, for example, the visibility or the presence of a pilot. Figure II.7 shows a graphical representation of the way in which the collision model operates.

Figure II.7 Graphical representation of the collision model



Frequency = (Frequency of encounters) x (probability of collision given an encounter)

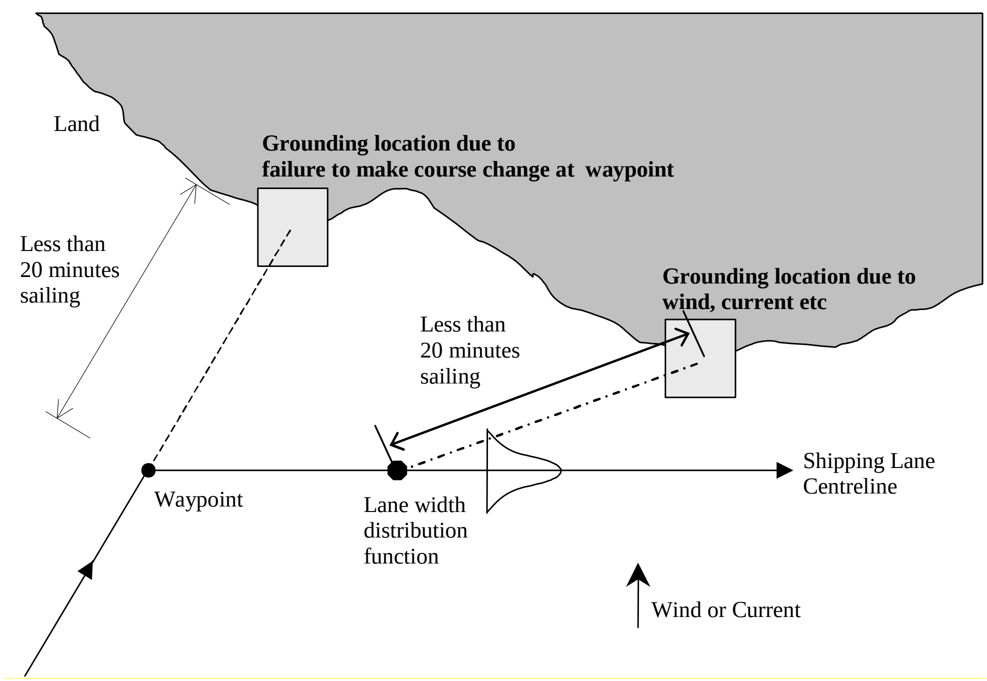
In Figure II.7, d_1 refers to the density of traffic associated with lane 1 at the location x,y. The frequency of encounters at location x,y through the interaction of lanes 1 and 2 is proportional to the product of d_1, d_2 and the relative velocity between the lane densities.

II.3.2 The Powered Grounding Model

The powered grounding frequency model calculates the frequency of serious powered grounding accidents in two stages. The model first calculates the frequency of critical situations (sometimes called "dangerous courses" for powered grounding accidents). Two types of critical situation are defined as illustrated in Figure II.8. The first critical situation arises when a course change point (waypoint) is located such that failure to make the course change would result in grounding within 20 minutes navigation from the planned course change point if the course change is not made successfully. The second critical situation results when a grounding location is within 20 minutes navigation of the course centerline. In this case crew inattention combined with wind, current or other factors could result in a powered grounding.

The frequency of serious powered groundings is calculated as the frequency of critical situations multiplied by the probability of failure to avoid grounding.

Figure II.8 Graphical representation of the powered grounding model



The powered grounding probabilities are derived from the fault tree analysis of powered grounding. The powered grounding fault tree contains 2 main branches:

1. Powered grounding through failure to make a course change whilst on a dangerous course. A dangerous course is defined as one that would ground the vessel within 20 minutes if the course change were not made.
2. Powered grounding caused by crew inattention and wind or current from the side when the ship lane runs parallel to a shore within 20 minutes sailing.

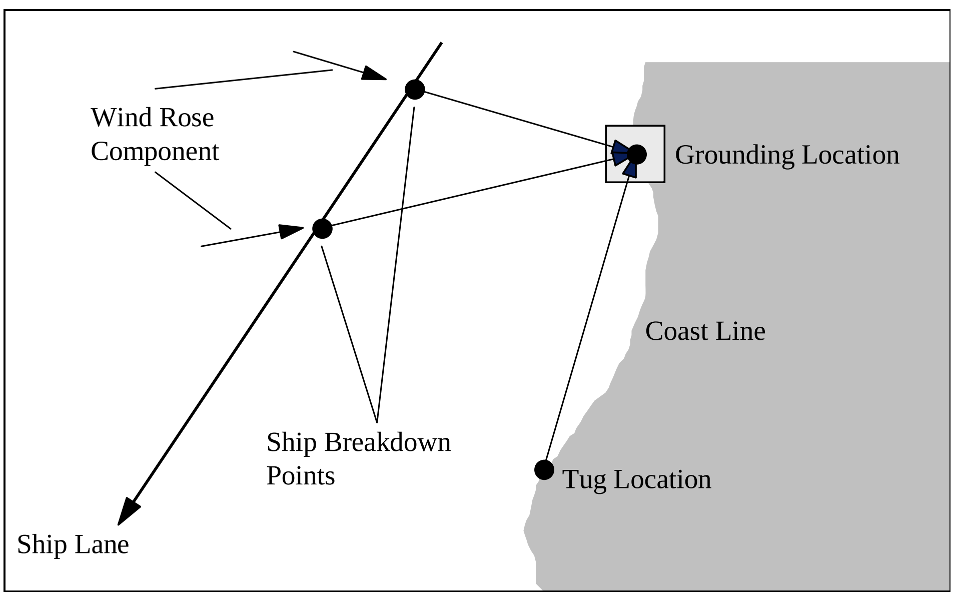
Both these branches are illustrated in Figure II.8. The powered grounding frequency model takes account of internal and external vigilance, visibility and the presence of navigational aids (radar) in deducing failure parameters.

II.3.3 The Drift Grounding Model

The drift grounding frequency model consists of two main elements as follows: first, the ship traffic image is combined with the ship breakdown frequency factor to generate the location and frequency of vessel breakdowns; second, the recovery of control of drifting ships can be regained by one of 3 mechanisms: a) repair, b) emergency tow assistance, or c) anchoring. Those drifting ships that are not saved by one of these three mechanisms (and do not drift out into the open sea) contribute to the serious drift grounding accident frequency results.

The number and size distribution of ships which start to drift is determined from the ship breakdown frequency, the annual number of transits along the lane and the size distribution of vessels using the lane. The proportion of drifting vessels which are saved (fail to ground) is determined from the vessel recovery models. The drift grounding frequency model is illustrated in Figure II.9.

Figure II.9 Graphical representation of the drift grounding model

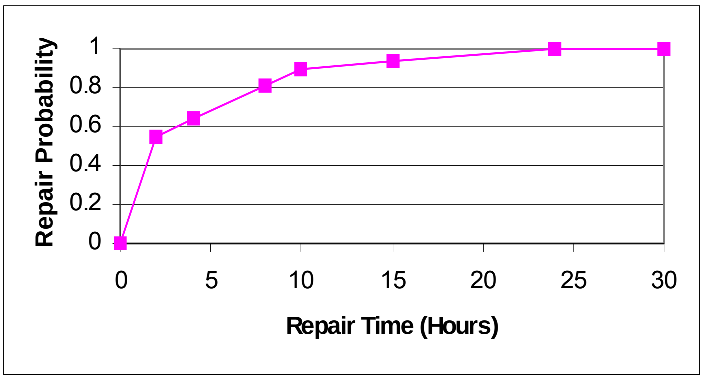


Implicit in Figure II.9 is the importance of the time taken for the ship to drift aground. When this time is large (because the distance to the shore is large and/or because the drift velocity is small due to low wind speed) then the probability that the ship will recover control before grounding (via repair or tug assistance) will be increased.

Repair Recovery Model

Vessels which start to drift may recover control by effecting repairs. For a given vessel breakdown location, grounding location and drift speed there is a characteristic drift time to the grounding point. The proportion of drifting vessels which have recovered control by self-repair is determined from this characteristic drift time and the distribution of repair times. Drift time in this case will be equivalent to repair time. Figure II.10 presents the graphical representation of repair probability versus repair time.

Figure II.10 Graphical representation of the self repair save mechanism



Recovery of Control by Emergency Tow

Drifting vessels may be brought under control (saved from grounding) by being taken in tow by an appropriate tug. It should be noted that the tug save model assumes a save is made when the ship is prevented from drifting further towards the shoreline by the attachment of a suitable tug. In practice, two or more tugs would be required to complete the ship save, by towing the vessel to a safe location, but this aspect of the save is not modelled in MARCS.

Two types of tug can be represented within MARCS. Close escort tugs move with ships through their transit, thus their time to reach a drifting ship is always small. Pre-positioned tugs are located at strategic points around the study area. The model works by calculating for each tug, the following scenarios:

- If the tug can reach the drifting vessel in time to prevent it grounding. This time consists of the time to reach the ship (almost zero when close escorting) and the time to connect and take control of the ship (which is a function of sea state).
- If the tug can reach the ship before it grounds, then the adequacy of the tug with regard to control of the ship is evaluated. (The presence of several tugs of differing power is assumed to be represented by the presence of one tug of the largest power. This is because only one tug is usually used to exert the main “saving” pull. Other tugs present are used to control the heading of the disabled ship, and to bring the ship to a safe location.).

- When several tugs of various capabilities can reach the drifting ship in time, then the tug with the best performance is assumed to be connected to the ship and takes control of the largest proportion of the drifting vessels.

The tug model contains parameters to take explicit account of:

- The availability of the tug (some tugs have other duties);
- The tugs response time (delay before assistance is summoned);
- The tug speed (as a function of sea state);
- The time to connect a line and exert a controlling influence on the ship (as a function of sea state); and
- The performance of the tug (identified as the maximum control tonnage for the tug) as a function of wind speed and location (since the wind speed and the fetch control sea state).

Tug performance parameters can take account of ship wind and wave resistance, tug wind and wave resistance, and tug length and propulsion arrangement (open versus nozzle); which influences the propulsion efficiency.

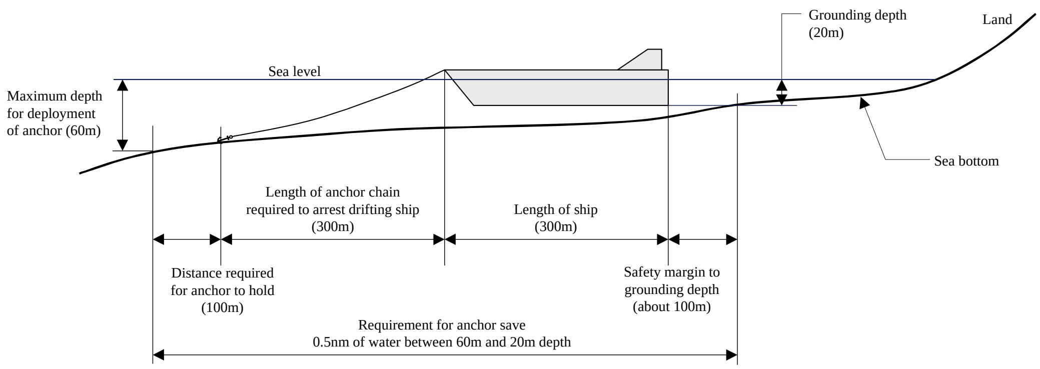
Recovery of Control by Anchoring

The anchor save model is derived with reference to the following reasoning:

1. Anchoring is only possible if there is a sufficient length of suitable water to prevent the ship running aground. Suitable water is defined as a depth of between 30 fathoms (about 60m - maximum for deployment of anchor) and 10 fathoms (about 20m - minimum for ship to avoid grounding). Sufficient length is calculated as 100m for anchor to take firm hold of the seabed + 300m to stop ship + 300m for length of ship + 100m for clearance = 800m, or 0.5 nautical miles (to be slightly conservative).
2. If such a track exists, then the probability that the anchor holds is calculated as a function of the wind speed and the sea bottom type (soft sea beds consist predominantly of sands, silts and muds). If the anchor holds, then an anchor save is made.

The assumptions and corresponding relationships of the anchor save mechanism are depicted in Figure II.11.

Figure II.11 Graphical representation of the Anchor save mechanism



The anchor save model is conservative in that it under-predicts the effectiveness of this save mechanism for average and smaller ships.

II.3.4 The Structural Failure Model

The structural failure/foundering accident frequency model applies accident frequency parameters derived from accident data or fault tree analysis with calculations of the ship exposure time to obtain the serious accident frequency. The structural failure/foundering parameters take account of the greater structural strength of some hull designs, such as double hulled vessels.

The total ship exposure time (number of vessel hours) in any area for a given wind speed category (used by MARCS to infer the sea state) can be calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds) and the local wind speed parameters. The serious structural failure/foundering frequency is then obtained by multiplying these vessel exposure times by the appropriate structural failure frequency factor for the wind speed (sea state) category.

II.3.5 The Fire and Explosion Model

The fire/explosion accident frequency model applies the accident frequency parameters derived from accident data or fault tree analysis with calculations of the ship exposure time to obtain the serious accident frequency. The total ship exposure time (number of vessel hours) in any area can be calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds). The fire/explosion serious accident frequency is then obtained by multiplying these vessel exposure times by the appropriate fire/explosion frequency factor (accidents per ship-hour). It should be noted that fire/explosion frequency factors are assumed to be independent of environmental conditions outside the ship.

II.4 Description of Accident Consequence Models

II.4.1 Introduction

MARCS evaluates the consequences of an accident in terms of, for example, the loss of containment of any fluid stored within a ship. This loss of containment can be in the form of either a bunker (fuel) oil spillage, a loss of liquid cargo stored in atmospheric tanks (tanks at the same pressure as the atmosphere), or a loss of gas cargo from pressurised or refrigerated tanks. It should be noted that MARCS does not calculate any consequences based upon the dispersion of fluid that might result from a loss of containment, though DNV are able to assess such consequences using other DNV tools.

Marine accident consequences are typically expressed in terms of cargo spilled, lives lost or financial loss. They are used with the frequency of a marine accident to estimate the resulting marine accident risk(s).

II.4.2 Factors affecting Cargo Loss Risk

There are various factors or events that can affect the risk of loss of containment following an accident ranging from those that relate to accident frequencies to those that relate to accident locations. Listed below are the factors which may be referenced by MARCS, depending on the situation, when evaluating the consequence(s) of a particular scenario.

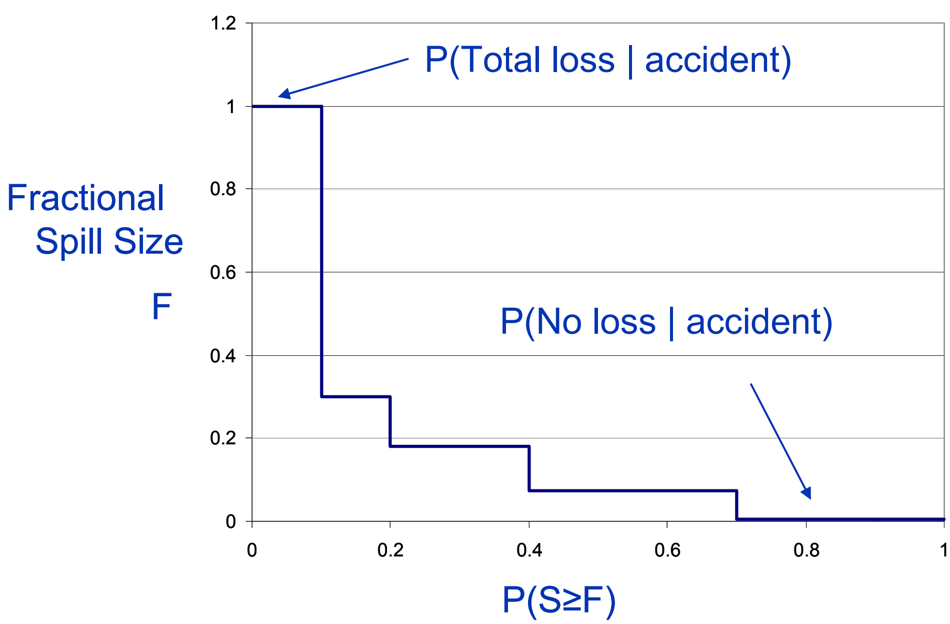
- Frequency of serious accidents. This is taken from the accident frequency models based upon historical accident data, as described in Section IV.4 above, and is one of the main factors that affect risk.
- The probability of loss of containment given a serious accident. This could be a function of the following:
    - Ship Type. A laden crude tanker has both cargo and bunker oil that could spill compared with, for example, a container ship that has only bunker oil;
    - Ship Structure. Ships may be single or double hulled, or a variation of either;
    - Probability of grounding on rocks. Grounding on rocks will increase the likelihood of a loss of containment;
    - Severity of accident. For example, an increase in the momentum of a colliding ship will increase the severity of an accident because of the resulting increase in energy that needs to be dissipated; and
    - Location of accident. For example, high wave energy shore lines lead to an increased risk of ship damage and hence increased risk of loss of containment or, if the loss of containment has already occurred, then an increased risk in total loss of the ship.
- Probability of outflow of a specific quantity given a serious accident. This is the probability that there is a spillage of certain mass following a serious accident.
- Probability of the total loss of a ship given a serious accident. This assumes a total loss of cargo, though in practice some cargo may be recovered without spillage.

II.4.3 Generic Spill Model

The spill models developed for use by MARCS are based upon one or more of three main sources of information. These are historical accident analysis, engineering calculations, and judgements based upon other sources of data. Historical accident analysis, where available, can provide information on the number of accidents per ship category and the size of spillage in each case. This is usually the most robust source of data and is often complemented by further calculations to obtain spill models. In certain cases it is necessary to make judgements where relevant data is lacking; this can be the least robust method available.

Previous projects performed by DNV have developed crude oil outflow models for different accident types (collision, fire/explosion etc) and different hull configurations (single hull, double hull etc). These models (normalized cumulative probability distributions) take the generic form shown in Figure II.12. This shows a typical spill model as used by MARCS. The fractional spill size, on the y-axis, is defined as the size of the spillage divided by the total cargo capacity of the ship in DWT and the value on the x-axis is the probability that an actual spill (as a fraction of the total capacity) is greater than a certain defined fractional spill size.

Figure II.12 Generic MARCS Spill Model



DNV has also developed bunker fuel oil spill models for all ship types, using a similar form to that shown in Figure II.12. It should be noted that, in general, double hulled ships do not have "double skin" protection for their bunker fuel.

II.4.4 MARCS Spill Model Parameters

There are various parameters that MARCS utilizes to reference a particular spill model in order to correctly estimate the marine accident risks. These are listed below along with examples:

- Accident Type. For example, collision, powered grounding, etc.
- Vessel Type and Size. For example, oil tanker with a cargo capacity of 100,000 DWT.
- Accident Severity. For example, collision energy.
- Accident Location. For example, high wave energy shoreline.
- Hull Type. For example, single hull, double hull, double bottom, double side.
- Loading Type. For example, fully laden, empty (contains bunker oil only).
- Probability of vessel being laden for each cargo type. For example, a vessel might be laden 50% of the time and empty the other 50% of the time resulting in the vessel having a 0.5 probability of being laden.

These parameters are used by MARCS to calculate the risks from marine traffic accidents.

II.4.5 Behaviour of MARCS Accident and Spill Models

This section summarises how the MARCS results are likely to vary with plausible changes to input assumptions. Almost all the comments provided below can be derived from reading the annex on the MARCS model.

<u>Variation of Accident Frequencies</u>

All the accident frequency models vary linearly with traffic frequency except for the ship-ship collision model, which increases with the product of the pair wise traffic frequency.

The powered grounding and collision models give increased accident frequency with increased probability of poor visibility.

The drift grounding and the structural failure model give increased accident frequency with increased probability of higher wind speed states (since sea state is assumed to correlate with wind speed).

<u>Variation of Accident Consequences</u>

There are two types of accident consequence model used: cargo spill models and bunker fuel oil models.

All spill models do not currently represent correlation effects, though MARCS is capable of representing such effects if the data is available to derive secure parameters. That is, the severity of the accident that could be determined from the accident frequency calculator does not affect the magnitude of the accident consequence calculated from the spill model. Instead, MARCS calculates the frequency of serious accidents and then applies a probabilistic spill model per serious accident. The spill model defines the probability of different outflows, including no outflow and all cargo lost from containment.

The cargo spill models for double hulled tankers generally define a significant probability of no spill given a serious accident. Then they usually consider 2 additional damage events and a total loss event. The 2 damage events consider damage to 1 tank and to 2 tanks. Different outflows arise for different types of accident (e.g. grounding outflows are different from collision outflows because the damage generally occurs at different heights relative to the keel and the waterline). The average cargo spill risk is generally dominated by the total loss events which occur for fewer than 90% of all accidents.

The bunker spill models result in no spill for 90% or more of all accidents. This is because of the location of bunker spill tanks on the ship. A total of 4 events are considered: no spill, spill from 1 bunker tank, spill from 2 bunker tanks and total loss. The data for bunker spills is not sufficient to support different consequence models for different accident types.

II.4.6 MARCS Correlation Effects

Like any model, MARCS has strengths and weaknesses in how well it represents reality. The great strength of MARCS is that it is a relatively simple model with relatively simple data requirements that is capable of representing a large area and large quantities of shipping in a single calculation.

This strength is achieved in part by a number of simplifications that some might argue do not fully represent reality. A few of the more significant effects are noted below:

- As noted previously, there is not an assessment or a correlation between the severity of an accident in the frequency model and the magnitude of the outflow in the consequence model.

- Wind speed and sea state are assumed to be perfectly correlated. Thus the sea state is always fully developed for the defined wind state.

- Weather routing dependencies are not easily included in MARCS, though they are partly included within the input traffic dataset.

Despite these simplifications, MARCS is fully capable of providing semi-quantitative risk results for this project.

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