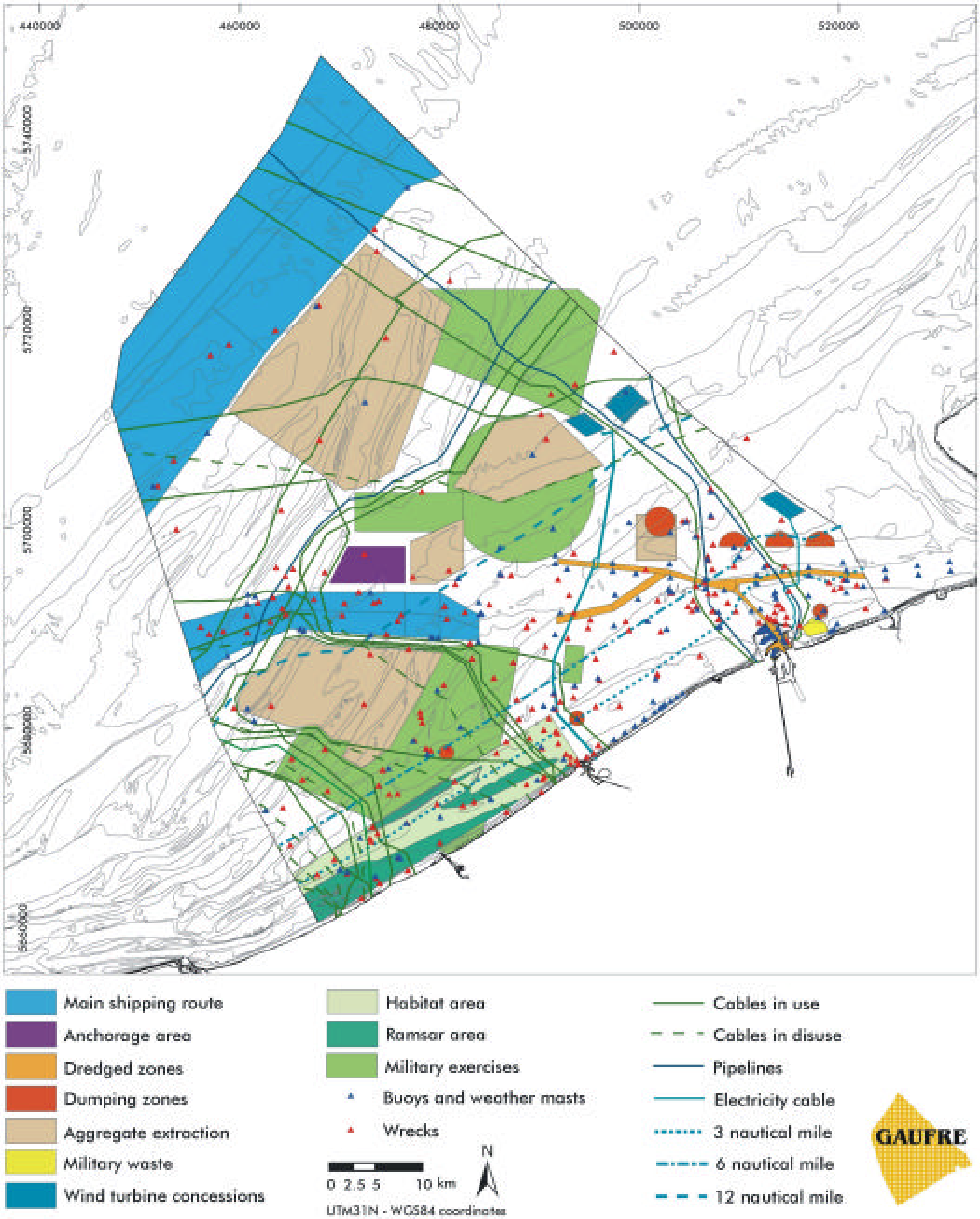
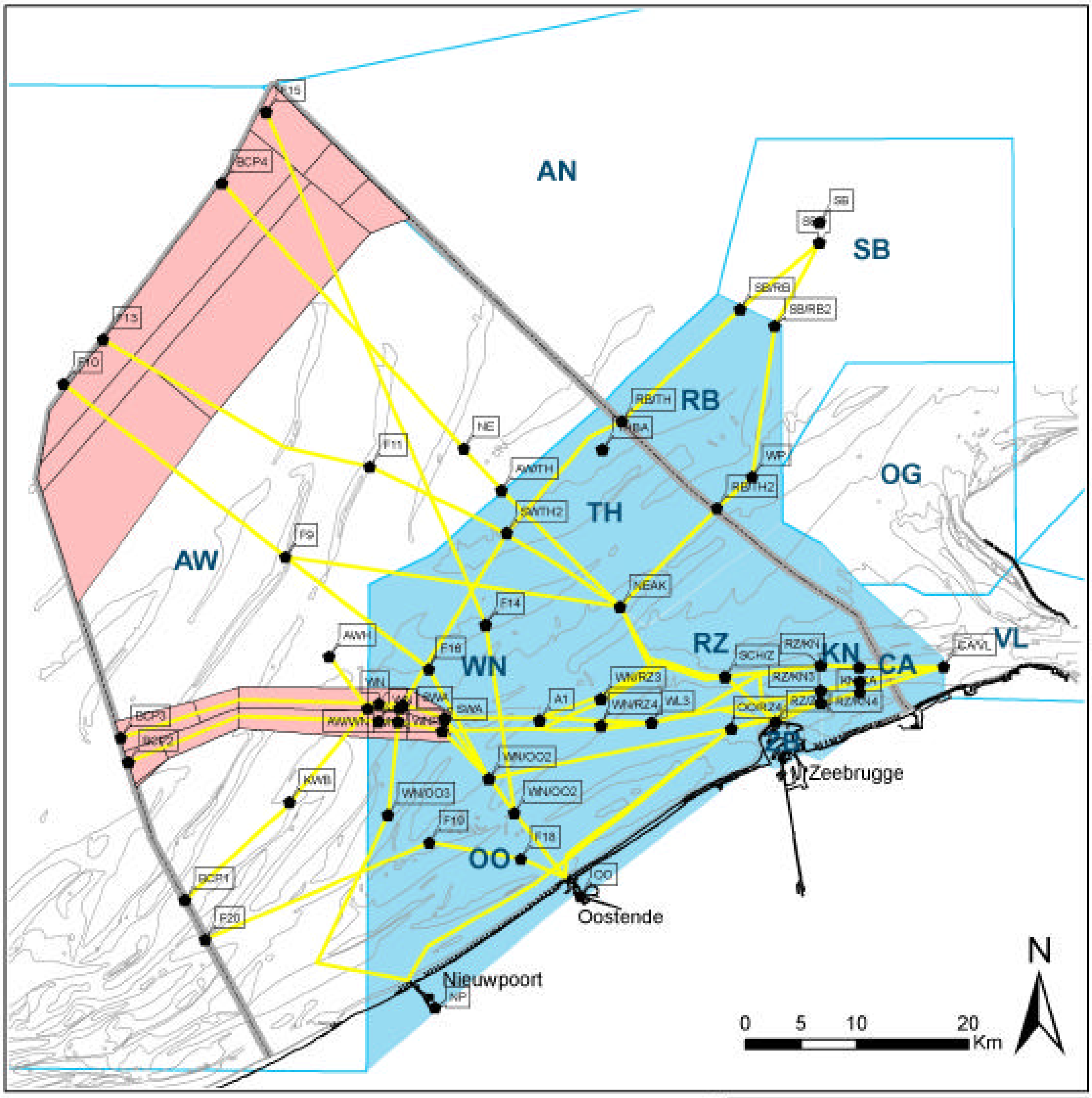
Annex 2.1: Users of the Belgian Part of the North Sea (Maes *et al*, 2005)



Original data source: cfr. all spatial distribution maps
Map preparation: RCMG - Ghent University

May 2005

Annex 2.2: The identified route segments on the Belgian Part of the North Sea



Risk Analysis of Human Activities at the Belgian Part of the North Sea (RAMA)
Financed by the Federal Science Policy Office

Data source shipping data: IVS-SRK database (AWZ, B&RWS, NL),
Ferryways, Transeurope ferries
Dat period: 01/04/2003 - 31/03/2004

ECOLAS

Legend

Route segment

IMO-scheme

IVS-block

<all other values>

Og.shp

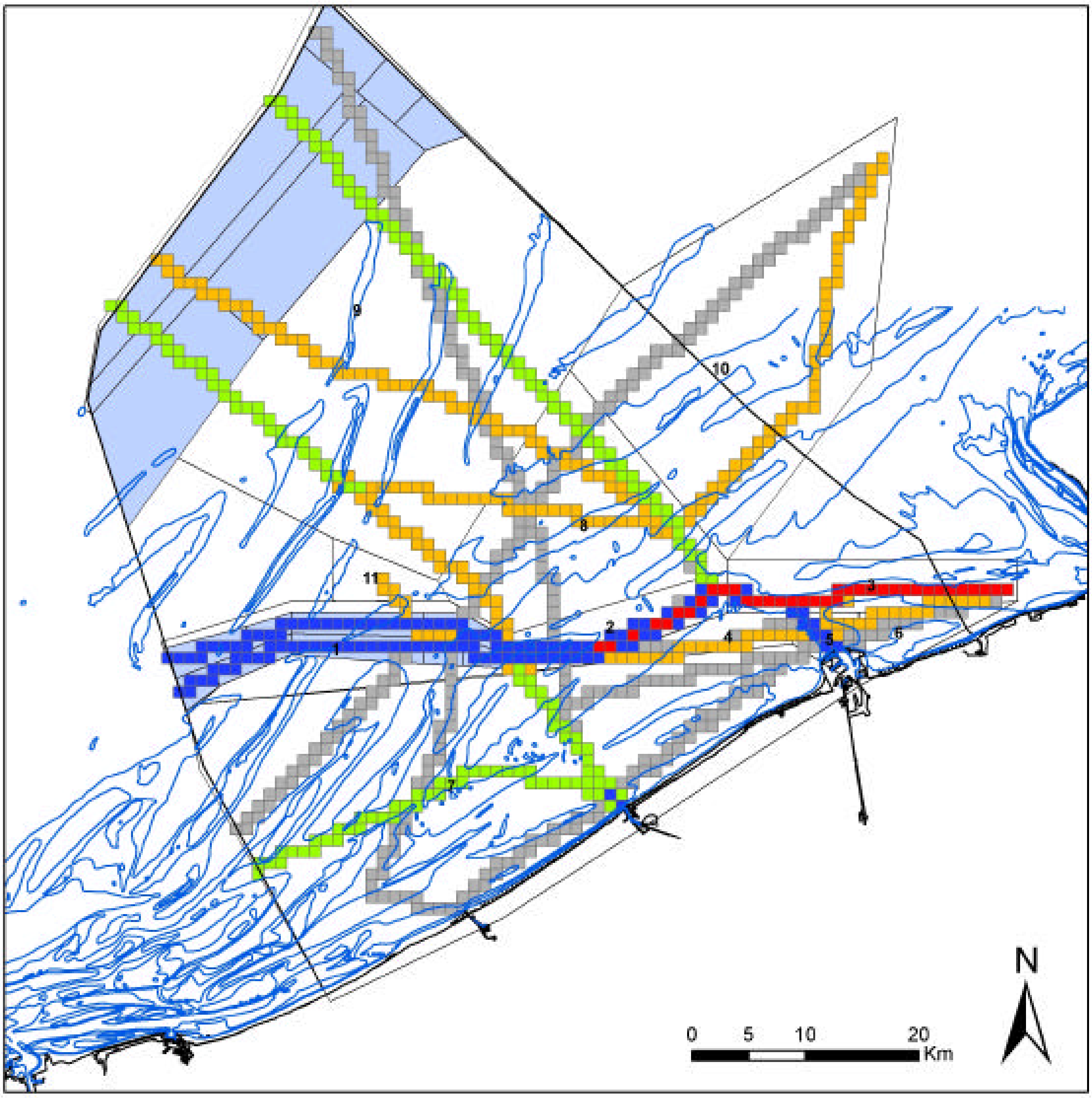
Vl.shp

Sb.shp

Aw.shp

An.shp

Annex 2.3: Geographical distribution of the ship movements (per km²) on the BPNS



Risk Analysis of Human Activities at the Belgian Part of the North Sea (RAMA)
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Data source shipping data: IVS-SRK database (AWZ, B & RWS, Nl), Ferryways, Transeuropa ferries
Data period: 01/04/2003 - 31/03/2004

Legend

Shipmovements (#/km²)

- 1 - 950
- 951 - 3110
- 3111 - 8393
- 8394 - 23880
- 23881 - 56977
- Subareas

Annex 2.4: Quantitative analysis of the different cargo types per ship type

Ship type 1: oil (crude) tankers					
Cargo class	Avg quantity/ CTSMRS (ton)	Stdev quantity/ CTSMRS (ton)	# CTSMRS quantity data	total # CTSMRS	% known data
1	561,17	940,02	62	76	81,58%
2	39.353,98	40.076,44	1.118	1.191	93,87%
3	865,18	1.736,07	455	474	95,99%
4	9.139,93	29.444,70	12.327	12.735	96,80%
5	9.645,82	16.848,06	2.185	2.245	97,33%
6	14.238,46	128.368,10	859	909	94,50%
7	2.472,17	9.919,32	8.227	9.308	88,39%
8	4.184,98	8.967,77	943	4.366	21,60%
9	0,86	0,35	70	500	14,00%
10	3.518,55	6.247,20	185	5.580	3,32%
Ship type 2: Chemical tankers + refined					
Cargo class	Avg quantity/ CTSMRS (ton)	Stdev quantity/ CTSMRS (ton)	# CTSMRS quantity data	total # CTSMRS	% known data
1	1.305,60	1.659,26	53	61	86,89%
3	400,67	559,52	110	110	100,00%
4	4.741,99	9.164,92	2.188	2.303	95,01%
5	1.494,78	2.495,06	939	967	97,10%
6	1.355,93	1.244,07	471	495	95,15%
7	1.846,45	2.811,03	4.660	4.934	94,45%
8	1.455,46	1.901,61	555	1.671	33,21%
9	0,96	0,20	24	154	15,58%
10	4.247,31	7.151,67	123	2.648	4,65%
Ship type 3: Gas tankers					
Cargo class	Avg quantity/ CTSMRS (ton)	Stdev quantity/ CTSMRS (ton)	# CTSMRS quantity data	total # CTSMRS	% known data
1	200,00	0,00	1	1	100,00%
2	1.206,69	200,21	26	26	100,00%
5	880,49	1.192,18	1.011	1.027	98,44%
6	5.780,70	6.983,53	1.078	1.099	98,09%
7	5.361,35	34.499,98	11.565	12.516	92,40%
8	349,44	614,03	52	1.291	4,03%
9	0,00	0,00	0	41	0,00%
10	14,00	0,00	1	1.654	0,06%

Annex 2.4: Quantitative analysis of the different cargo types per ship type (continued)

Ship type 4: RoRo + car carriers + Ropax					
Cargo class	Avg quantity/ CTSMRS (ton)	Stdev quantity/ CTSMRS (ton)	# CTSMRS quantity data	total # CTSMRS	% known data
1	11,38	18,22	82	97	84,54%
2	2,00	0,00	1	1	100,00%
3	1.800,00	0,00	4	4	100,00%
4	13,52	16,35	9	9	100,00%
5	32,24	404,36	526	714	73,67%
6	215,47	1.932,04	2.624	4.218	62,21%
7	367,05	2.792,49	7.667	19.883	38,56%
8	1.640,22	9.874,46	2.318	16.749	13,84%
9	0,00	0,00	3	26	11,54%
10	0,00	0,00	0	68.559	0,00%
Ship type 5: Bulk carriers					
Cargo class	Avg quantity/ CTSMRS (ton)	Stdev quantity/ CTSMRS (ton)	# CTSMRS quantity data	total # CTSMRS	% known data
4	39.185,16	32.807,37	812	823	98,66%
5	30.282,56	29.417,57	57	57	100,00%
7	31.441,80	36.029,97	237	383	61,88%
8	33.027,03	24.049,64	61	358	17,04%
10	17.194,77	11.979,70	26	15.879	0,16%
Ship type 6: General cargo + reefers					
Cargo class	Avg quantity/ CTSMRS (ton)	Stdev quantity/ CTSMRS (ton)	# CTSMRS quantity data	total # CTSMRS	% known data
1	291,00	305,56	15	22	68,18%
4	3.783,80	3.291,78	99	99	100,00%
5	211,15	2.412,82	322	332	96,99%
6	10,62	15,27	82	123	66,67%
7	1.632,23	9.993,01	1.527	2.367	64,51%
8	3.402,52	11.330,88	127	5.301	2,40%
9	0,00	0,00	0	1	0,00%
10	2.969,00	431,78	3	75.634	0,00%

Annex 2.4: Quantitative analysis of the different cargo types per ship type (continued)

Ship type 7: Containers					
Cargo class	Avg quantity/ CTSMRS (ton)	Stdev quantity/ CTSMRS (ton)	# CTSMRS quantity data	total # CTSMRS	% known data
1	167,84	764,64	177	205	86,34%
4	141,51	211,08	28	35	80,00%
5	3.158,94	11.359,45	577	658	87,69%
6	2.537,39	41.066,71	3.319	3.861	85,96%
7	2.812,42	47.293,77	9.858	12.299	80,15%
8	598,14	884,87	515	20.000	2,58%
9	8,50	0,00	7	14	50,00%
10	15.000,00	0,00	1	25.086	0,00%
Ship type 8: Others + passenger ships					
Cargo class	Avg quantity/ CTSMRS (ton)	Stdev quantity/ CTSMRS (ton)	# CTSMRS quantity data	total # CTSMRS	% known data
1	0,40	0,00	7	7	100,00%
3	216,67	125,00	9	9	100,00%
4	2.500,00	0,00	1	1	100,00%
5	12,13	16,57	21	25	84,00%
6	128,87	343,37	44	220	20,00%
7	308,78	1.674,52	263	1.927	13,65%
8	169,00	63,07	8	325	2,46%
10	0,00	0,00	0	28.332	0,00%

Annex 2.5: Average & total quantities (tons) of cargo type 1

Ship type 1	*Un nr*	*IMO*	*# voyages*	*total quant/ voyage (ton)*	*avg quant/ voyage (ton)*
Calciumarsenate, calciumarsenite, mixture, solid	1574	6.1	1	3.000,00	3.000,00
Acetone cyanohydrin	1541	6.1	1	1.300,00	1.300,00
Calciumcyanide	1575	6.1	1	624,00	624,00
Linear alkylbenzene		Cat A	1	600,00	600,00
1,2,4-Trichlorobenzen	2321	6.1	1	500,00	500,00
Tetrachloroethylene	1897	6.1	4	358,70	119,57
1-Pentanethiol	1111	3	2	321,00	160,50
Coal tar		9	2	1,00	1,00
(empty)		Cat A	1	1,00	1,00
1,5,9- Cyclododecatriene	2518	6.1	1		
(empty)	1143	3	2		
Ship type 2	Un nr	IMO	# voyages	total quant/voyage (ton)	avg quant/ voyage (ton)
Coal tar		9	3	4.920,00	1.640,00
Butanedione	2346	3	1	1.500,00	1.500,00
Aceton cyanohydrin	1541	6.1	2	1.000,00	500,00
1-Pentanethiol	1111	3	1	750,00	750,00
Trichlorobenzene	2321	6.1	1	500,00	500,00
Motor fuel anti-knock mixture	1649	6.1	1	500,00	500,00
Mercurysulfide, natural	2025	6.1	1	1,00	1,00
Tetrachloroethylene	1897	6.1	2		
Ship type 4	Un nr	IMO	# voyages	total quant/voyage (ton)	avg quant/ voyage (ton)
Chlorine	1017	2.3	18	152,59	10,90
Butanedione	2346	3	1	0,10	0,10
Ship type 7	Un nr	IMO	# voyages	total quant/voyage (ton)	avg quant/ voyage (ton)
Chlorine	1017	2.3	26	4.218,59	162,25
?	3019	non consis tent	1	15,27	15,27
?	1064	2.3	1	5,39	5,39

Annex 2.6: Average & total quantities (tons) of cargo type 2

Ship type 1	*Un nr*	*IMO*	*# voyages*	*total quant/voyage (ton)*	*avg quant/ voyage (ton)*
REBCO crude oil	1267	3	2	203.455,00	101.727,50
Crude oil, flashpoint > 60F		oil	1	95.986,00	95.986,00
Crude oil	1202	3	1	89.214,00	89.214,00
Asgard crude oil		oil	1	80.330,00	80.330,00
Crude oil	1267	3	1	63.560,00	63.560,00
Petroleum crude oil with a flashpoint = 23°C & < 0	1267	3	27	1.420.578,00	61.764,26
?	1267	3	61	1.793.452,25	45.985,96
Crude oil		3	13	395.618,00	39.561,80
Petroleum crude oil with a flashpoint < 23°C	1267	3	45	1.409.483,00	37.091,66
Crude		crude	3	107.117,00	35.705,67
Crude oil (bulk)		oil	1	34.898,00	34.898,00
Crude benzene		crude	1	3.469,00	3.469,00
Crude oil		3	1	1,00	1,00
Crude oil		3.1	1	1,00	1,00

Annex 3.1: Incidents in the BPNS and neighbouring waters (period 1960-2003)

Name of ship	*Year*	*Country*	*Chemical product*	*Spilled quantity (ton)*
Esso Wandsworth	1965	Great Britain	fuel oil	5.000
Seestern	1966	Great Britain	Nigerian light crude oil	1.700
Sitakund	1968	Great Britain	bunker and ballast	500
Monte Ulia	1970	Great Britain	crude oil, fuel oil	500
Pacific Glory	1970	Great Britain	Nigerian light crude oil	5.000
Hullgate	1971	Great Britain	oil	600
Texaco Caribbean	1971	Great Britain	bunker and ballast	600
Olympic Alliance	1975	Great Britain	Iranian light crude oil	10.000
Pacific Colocotronis	1975	Netherlands	light crude oil	1.500
Eleni V	1978	Great Britain	heavy fuel oil	5.000
Sindbad	1979	Netherlands	chlorine	30
Mont Louis	1984	Belgium	uranium hexafluoride	0
Herald of Free Enterprise	1987	Belgium	100 different chemicals (TDI, cyanides, hydroquinone, toluene, lead, etc.)	24
Skyron	1987	France	fuel oil	?
Anna Broere	1988	Netherlands	acrylonitrile (DE), dodecylbenzene (F)	700
Serafina	1990	Netherlands	oil	300
Korsnäs Link	1991	Great Britain	sodium chlorate	40
Amer Fuji/ Meritas	1992	Belgium	oil	225
Westhinder 'incident'	1992	Belgium	oil	170
Cast muskox/long lin	1992	France	oil	190
?	1992	Netherlands	chlorhydric acid	?
Ariel	1992	Netherlands	white spirit	?
Davidgas/athos	1992	Netherlands	oil	10
British Trent/ Western Winner	1993	Belgium	unleaded gasoline	5.100
Sherbro	1993	France	pesticides	?
Aya	1993	Netherlands	oil	15
Carina/ MSC Samia	1995	Belgium	oil	45
Spauwer	1995	Belgium	oil	10
?	1996	Netherlands	aluminium phosphate	?
Mundial Car/Jane	1997	Belgium	oil	20
Rosa M	1997	France	hazardous materials	?
Bona Fulmar/ Teoatl	1997	France	gasoline	7.000

Name of ship	*Year*	*Country*	*Chemical product*	*Spilled quantity (ton)*
Vigdis Knutsen/ Saint Josse	1997	France	risk oil	0
Apus	1998	Netherlands	flammable solids (fire lighters)	?
Ban-Ann	1998	Netherlands	sulfur-phosphine	?
Dart 2	1998	Netherlands	methane sulphon acid	?
European Tideway	1998	Netherlands	detergent agent (alkyl phenol ether phosphate (OLETH 20)	?
Ever Decent/ Norwegian Dream	1999	Great Britain	hazardous materials	?
Adelaide/ Saar Ore	2000	Belgium	oil	10
China Prospect/ Veerseborg	2001	Belgium	coal	?
"Noordpas" incident	2001	Belgium	oil	10
Heinrich Behrman	2001	Belgium	risk oil	?
Music/ Vera	2001	Belgium	oil	20
St Jacques/ Gudermes	2001	Great Britain	oil	100
Tricolor/ Kariba/ Alphonse Letzer	2002	France	fuel (IFO 380)	500
Vicky	2003	Belgium	fuel oil, diesel oil	?

Annex 3.2: Description of the Marcs model

APPENDIX I

DESCRIPTION OF THE MARCS MODEL

Contents

I. DESCRIPTION OF THE MARCS MODEL

I.1 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 categorised 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);
- 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.

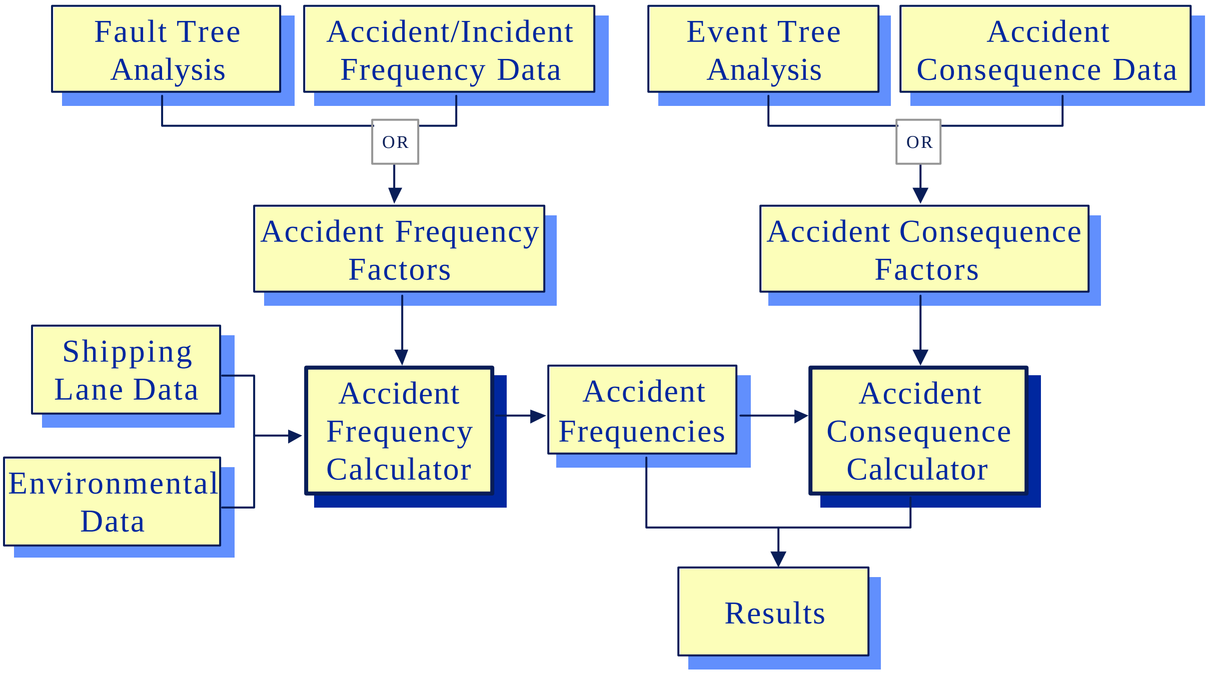
Marine transport risk analysis can be performed by assessing the frequency of the above accident types, followed by an assessment of the accident consequences, typically in terms of cargo spill, lives lost or in financial terms. DNV has developed the MARCS model to perform such marine transport risk 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).

I.2 Introduction to MARCS

I.2.1 Overview

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

Figure I.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;
- Environment data describes the conditions within the calculation area, including the location of geographical features (land, offshore structures etc) and meteorological data (visibility, windrose, currents and seastate);
- 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 I.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.

I.2.2 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 depending on the chosen calculation resolution). The definition of a critical situation varies with the accident mode, see Section

I.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.

I.2.3 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 analysed 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 output 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 is present.

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

Figure I.2 Fault tree symbols

The OR gate, see Figure I.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;

$$P(\text{event 1 OR event 2}) = P1 + P2 - P1*P2$$

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 I.3: OR - gate

The AND gate, see Figure I.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 I.4: AND - gate

It should be emphasised 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).

I.3 Data used by MARCS

I.3.1 Traffic Image Data

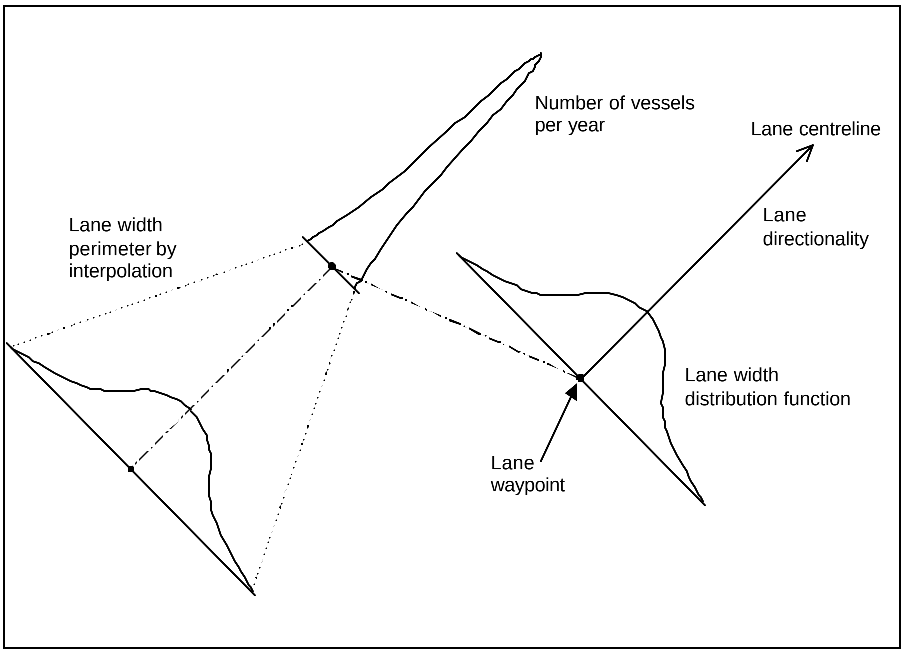
The marine traffic image data used by MARCS is a representation of the actual flows of traffic within the calculation area. Marine traffic data is represented using lane data structures. Different traffic types are divided into separate marine databases in order to facilitate data verification and the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

A typical traffic lane is shown in Figure I.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;
6. The vessel size distribution on the lane.

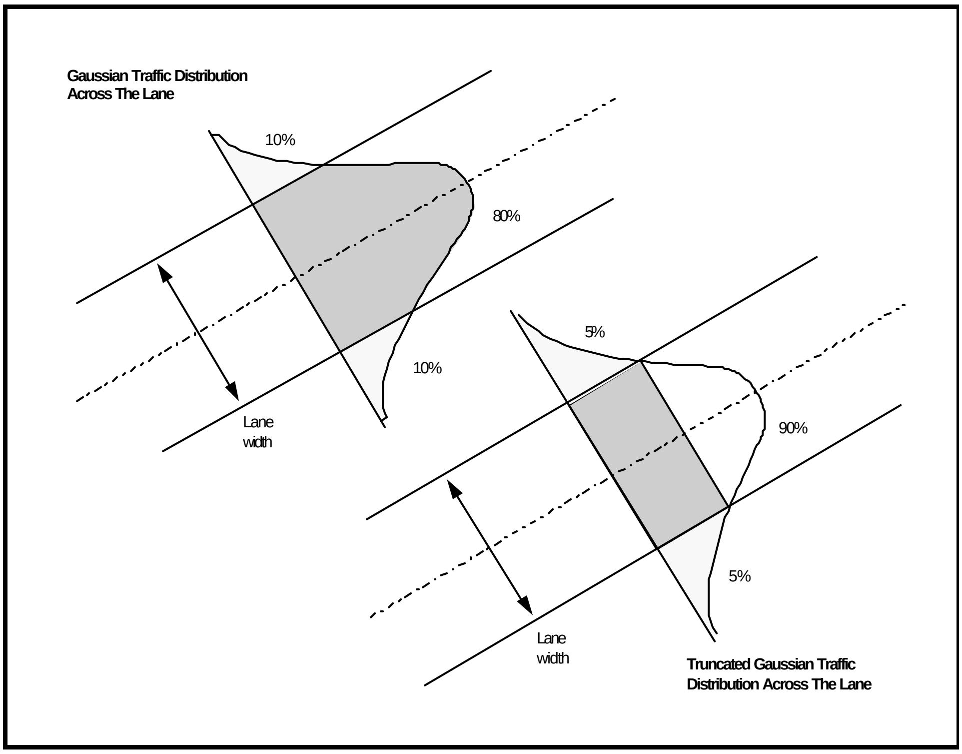
Additional data may be attached to the lane, such as: the hull type distribution (single hull, double hull, etc) for tankers; the loading type (full loading, hydrostatic loading) for tankers; ship type etc.

Figure I.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 I.6.

Figure I.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:

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%);
4. Fraction of vessels that exhibit "rogue" behaviour (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 personal 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.

I.3.2 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;
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.

I.3.3 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.

I.3.4 Environment Data

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

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

Windrose data is defined within 8 compass points (north, north-east, east etc) in 4 wind speed categories denoted: calm (0 – 20 knots); fresh (20 to 30 knots); gale (30 to 45 knots); and storm (greater than 45 knots). Seastate (wave height) within MARCS is inferred from the windspeed 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.

I.4 Description of Accident Frequency Models

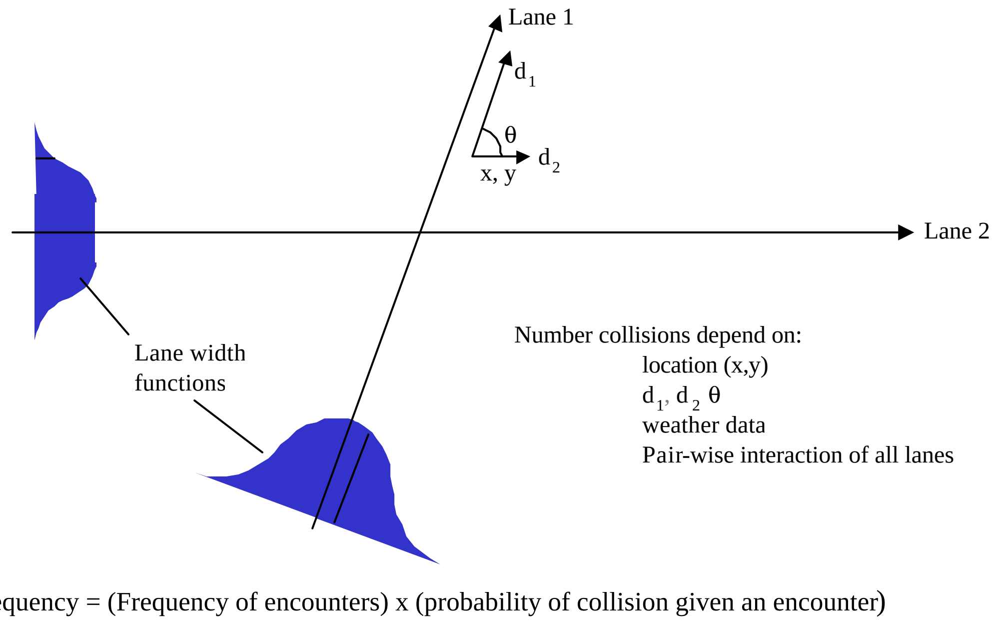
The section describes how MARCS uses the input data (traffic image, internal operational data, external operational data and environment data) to calculate the frequency of serious accidents in the study area.

I.4.1 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 I.7 shows a graphical representation of the way in which the collision model operates.

Figure I.7 Graphical representation of the collision model



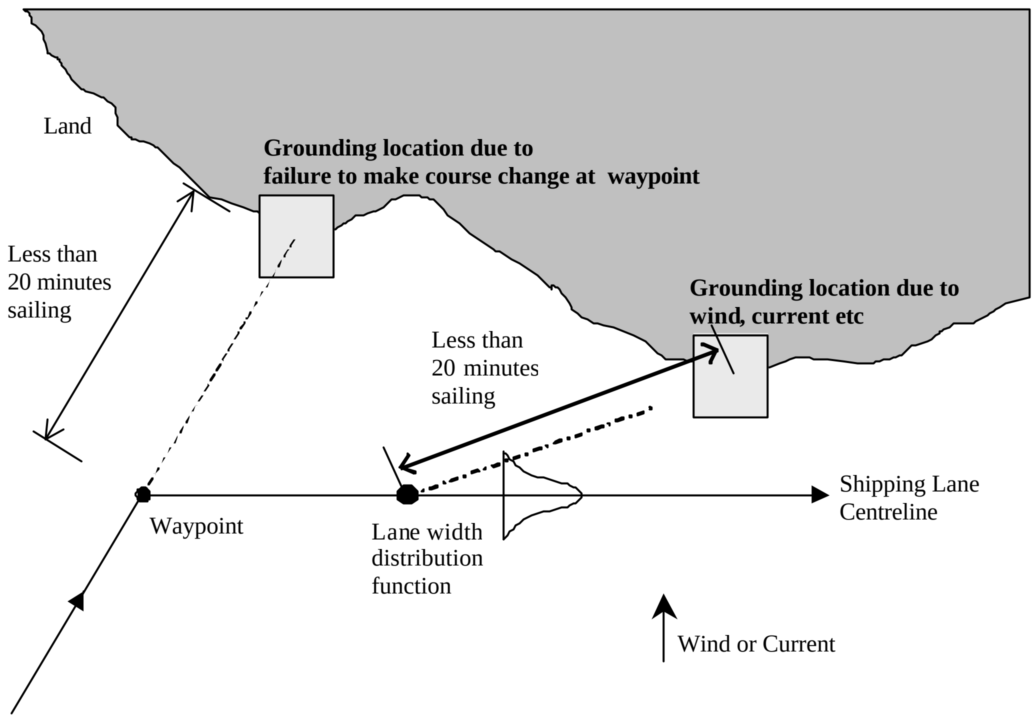
In Figure I.7, d_1 refers to the density of traffic associated with lane 1 at the location x,y. The frequency of encounters at location x,y through the interaction of lanes 1 and 2 is proportional to the product of d_1, d_2 and the relative velocity between the lane densities.

I.4.2 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 I.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 centreline. 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 I.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.

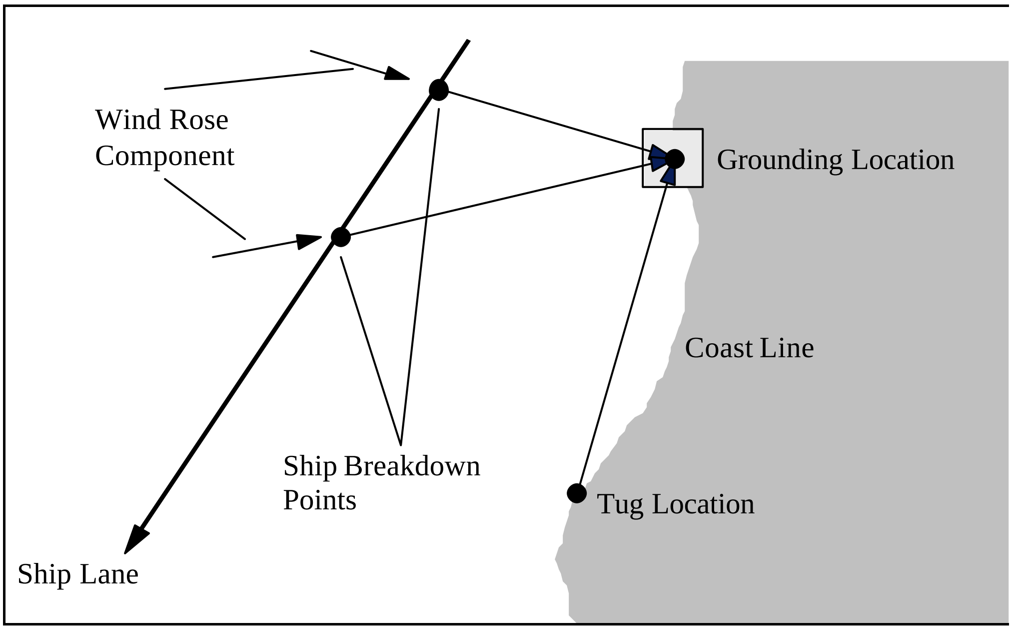
Both these branches are illustrated in Figure I.8. The powered grounding frequency model takes account of internal and external vigilance, visibility and the presence of navigational aids (radar) in deducing failure parameters.

I.4.3 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 I.9.

Figure I.9 Graphical representation of the drift grounding model

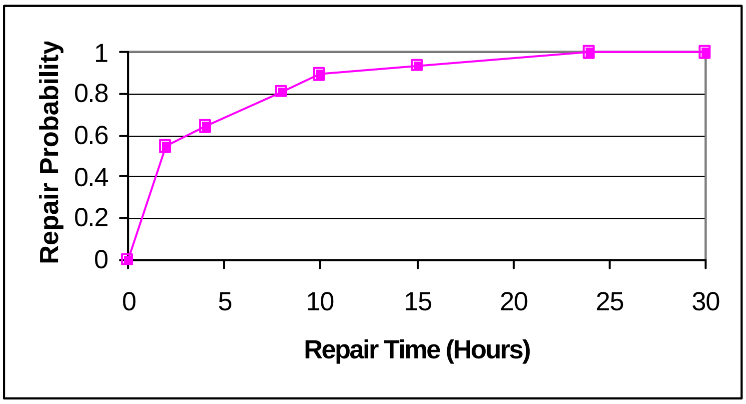


Implicit in Figure I.9 is the importance of the time taken for the ship to drift aground. When this time is large (because the distance to the shore is large and/or because the drift velocity is small) then the probability that the ship will recover control before grounding (via repair or tug assistance)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

Figure I.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:

- 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 seastate);
- 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 seastate);
- The time to connect a line and exert a controlling influence on the ship (as a function of seastate);

- 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).

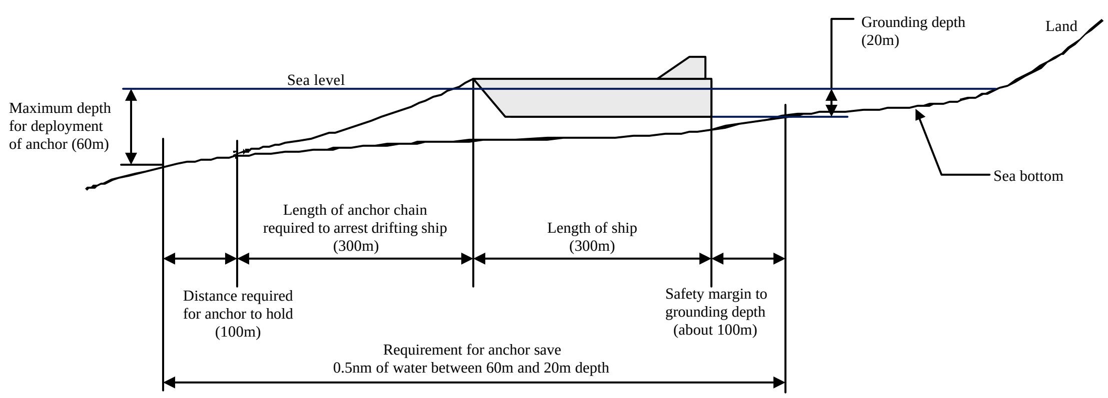
Tug performance parameters can take account of ship wind and wave resistance, tug wind and wave resistance and tug length and propulsion arrangement (open versus nozzle) which influences the propulsion efficiency.

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 hold, then an anchor save is made.

Figure I.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.

I.4.4 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 seastate) 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 (seastate) category.

I.4.5 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 assumed to be independent of environmental conditions outside the ship.

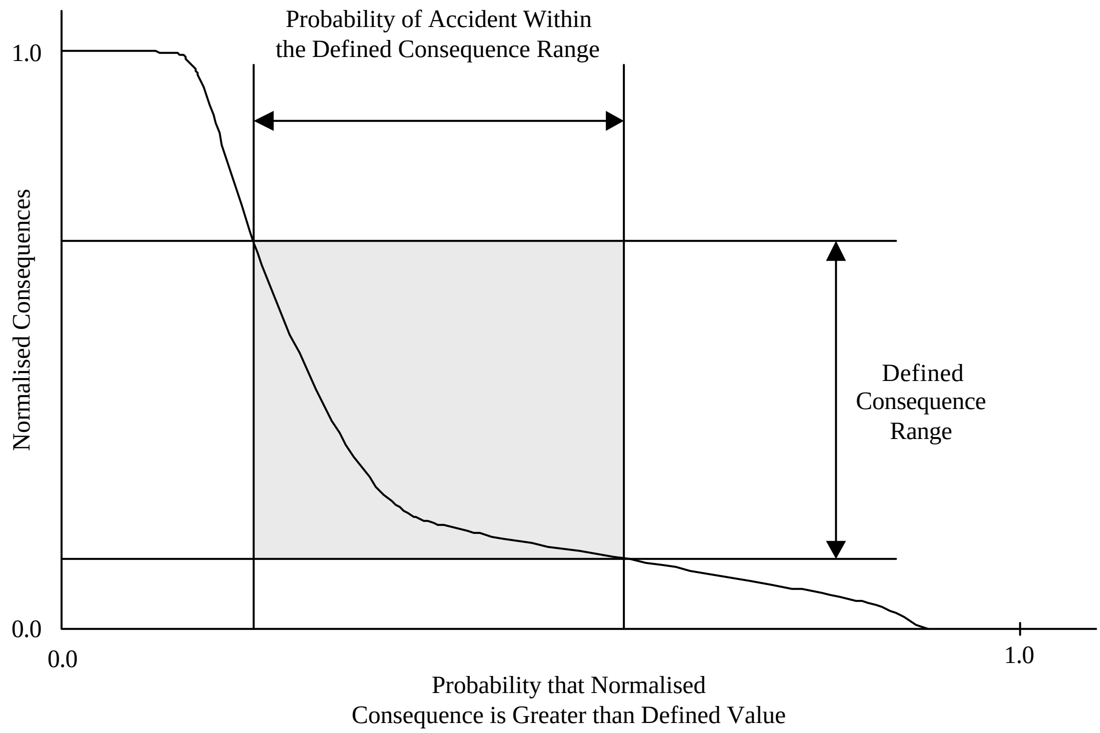
I.5 Generic Description of Accident Consequence Models

Marine transport risks are estimated by combining the frequencies of serious accidents with the accident consequences, given a serious accident. Marine accident consequences are typically expressed in terms of cargo spilled, lives lost or financial loss.

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 (normalised cumulative probability distributions) take the generic form shown in Figure I.12. The curve shows the normalised consequence (in terms of, for example, cargo mass outflow into the environment) versus the probability that the consequence is greater than this value. Thus the normalised consequence of 1.0 (equal to total loss of all cargo carried) occurs for relatively low probabilities, whereas the probability that the normalised consequence is greater than a small fraction of the cargo carried generally approaches 1.0 for single hulled ships.

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

Figure I.12 Generic Accident Consequence versus Probability Curve



I.6 Model Enhancements made for the RAMA Project

In order to meet the objectives of the RAMA project DNV has made the following changes and enhancements to the MARCS model.

- MARCS has been amended to better represent areas of shallow water and the grounding behaviour of mixed lanes of deep and shallow draft ships;
- MARCS has been amended so that different cargo types can be transported by ships of the same ship type;
- The need for revised and extended cargo spill models has been considered.

These amendments are described in this section.

In the calculation control file a new location descriptor has been introduced to represent the shallow water grounding line. Only ships of draft greater than the depth of the shallow water can ground on a shallow water location, whereas all ships will ground on a coastal location (assuming that the sea bottom rises sufficiently fast that a shallow water location cannot be represented separately).

A new label has been attached to each shipping lane to represent the cargo type that is transported by the lane. This label is used by the accident consequence calculation so that the consequence calculation can be performed on for each cargo type separately (10 types of cargo are defined, see Appendix II. Bunker fuel oil spills directly from the fuel tanks are also calculated separately).

During previous studies (SAFECO I, SAFECO II) DNV has established oil outflow models for spillage of hydrocarbon products from tanker ships, and for spillage of bunker oil from bunker fuel tanks. The bunker fuel outflow models are assumed to be directly applicable to all ship types without modification.

DNV's current outflow of hydrocarbon cargo from tankers are assumed to be directly applicable to oil tankers and chemical tankers (ship types 1 and 2).

DNV do not have specific gas outflow models for gas tankers (ship type 3). Such tankers are less likely to release cargo compared to conventional tankers because of the pressure vessel, but if a puncture does occur then more cargo will be released because of the excess pressure. On balance gas outflows are calculated from the liquid hydrocarbon models for double hulled crude tankers.

DNV do not have specific cargo loss models for the remaining ship types (ro-ro/ car ferry, bulk carrier, general cargo, container ships, passenger ships/ other). It is anticipated that for each of these ship types the liquid hydrocarbon outflow models will over-estimate the cargo loss for the following reasons:

- Liquid cargos will "flow" more than the cargos in ship types 4 to 8;
- The proportion of dangerous cargo relative to the deadweight capacity in a ro-ro, container ship etc is likely to be less than for a crude oil tanker (data for container ships suggests that only 10% of all containers carry dangerous goods).

However, in the absence of better alternative data, DNV apply the liquid hydrocarbon cargo outflow models to ship types 4 to 8 as a conservative assumption.

I.7 References

Cockcroft, 1988: "A guide to the collision avoidance rules", Cockcroft, A N and Lameijar J N F, Stanford Maritime, 1982.

Cooke R.M., 1995: "Methods and Code for Uncertainty Analysis", UNICORN, AE Technology, TUDelft,

Henley EJ., Kumamoto H., 1981: "Reliability Engineering and Risk Assessment", Prentice-Hall Inc.

HMSO, 1985: "Shipping routes in the area of the UK continental shelf: Offshore technology report", OTH 85 213, HMSO, March 1985.

SAFECO I: "Safety of Shipping in Coastal Waters (SAFECO I) Summary Report", DNV 98-2038, 1998.

SAFECO II: “Safety of Shipping in Coastal Waters (SAFECO II) Summary Report”, DNV 99-2032, 1999.

Annex 3.3: Data used by the Marcs model

APPENDIX II

DATA USED BY THE MARCS MODEL

Contents

II. DATA USED BY THE MARCS MODEL

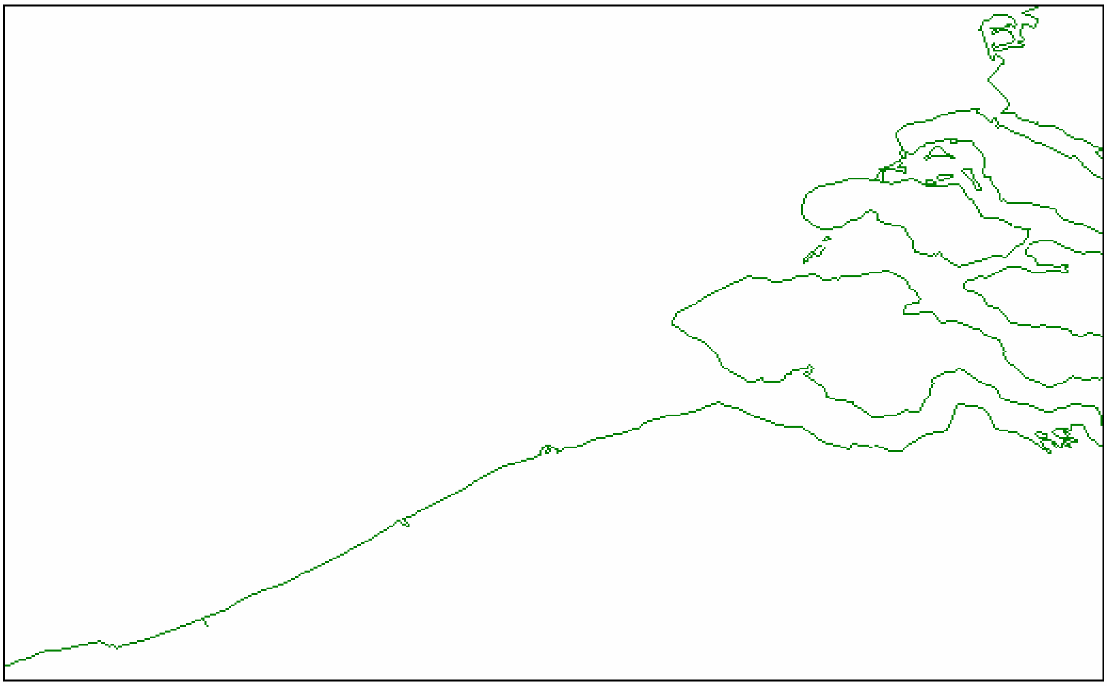
This appendix describes the data and reasoning behind the risk analysis parameters used to generate the marine risk results used in this project.

II.1 Risk Modelling Approach

This section describes the overall approach to the modelling of the risks posed by the marine traffic trading off the coast of Belgium. The marine risk model (MARCS, or Marine Accident Calculation System) is described in detail in Appendix I.

The study area is shown in Figure II.1. This has been chosen so that all ship routes within 50nm (nautical miles) of the Belgian coast are included within the study area. This limit is selected because in previous marine projects performed by DNV it has been judged that 50nm is the highest credible drift distance for a mechanically disabled ship. It should be noted that any ships outside the defined study area cannot influence the marine risk analysis, or the risk results obtained.

Figure II.1 Definition of the Project Study Area



The co-ordinates of the study area are between 52° and 51° north to south and between 2° 10' and 4° 15' west to east. The calculation resolution is 0.10 minutes (185m) by 0.20 minutes (236m); each small area defined by the calculation resolution is called a calculation location, see Appendix I.

Other inputs that contribute to the definition of the project study area, such as the location of offshore wind turbines and the location of the 5m depth grounding line, are described in Section II.4 below.

II.2 Marine Traffic Image Data

II.2.1 Traffic Characteristics

MARCS represents marine traffic in terms of up to 8 traffic types and traffic routes for each traffic type. For most projects, traffic types are defined in terms of the similarity of risks that each ship type poses and other similarities (for example, ferries tend to trade faster so may be grouped separately from general cargo ships). Non-hazardous traffic types, such as general cargo ships, container ships and ferries will also be defined. This is because these non-hazardous ships can collide with hazardous cargo ships, and because all ships carry bunker oil. In this study Ecolas were responsible for the collection of ship traffic data.

The traffic types defined in this study are as follows:

- Type 1: Oil (crude) tankers;
- Type 2: Chemical tankers and refined product tankers;
- Type 3: Gas tankers;
- Type 4: RoRo and Car carriers;
- Type 5: Bulk carriers;
- Type 6: General cargo and reefers;
- Type 7: Containers;
- Type 8: Passenger ships and other ships.

For each ship lane defined it is necessary to define a range of parameters which describe:

- The lane number and ship type (as above);
- The cargo type that is being transported (see below);
- The annual frequency of ship movements along the lane (ships/year);
- The lane type (all lanes in this study are one-way Gaussian – see Appendix I);
- Any tug escorts that may be present (none in this study);
- The type of ship loading (characterised by 3 parameters);
- The proportion of ships on the lane in each ship size (DWT) and hull type (single hull, double hull etc) category;
- The number of waypoints, the location of each waypoint and the lane width (twice the standard deviation) at each waypoint.

These parameters are provided in the spreadsheet InputDataSummary v0.xls, sheet Traffic Data.

The cargo type carried by each vessel type is defined by the IMO Dangerous Goods classes as follows:

- Class 1: Marine Pollutants + Bulk Cat A;
- Class 2: Crude oils;
- Class 3: Bunkers and heavy fuels;
- Class 4: Other oil products;
- Class 5: Potential Marine Pollutants + Bulk Cat B & C;
- Class 6: Toxic Products (IMO-code 6.1 & 2.2);

- Class 7: Other identifiable dangerous goods or HNS;
- Class 8: Dangerous goods, with insufficient product information;
- Class 9: Empty but with leftover fractions from dangerous goods;
- Class 10: No dangerous goods.

In addition, it is assumed that all ships carry bunker fuel oil in their bunker fuel oil tanks (distinct from bunker fuel oil as a cargo).

Cargo Classes 9 and 10 are not included in the risk analysis (see Section 2.3 of main report).

II.2.2 Internal Operational Data

In DNV's previous marine risk analysis projects we have derived internal operational data, such as ship-ship collision probabilities given an encounter, from North Sea fleet data. This is assumed to apply to marine traffic in Belgian waters. Table II.1 shows the internal operational data which DNV normally applies for North Sea average ships [DNV, 1997; DNV, 1998].

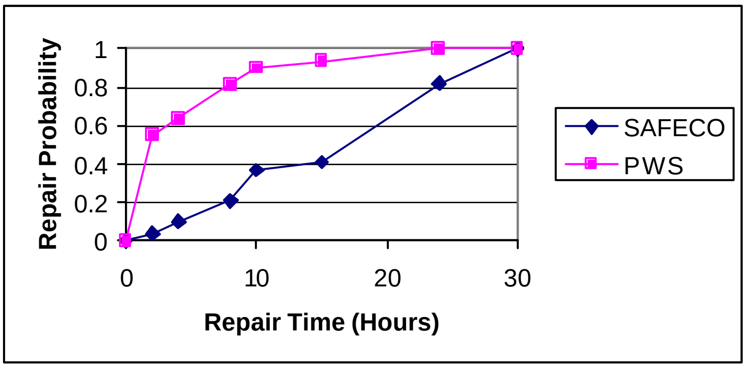
Table II.1 Risk Parameters for North Sea Average Ships

Risk Parameter			**Average ship probability (all ship types)**
Accident Type	**Pilot**	**Visibility**	
Collision	No	Good	8.48e-5
Collision	No	Poor	5.80e-4
Collision	Yes	Good	6.83e-5
Collision	Yes	Poor	4.64e-4
Powered Grounding	No	Good	3.07e-4
Powered Grounding	No	Poor	8.57e-4
Powered Grounding	Yes	Good	2.47e-4
Powered Grounding	Yes	Poor	6.87e-4

Accident Type and Parameter Description	**Ship Type**	**Average ship frequency (per hour)**
Drift Grounding Ship breakdown frequency per hour	Type 1: Oil (crude) tankers; Type 2: Chemical tankers; Type 3: Gas tankers; Type 4: RoRo; Type 5: Bulk carriers; Type 6: General cargo; Type 7: Containers; Type 8: Passenger and other ships.	3.60e-4 3.60e-4 3.60e-4 5.00e-4 3.00e-4 5.00e-4 5.00e-4 1.30e-5
Structural Failure Structural failure frequency per hour in calm/ fresh, gale and storm seastates respectively	Type 1: Oil (crude) tankers; Type 2: Chemical tankers; Type 3: Gas tankers; Type 4: RoRo; Type 5: Bulk carriers; Type 6: General cargo; Type 7: Containers; Type 8: Passenger and other ships.	1.85e-7 1.85e-7 4.62e-7 1.85e-7 1.85e-7 4.62e-7 1.85e-7 1.85e-7 4.62e-7 6.92e-7 4.62e-7 4.62e-7 4.62e-7 4.62e-7 9.23e-7 6.92e-7 4.62e-7 4.62e-7 6.92e-7 4.62e-7 4.62e-7 1.85e-7 1.85e-7 4.62e-7
Fire/Explosion	Type 1: Oil (crude) tankers; Type 2: Chemical tankers, Type 3: Gas tankers; Type 4: RoRo; Type 5: Bulk carriers; Type 6: General cargo; Type 7: Containers; Type 8: Passenger and other ships.	4.08e-7 4.08e-7 4.08e-7 1.00e-7 1.00e-7 1.00e-7 1.00e-7 1.00e-7

Figure II.2 shows the distribution of self-repair times derived from these two projects (Prince William Sound Risk Assessment and SAFECO respectively). As shown in Figure II.2, there is considerable uncertainty regarding the time required to repair mechanical failures onboard ship. In the current project the SAFECO curve is assumed to apply to all ships, though we note that this assumption is likely to result in conservative (higher) risk results for drift grounding and drifting obstacle collision results.

Figure II.2 Self Repair Distribution Function for Average (SAFECO) and Above Average (Prince William Sound - PWS) Ships



II.2.3 Traffic speeds

Table II.2 shows the average speed of each vessel type in the study area as used in the risk calculation.

Table II.2 Average Vessel Speed (knots) applied in the Study Area

Ship Type	All Locations
Type 1: Oil Tanker	12
Type 2: Chemical tankers	12
Type 3: Gas tankers	12
Type 4: RoRo	12
Type 5: Bulk carriers	12
Type 6: General cargo	10
Type 7: Containers	14
Type 8: Passenger and other ships	16

II.3 External Operational Data for Study Area

The use of pilots within certain areas reduces the frequency of collision, powered grounding and powered collision with fixed obstacles due to the improved local knowledge of the pilot compared with the ship's normal crew. The location of piloted areas in this study is shown in Figure II.4. Within these areas the reduced probability of accidents, as shown in Table II.1, are applied.

Figure II.4 Location of Piloted Areas

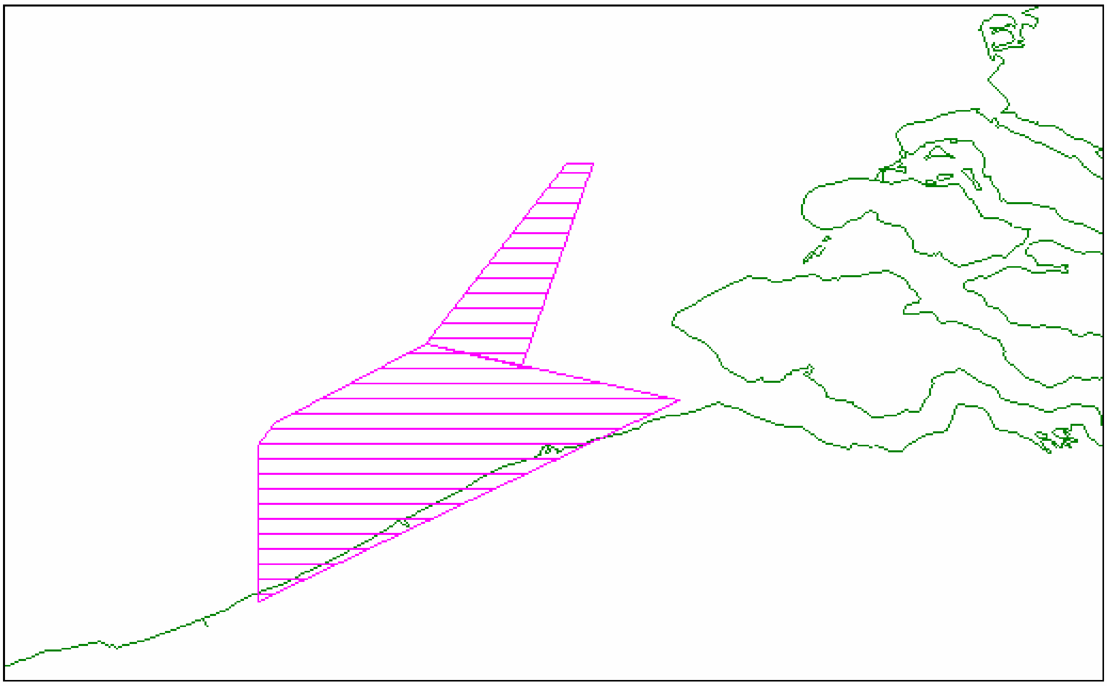


Table II.3 summarises the emergency tows which are potentially available (data from Ecolas, see InputDataSummary v0.xls, sheet TugData).

Table II.3 Locations and Performances of Emergency Tows

Location	North	East	Number	Bollard Pull (te)
Terneuzen	51° 22'	3° 48'	2	55, 55
Zeebrugge	51° 20'	3° 12'	7	45 to 66, 95
Antwerpen	51° 22'	3° 48'	12	40 to 66
Gent – Terneuzen	51° 22'	3° 48'	14	30 to 40
Oostende	51° 15'	2° 58'	1	30

Due to the high levels of traffic in the area, it is possible that other tugs or salvage vessels might fortuitously be in the vicinity of a drifting vessel and therefore be able to offer assistance. This eventuality has not, however, been included in the drift grounding frequency calculator within MARCS, to ensure that a conservative approach to the risk modelling is maintained throughout the study.

The tug input data to the MARCS model is shown in Table II.4. Each tug type in Table II.3 is assigned to a tug performance class by reference to previous tug performances characterised by DNV. The availability of each tug is determined by assuming that each individual tug is available for only 10% of the time. Thus the availability for controlling a drifting vessel is estimated from the equation:

$$\text{Availability} = 1.0 - 0.9^{\text{(number of tugs of similar performance at the location)}}$$

Table II.4 Tug Input Data

Tug Class	Availability	North	East	Comment
1	0.19	51.3667	3.8000	2 tugs at Terneuzen
2	0.47	51.3333	3.2000	6 tugs at Zeebrugge
4	0.10	51.3333	3.2000	1 powerful tug at Zeebrugge
2	0.71	51.3667	3.8000	12 tugs at Antwerpen

Tugs less than 40 tons of bollard pull are judged to be ineffective in open water.

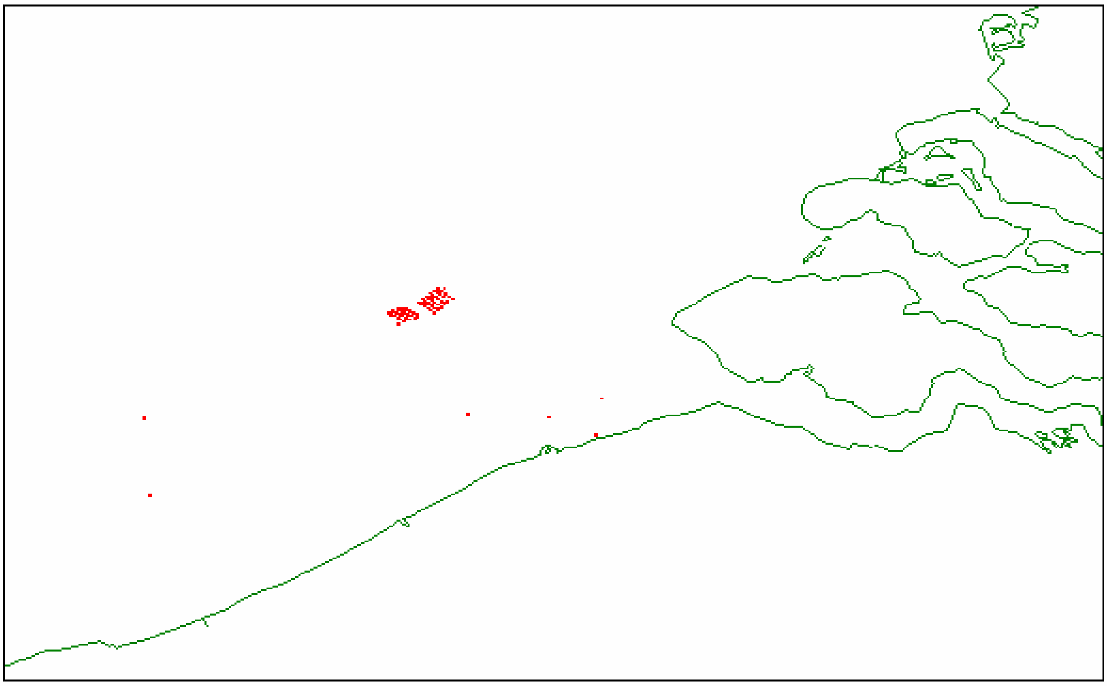
The performance (speed of the tug and the maximum size of ship it can control in kdwt) of each tug type, taken from previous work by DNV, is shown in Table II.5.

Table II.5 Tug Performance Data for a Semi-Sheltered Location – see wave height data below(Save = Maximum size of ship in kdwt that can be controlled by the tug in the specified conditions)

Wind	Calm		Fresh		Gale		Storm	
	Speed kts	Save	Speed kts	Save	Speed kts	Save	Speed kts	Save
Type 1	14	999	11	999	8	0	5	0
Type 2	14	999	11	999	8	62	5	0
Type 3	14	999	11	999	8	138	5	0
Type 4	14	999	11	999	8	262	5	34
Type 5	14	999	11	999	8	999	5	264

The location of offshore wind turbines (installed and approved but not yet installed) plus other obstacles are shown in Figure II.5. The data is recorded InputDataSummary v0.xls, sheet Obstacles.

Figure II.4 Location of Offshore Wind Turbines (installed and approved) and other Obstacles



II.4 Environmental Data for the Study Area

Visibility data was obtained from two local data sources as indicated in Table II.7. Typical values for the North Sea from a previous project are shown for comparison.

Table II.7 Visibility Data for the Study Area and Data used in this Project

Sea Area	Good Visibility (time fraction greater than 2 nm)	Poor Visibility (time fraction less than 2 nm)	Data Source
North Sea Average	0.95	0.05	DNV, 1998
Goeree	0.9516	0.0484	NL, 2001
Europlatform	0.9448	0.0552	Ecolas, 2004a
Ostend Airport	0.959	0.041	Ecolas, 2004b
Data applied in this study	0.95	0.05	

The local data shown in Table II.7 are not significantly different from the North Sea average, therefore the North Sea average data was applied to this study. That is, visibility of less than 2nm occurs 5% of the time.

Windrose data from four local measuring locations are shown in Table II.8 and compared to North Sea average data.

**Table II.8 Windrose Data for the Study Area
(First 4 Tables from Ecolas, 2004c, Final Table DNV, 1998)**

Wind State	Wind Speed	Wind Direction - MOW0 Wandelaar H19.2m. jun86-sept01							
		N	NE	E	SE	S	SW	W	NW
Calm	0-20 kts	0.06737	0.10510	0.07776	0.06661	0.10566	0.11616	0.08536	0.05780
Fresh	20-30 kts	0.01873	0.02401	0.01841	0.01311	0.04649	0.08559	0.04455	0.02370
Gale	30-45 kts	0.00160	0.00207	0.00193	0.00089	0.00632	0.01564	0.00989	0.00393
Storm	>45 kts	0.00001	0.00000	0.00000	0.00000	0.00016	0.00060	0.00049	0.00006

Wind State	Wind Speed	Wind Direction - MOW7 Westhinder H25.25m maa94-sapt01							
		N	NE	E	SE	S	SW	W	NW
Calm	0-20 kts	0.06079	0.08483	0.07655	0.07093	0.08747	0.11701	0.07895	0.05206
Fresh	20-30 kts	0.02696	0.03576	0.02468	0.01061	0.02941	0.09983	0.05057	0.03124
Gale	30-45 kts	0.00339	0.00359	0.00292	0.00057	0.00504	0.02748	0.01166	0.00601
Storm	>45 kts	0.00004	0.00003	0.00000	0.00000	0.00017	0.00107	0.00035	0.00004

Wind State	Wind Speed	Wind Direction - MOW5 Droogte van 't Schooneveld periode ? Waarschijnlijk 86-91)							
		N	NE	E	SE	S	SW	W	NW
Calm	0-20 kts	0.08322	0.09093	0.07829	0.05491	0.09107	0.10554	0.08856	0.06428
Fresh	20-30 kts	0.02998	0.02466	0.01345	0.00815	0.04954	0.08359	0.05771	0.02656
Gale	30-45 kts	0.00317	0.00208	0.00026	0.00085	0.00813	0.01706	0.01269	0.00354
Storm	>45 kts	0.00002	0.00000	0.00001	0.00002	0.00021	0.00070	0.00070	0.00011

Wind State	Wind Speed	Wind Direction - VR Vlakte vd Raan, H416.5m, nov88-mei98							
		N	NE	E	SE	S	SW	W	NW
Calm	0-20 kts	0.08027	0.09256	0.08185	0.06938	0.09218	0.12576	0.09481	0.06428
Fresh	20-30 kts	0.02346	0.02392	0.01445	0.00763	0.03851	0.08797	0.04819	0.02656
Gale	30-45 kts	0.00152	0.00114	0.00030	0.00015	0.00334	0.01054	0.00730	0.00357
Storm	>45 kts	0.00000	0.00000	0.00000	0.00000	0.00003	0.00015	0.00016	0.00005

Wind State	Wind speed	Wind Direction - North Sea Average (DNV, 1998)							
		N	NE	E	SE	S	SW	W	NW
Calm	0–20 kts	0.058	0.028	0.042	0.053	0.090	0.090	0.08	0.08
Fresh	20–30 kts	0.029	0.014	0.021	0.027	0.045	0.045	0.04	0.04
Gale	30-45 kts	0.023	0.011	0.017	0.021	0.036	0.036	0.032	0.032
Storm	> 45 kts	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002

Analysis of these windrose tables indicates that the wind directions, irrespective of windspeed, are very similar for each dataset (mostly within 10% and always within 16%). Windspeeds however are highest for the second windrose (MOW7 Westhinder H25.25m maa94-sapt01). High windspeeds result in higher marine accident risk results, thus this second data set has been applied across the entire study area, since this will give the more conservative risk result. (Note, it is considered that there is insufficient difference between the windroses to justify use of multiple windroses in defined sub-areas, though the MARCS model is capable of using such data.)

The significant wave height observed is a function of the windspeed, the time for which that windspeed has been observed and the "fetch" of the location (the sea distance over which the wind acts and the wave heights are built). In previous work (DNV, 1997), DNV defined 3 types of sea location and approximate significant wave heights as a function of wind speed, as shown in Table II.9. Within Table II.9, the "Open Ocean" location considered was the northern Pacific Ocean (i.e. a large body of water with some very large waves).

Table II.9 Approximate Significant Wave Height as a function of Wind Speed and Location Characteristics

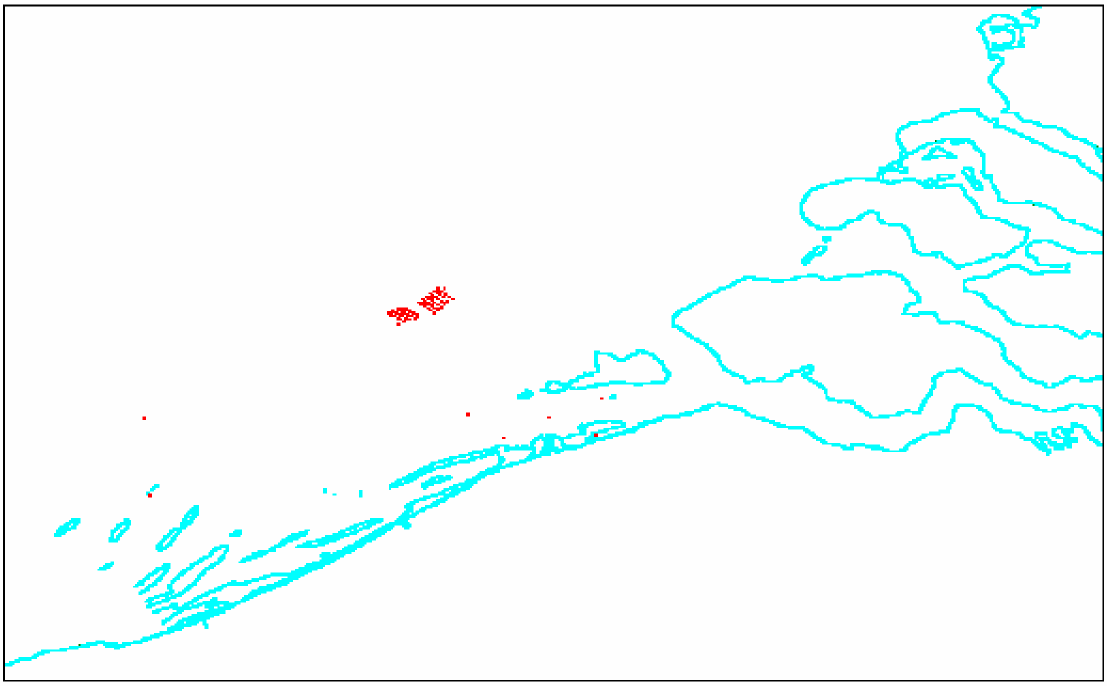
Wind State	Wind Speed	Sheltered Wave Height	Semi-Sheltered Wave Height	Open Ocean Wave Height
Calm	20 kts	1.2m	1.6m	2m
Fresh	30 kts	2.4m	3.2m	4m
Gale	45 kts	4.2m	5.6m	7m
Storm	58 kts	5.4m	7.2m	9m

Examination of wave height data for various locations within the study area (Ecolas, 2004d) indicate that the study area is between sheltered and semi-sheltered (the maximum 100% percentile wave height in large detailed datasets across all wind conditions was 4.5m, but the 90^{th} percentile waveheight was generally less than 2 to 2.5m, depending on the dataset). The study area in this project has, therefore, been characterised as semi-sheltered in order to provide conservative risk results.

The navigation charts were examined for sea current data but no significant currents were found (excluding tidal currents which cannot be represented adequately by a statistical model such as MARCS) and so none were included in the risk analysis calculations.

The grounding line for the marine traffic is defined to be the 5m depth line shown in Figure II.5. Such sand banks would result in contacts with deeper draft ships. However the soft sea bottom and the depth of water (that helps to support the weight of the ship) is likely, in most cases, to allow grounding without significant damage to the ship or loss of bunker oil or ship's cargo.

Figure II.5 Location of the 5m Grounding Line



The sea bottom and shoreline that predominates within the study area is mainly soft mud or sand. Thus, in the case of a grounding, the probability of a cargo or fuel oil release is relatively low compared to a more rocky sea-bottom or shoreline. Thus a uniform probability of a cargo spill given a grounding of 0.1 is applied throughout the study area.

A drifting ship can save itself from grounding by deploying its anchoring systems, provided that the sea bottom geometry is suitable. For anchor saves to be effective, the sea depth should lie between 60 and about 20m for a distance of half a nautical mile, see Appendix I. Anchor saves are more effective at low wind speeds and for softer sea bottoms.

The water depth throughout the study area is generally shallow and suitable for saving a drifting ship using the anchor save mechanism. Thus the anchor save mechanism has been applied throughout the study area.

II.5 References

DNV, 1997: “Prince William Sound Risk Assessment”, Final Report to the Prince William Sound risk assessment steering committee, December 1996.

DNV, 1998: “Demonstration of risk analysis techniques for ship transportation in European waters”, Report 98-2021, Final report to SAFECO project.

Ecolas, 2004a: Spreadsheet “zichtbaarheid-in-nl.xls” supplied by Ecolas.

Ecolas, 2004b: Spreadsheet “Zichtb_IRM-bd.xls” supplied by Ecolas.

Ecolas, 2004c: Spreadsheet “winddata 3Estudie c-power.xls” supplied by Ecolas.

Ecolas, 2004d: Spreadsheets “golfhoogte.xls”, “presentsignifgolfh79-98.xls” and “wave height Akkaert, MP7westhinder.xls”, supplied by Ecolas.

Annex 3.4: Risk results of the Marcs model

APPENDIX III

RISK RESULTS FROM THE MARCS MODEL

Contents

III. RISK RESULTS FROM THE MARCS MODEL

III.1 Introduction

This Appendix presents the results of the risk analysis of marine traffic in Belgian waters. The results presented are based upon the modelling methodology shown in Appendix I and the model input data described in Appendix II.

The format and keys for the results described below are shown in Section 2.4 of the main report.

III.2 Marine Traffic Analysis

The geographical distribution of shipping traffic for each vessel type is shown in the bitmap files L1.bmp to L8.bmp for vessel types 1 to 8 respectively.

The sub-area analysis of the number of vessel miles is included in the Excel sheet Results v0.xls, sheet "Traffic".

III.3 Modelling Results

III.3.1 Accident Frequency Results

The total frequency of serious accidents is shown as a function of accident type, ship type, cargo spill type and sub-area in the Excel sheet Results v0.xls, sheet "Results D1", rows 8 to 138.

The geographical distribution of accident frequency results are shown in the files map1_x.bmp, where x=0 for all cargo spill, 1 to 10 is for cargo classes 1 to 10 respectively and 20 is for bunker spills.

III.3.2 Cargo Spilling Accident Frequency Results

The total frequency of serious accidents is shown as a function of accident type, ship type, cargo spill type and sub-area in the Excel sheet Results v0.xls, sheet "Results D1", rows 140 to 270.

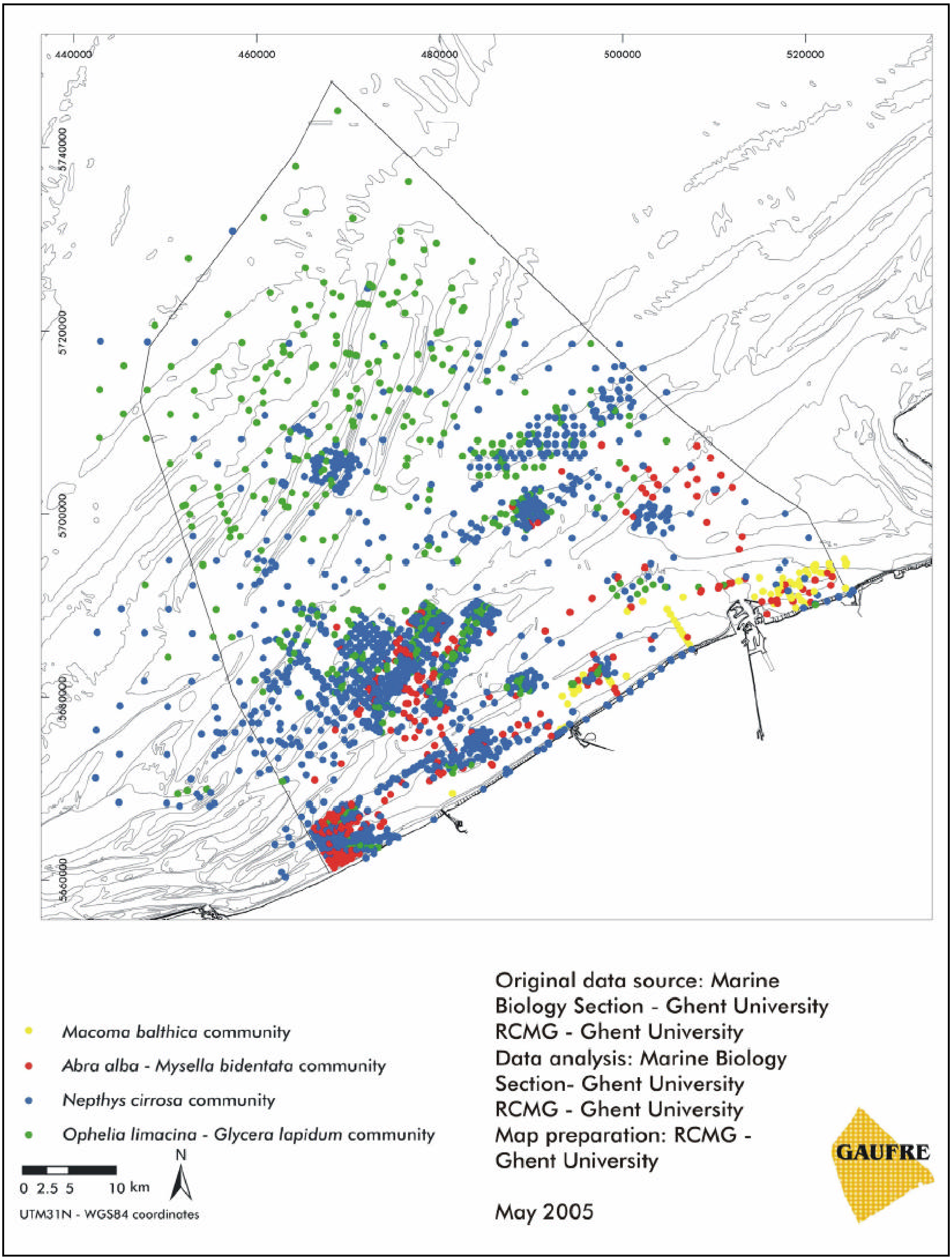
The geographical distribution of accident frequency results are shown in the files map2_x.bmp, where x=0 for all cargo spill, 1 to 10 is for cargo classes 1 to 10 respectively and 20 is for bunker spills.

III.3.3 Cargo Spilling Risk Results

The total frequency of serious accidents is shown as a function of accident type, ship type, cargo spill type and sub-area in the Excel sheet Results v0.xls, sheet "Results D1", rows 272 to 402.

The geographical distribution of accident frequency results are shown in the files map3_x.bmp, where x=0 for all cargo spill, 1 to 10 is for cargo classes 1 to 10 respectively and 20 is for bunker spills.

Annex 4.1: Spatial distribution of benthic communities at BPNS (Maes *et al.*, 2005)



Annex 4.2: Importance for biographical population, protection status (BD= bird directive, BE= Bern Convention, BO= Bonn Convention) and function BPNS (R= resting place (winter; M= migration corridor, F= fouraging area (breading seaon)) of the most important bird species (Stienen & Kuijken, 2003)

Bird species (English name)	*Bird species (scientific name)*	*Importance for biogeographical population*	*Protection*	*Function PPNS*
Common scoter	*Melanitta nigra*	low	-	R,M
Red throated diver	*Gavia stellata*	low	BD, BE, BO	R
Great crested grebe	*Podiceps cristatus*	medium	-	R, M
Little gull	*Larus minutus*	high	BE	M
Common tern	*Sterna hirundo*	high	BD, BE, BO	F, M
Sandwich tern	*Sterna sandvicensis*	high	BD, BE, BO	F, M
Razorbill	*Alca torda*	low	-	R
Guillemot	*Uria aalga*	low	-	R
Northern gannet	*Morus bassanus*	low	-	M
Lesser black-backer gull	*Larus fuscus*	medium	-	F, M
Fulmar	*Fulmar glacialis*	low	-	R
Great skua	*Stercorarius skua*	high	-	M
Black-headed gull	*Larus ridibundus*	low	-	R, M
Common gull	*Larus canus*	low	-	R
Herring gull	*Larus argentatus*	low	-	R, F, M
Great black-backed gull	*Larus marinus*	low	-	R, M
Kittiwake	*Rissa tridactyla*	low	-	R
Little tern	*Sterna albifrons*	low	BD, BE, BO	F, M
Arctic tern	*Sterna paradisaea*	negligible	BD, BE	
Black throated diver	*Gavia arctica*	negligible	BD, BE, BO	
Mediterranean gull	*Larus melanocephalus*	negligible	BD, BE, BO	

Annex 4.3: Determination of the sensitivity scores for the ecological and socio-economical parameters of the BPNS

GENERAL

A sensitivity analysis is set up to identify vulnerable areas in the marine and coastal zone of Belgium. The analysis consists of three important steps:

1. Criteria or parameters should be considered based on the characteristics that influence or describe the possible sensitivities best.
2. Scenarios should be identified to meet the temporal differences of the sensitivity analysis.
3. An objectively as possible sensitivity scoring (from zero to five) should be worked out for all parameters.

During a restricted public participation (PP) with the end-users of the RAMA project these three steps were treated to get a broader public platform for the sensitivity analysis. All end-users could evaluate the proposed parameters and add new parameters (ecological, socio-economical). They could give their opinion about possible scenarios. Finally all the parameters were scored by the different users. An average was taken of the different scores and divided (percentile) into a sensitivity class (5= high; 3= medium; 1= low) (PP).

A comparison of the results of the PP with the preliminary results of the RAMA project (Original) has led to the final identification of the scenarios and the ecological/ socio-economical parameters and their scoring used for the sensitivity analysis of the marine and coastal area of Belgium. In this final decision the results of the public participation (PP) has as much as possible been taken into account, but adapted where needed on the basis of expert judgement (PP + expert).

SENSITIVITY SCORING

		Original	*PP*	*PP+expert*
Ecological parameter				
Nature status	RAMSAR sites	5	5	5
	EC - Special Protected Areas (SPA) (in framework of habitat or bird directive)	5	5	5
	EC - Habitat Directive Area (Natura 2000)	5	5	5
	EC- Bird directive Area (Natura 2000)	5	3	5
	Marine Protected Areas (MPA)	3	3	3
	Strict nature reserve	3	3	3
	National park	3	1	1
	Beach (nature) reserves	1	3	3
	Nature reserve	1	1	1

		Original	*PP*	*PP+expert*
	Natural monument	1	1	1
	Landscape reserve (classified landscape)	1	1	1
Others				
Socio-economische parameters				
Recreation	Global tourist factor (beach recreation)	3	5	5
	Garded swimming zones	1	3	1
	Marinas	1	1	1
Fisheries	Spawning sites		5	5
	Concentration of fish		5	5
Shipping	Port	2	5	5
	Local port	1	1	1
	Anchorage area/ Shipping lane	0	1	0
Economical aspects	Touristal value coast	2	3	3
	Concession zone aggregate extraction at sea	1	1	1
	Concession zone wind energy at sea	1	1	1
Social aspects	High population (inh/km²)	1	3	1
	Overnight stays per month summer		3	3
	Overnight stays per month winter		1	1

SCENARIOS

During the public participation the end-users focused on the aspect that the interests of the different users of the BPNS vary in time. The tourist sector is mainly summer dependent, while for example some nature areas are of important value for wintering birds. Three different scenarios leading to different sensitivity maps have been identified through the public participation:

General scenario: scenario in which all parameters are evenly important or with other words have received the same weight factor (=1);

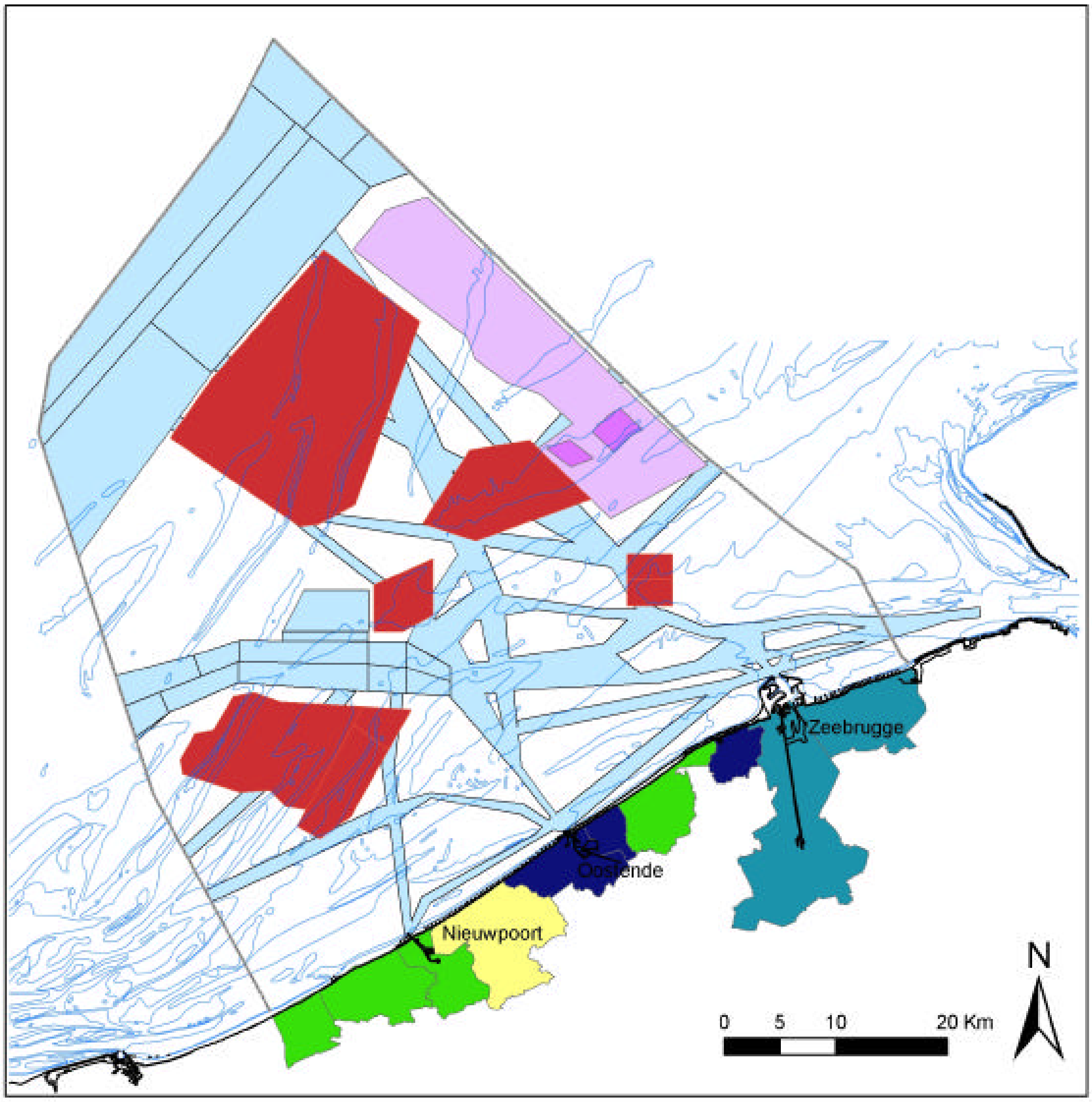
Summer scenario: scenario in which the tourist and recreational values of the coastal and marine areas have been given special attention (weight factor= 2), while the other factors have received a weight factor of 1;

Winter scenario: scenario in which the nature values (wintering-, foraging- and spawning areas) of the coastal and marine areas have been given special attention (weight factor= 2), while the other factors have received a weight factor of 1.

TOTAL SENSITIVITY SCORE

Taking into account the intensity of a parameter (absent/present (ecological); qualitatively (socio-economical), the sensitivity scoring and the weight factor, a total sensitivity score per cell (1 km^2) could be calculated.

Annex 4.4: Socio-economical parameters of the Belgian coast and marine waters



Risk Analysis of Human Activities at the Belgian Part of the North Sea (RAMA)
Financed by the Federal Science Policy Office

Data source shipping data: IVS-SRK database (AWZ, B&RWS, NL), Ferryways, Transeurope ferries
Data source wind concessions: EIA C-power & Cabinet North Sea
Data source aggregate concession: EIA Zeegra
Data source inhabitants: NIS statistics (2005)

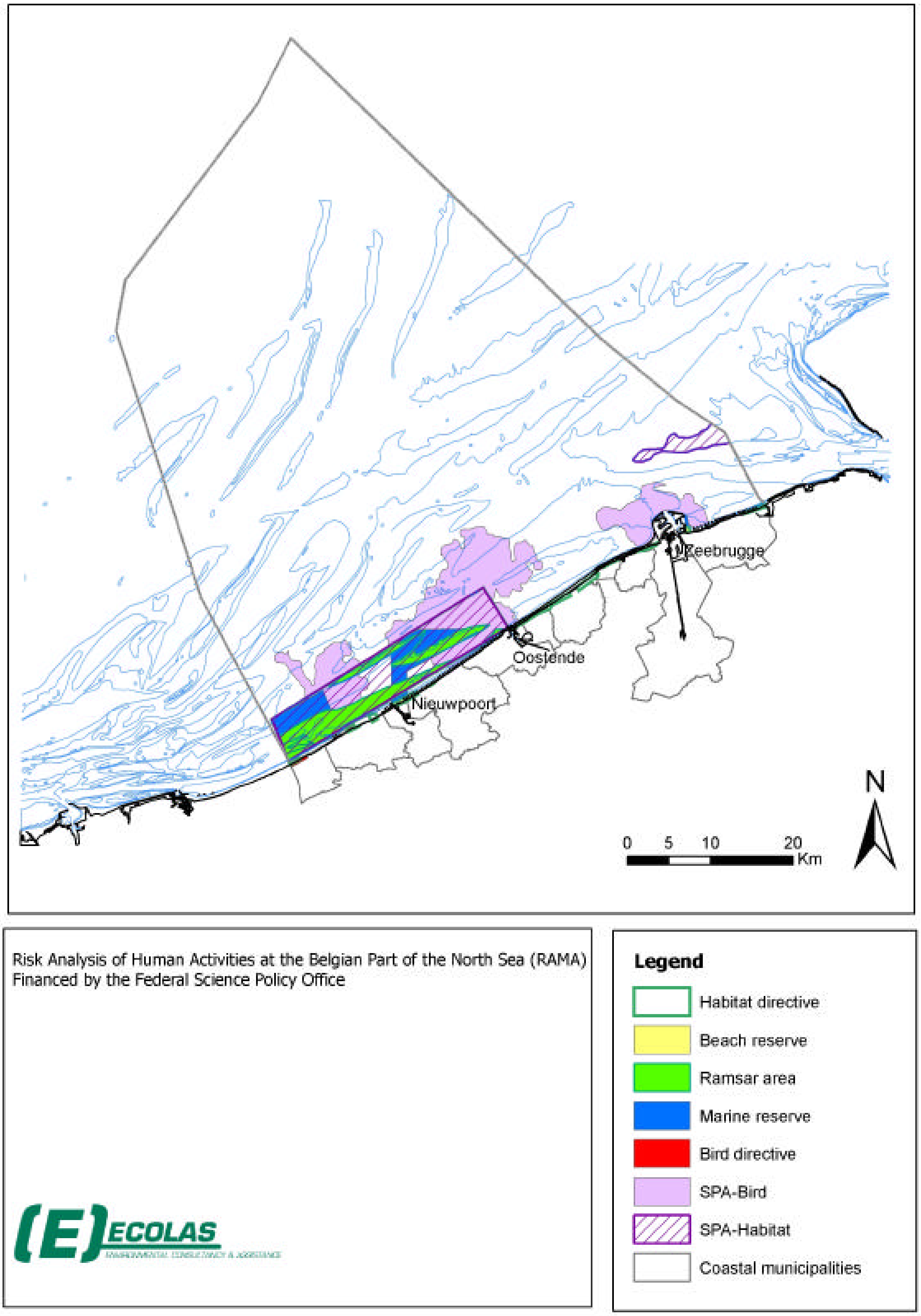
Legend

- C-power concession
- Wind concession
- Shipping lanes
- Aggregate concession

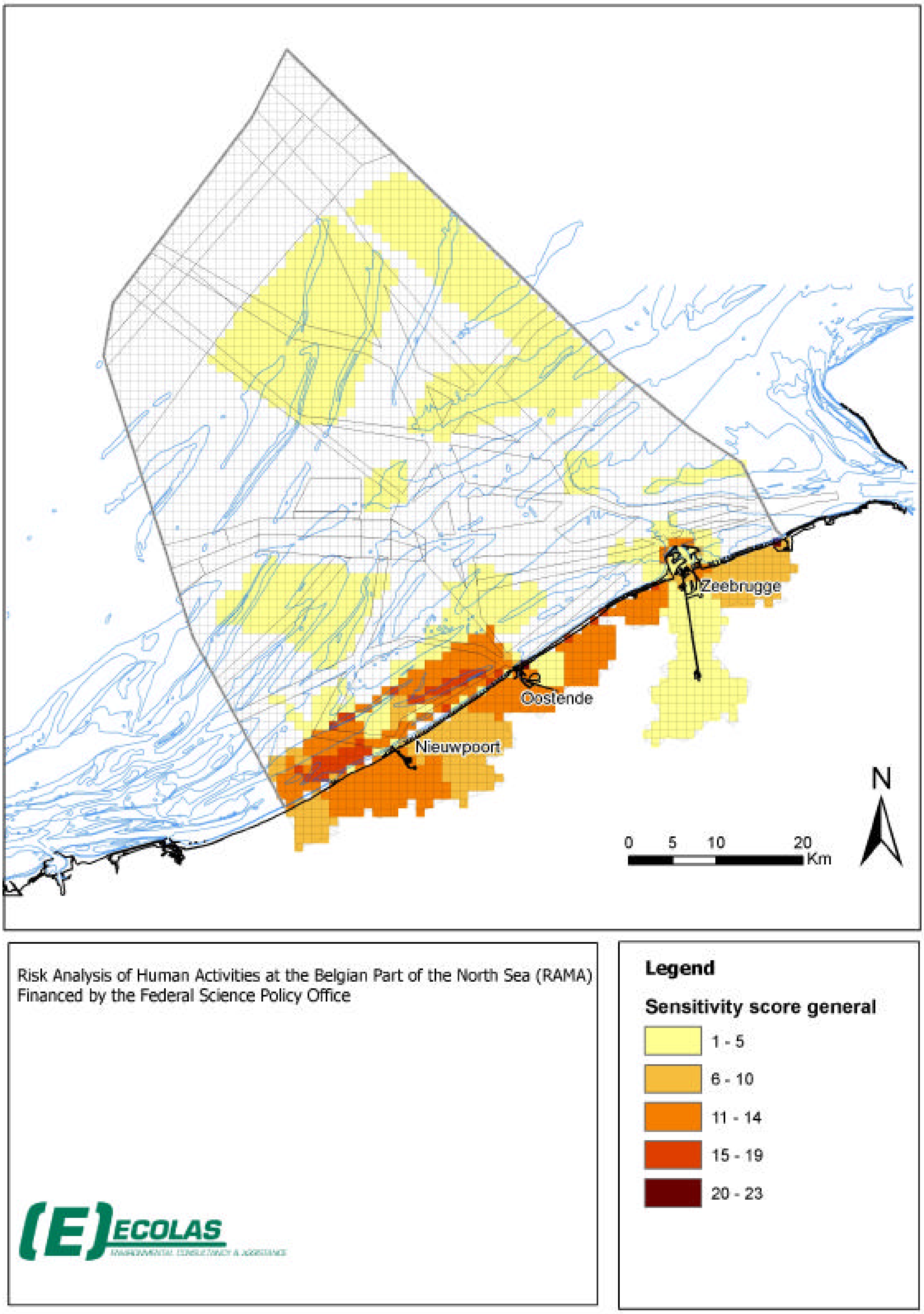
Coastal municipalities
(Inhabitants/km²)

- < 250
- < 500
- < 1000
- < 2000

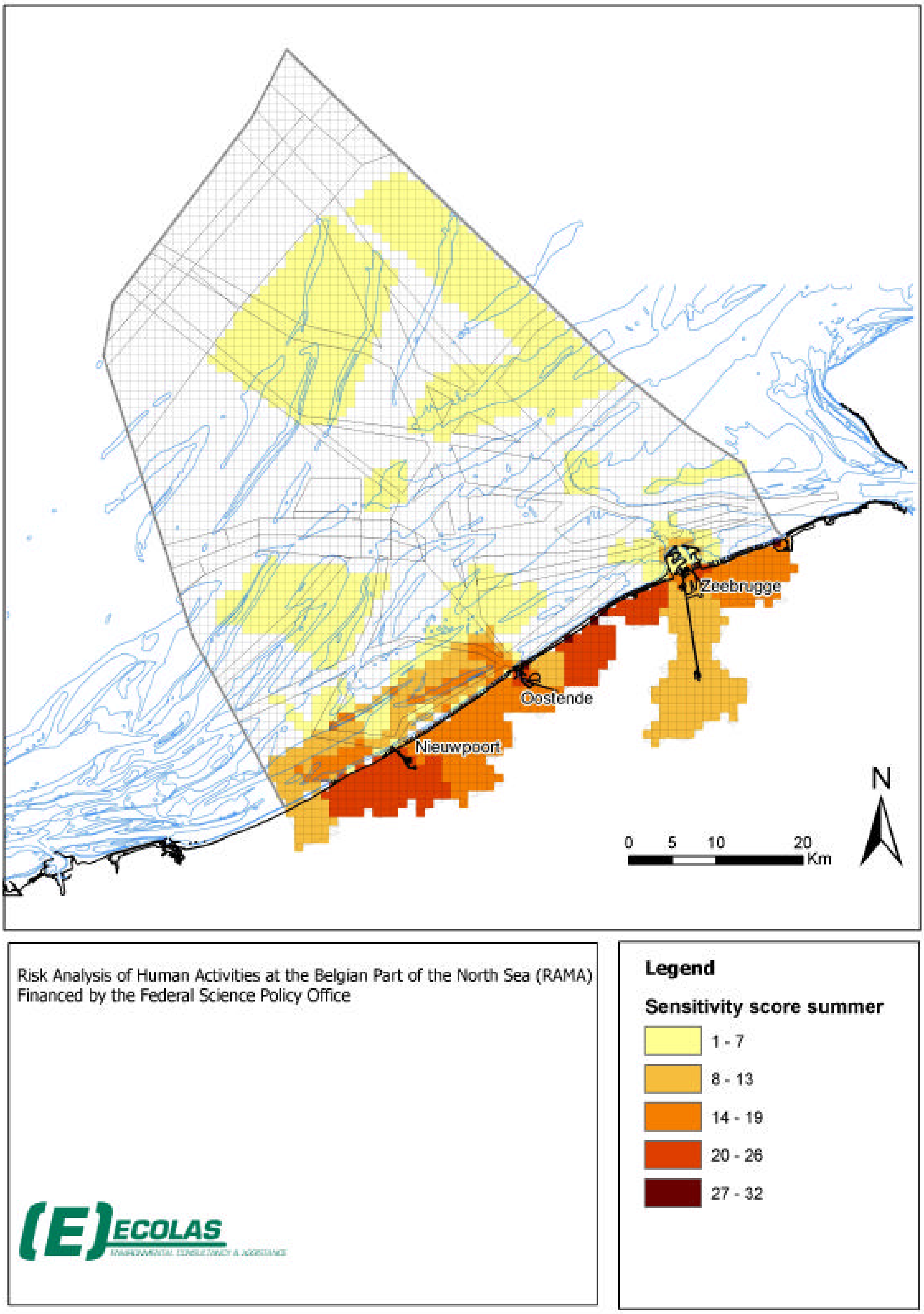
Annex 4.5: Ecological parameters of the Belgian coast and marine waters



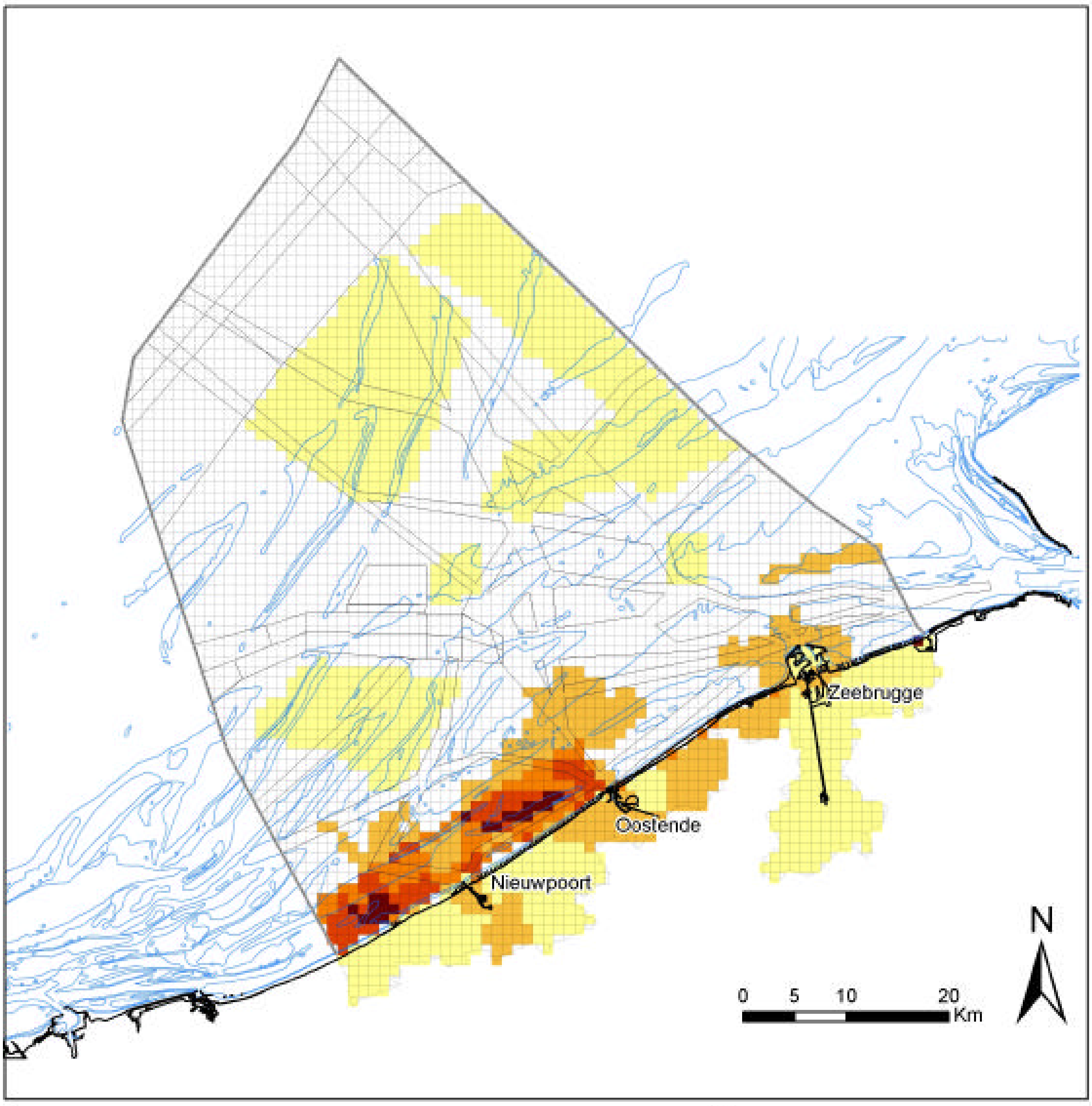
Annex 4.6: Sensitivity map (general scenario) of the Belgan coastal & marine area



Annex 4.7: Sensitivity map (summer scenario) of the Belgian coastal & marine area



Annex 4.8: Sensitivity map (winter scenario) of the Belgian coastal & marine area



Risk Analysis of Human Activities at the Belgian Part of the North Sea (RAMA)
Financed by the Federal Science Policy Office

ECOLAS

Legend

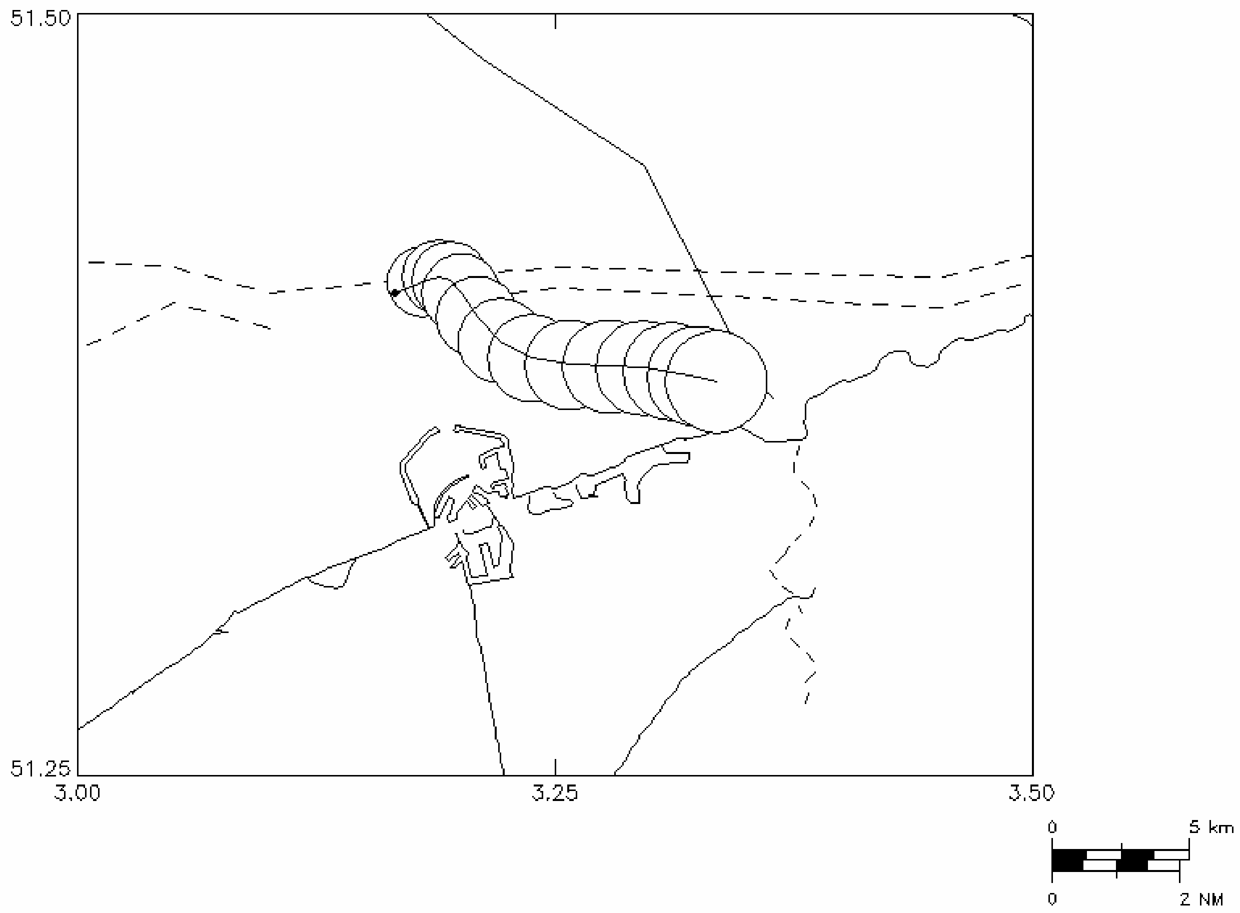
Sensitivity score winter

- 1 - 8
- 9 - 16
- 17 - 23
- 24 - 31
- 32 - 38

Annex 4.9: Modelling result of oil scenario (performed by MUMM, 2006)

Detailed description results MU-SLICKLETS model:

- Starting point in subarea SA3 (51°24’30’’N, 3°10’00’’E)
- Spill quantity: 19550 m³ heavy fuel 2
- Surface slick: 12,6 km² (Ø 4 km)
- Oil slick layer: 1 mm
- Time before coast (Zwin) is reached: 13 hours.



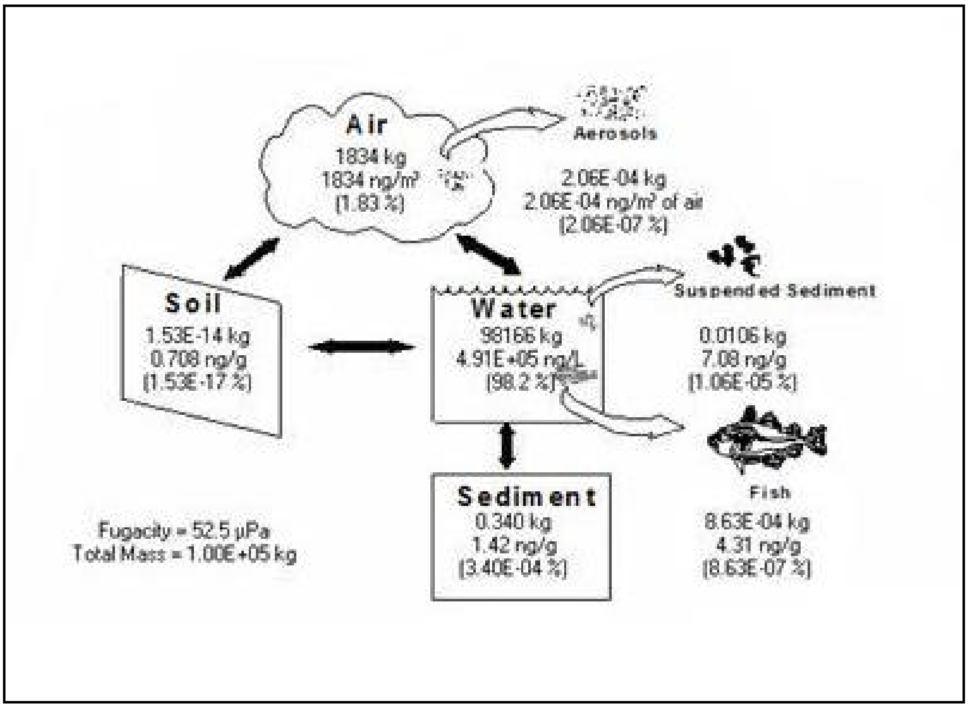
Annex 4.10: Density, oil vulnerability index (OVI) and% mortality –BPNS

Seabirds		*Max. density at BCP*	*Density per km²*	*Density per 30 km²*	*OVI*	*Mortality (%)*	*Mortality (#)*
Common scoter	*Melanitta nigra*	5846	2	49	52	62,97	31
Red throated diver	*Gavia stellata*	1382	0	12	50	60,55	7
Great crested grebe	*Podiceps cristatus*	3736	1	31	45	54,49	17
Little gull	*Larus minutus*	3670	1	31	46	55,70	17
Common tern	*Sterna hirundo*	7605	2	63	35	42,38	27
Sandwich tern	*Sterna sandvicensis*	4950	1	41	35	42,38	17
Razorbill	*Alca torda*	3791	1	32	64	77,50	24
Guillemot	*Uria aalge*	13163	4	110	62	75,08	82
Northern gannet	*Sula bassana*	3714	1	31	54	65,39	20
Lesser black-backed gull	*Larus fuscus*	15608	4	130	46	55,70	72
Fulmar	*Fulmarus glacialis*	1441	0	12	50	60,55	7
Great skua	*Stercorarius skua*	519	0	4	48	58,13	3
Black-headed gull	*Larus ridibundus*	2102	1	18	36	43,59	8
Common gull	*Larus canus*	11084	3	92	36	43,59	40
Herring gull	*Larus argentatus*	6094	2	51	42	50,86	26
Great black-backed gull	*Larus marinus*	5727	2	48	52	62,97	30
Kittiwake	*Rissa trdactyla*	6462	2	54	54	65,39	35
Little tern	*Sterna albifrons*	1275	0	11	35	42,38	5
Arctic tern	*Sterna paradisaea*	255	0	2	35	42,38	1
Black throated diver	*Gavia arctica*	101	0	1	50	60,55	1
Mediterranean gull	*Larus melanocephalus*	270	0	2	36	43,59	1

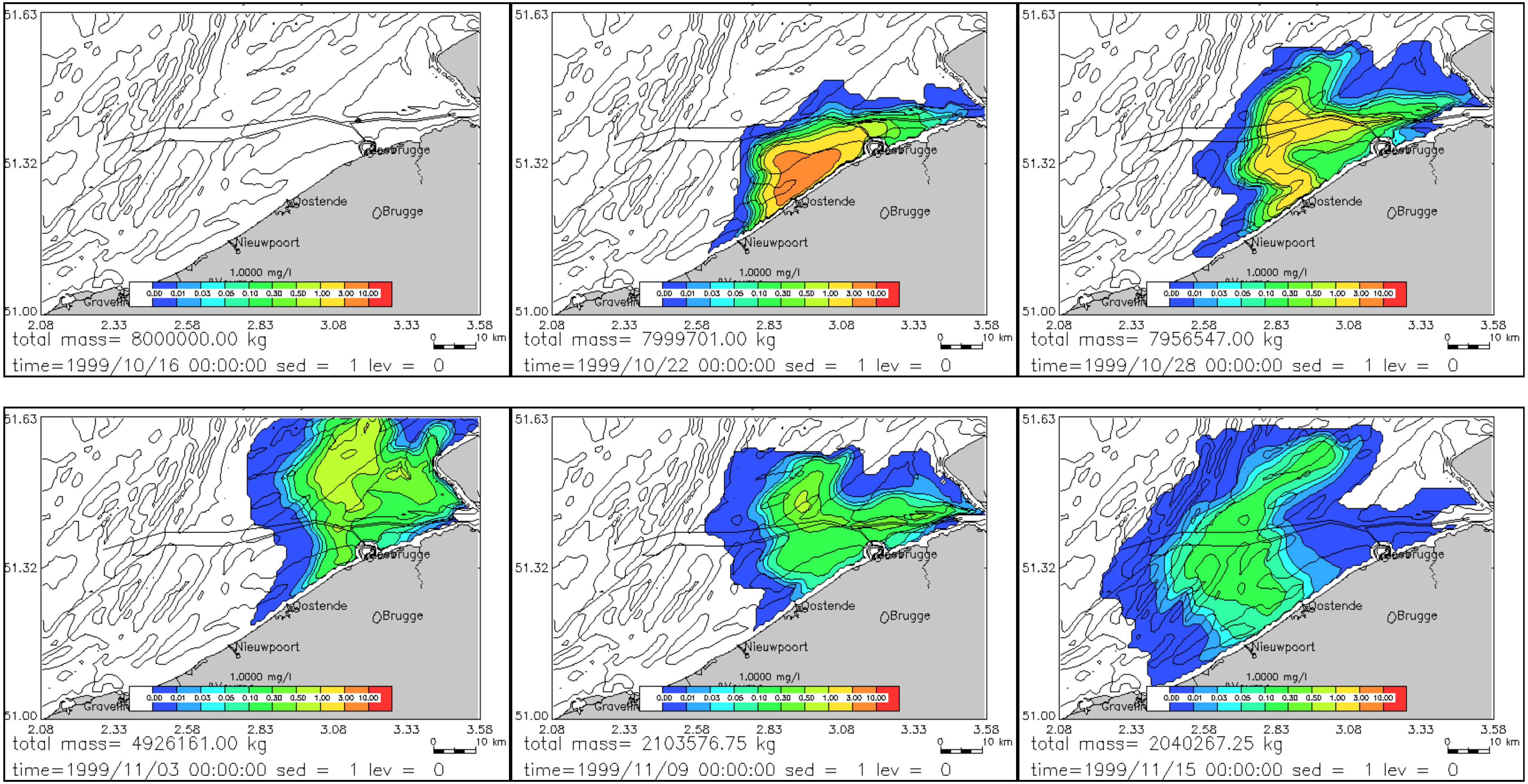
Annex 4.11: Density, oil vulnerability index (OVI) and% mortality – Zwin (winter)

Seabirds		*#/ha*	*#/75 ha*	*OVI*	*Mortality (%)*	*Mortality (#)*
Great crested grebe	*Podiceps cristatus*	0,15	12	45	54,49	6
Common goldeneye	*Bucephala clangula*	0,12	9	50	60,55	5
Mediterranean gull	*Larus melanocephalus*	0,07	5	36	43,59	2
Little gull	*Larus minutus*	0,01	1	46	55,70	0
Black-headed gull	*Larus ridibundus*	16,67	1250	36	43,59	545
Common gull	*Larus canus*	0,40	30	36	43,59	13
Lesser black-backed gull	*Larus graellsii*	0,01	1	46	55,70	0
Herring gull	*Larus argentatus*	3,50	263	42	50,86	134
Great black-backed gull	*Larus marinus*	0,04	3	52	62,97	2
Kittiwake	*Rissa tridactyla*	0,01	1	54	65,39	1
Sandwich tern	*Sterna sandvicensis*	0,00	0	35	42,38	0
Little tern	*Sterna albifrons*	0,00	0	35	42,38	0
Arctic tern	*Sterna paradisaea*	0,00	0	35	42,38	0
Common tern	*Sterna hirundo*	0,01	1	35	42,38	0
Guillemot	*Uria aalge*	0,00	0	62	75,08	0
Great cormorant	*Phalacrocorax carbo*	0,57	43	62	75,08	32
Northern gannet	*Morus bassanus*	0,00	0	54	65,39	0
Great skua	*Stercorarius skua*	0,00	0	48	58,13	0
Waterbirds		*#/ha*	*#/75 ha*	*OVI*	*Mortality (%)*	*Mortality (#)*
Mallard	*Anas platyrhynchos*	31,67	2375		50	1188
Lapwing	*Vanellus vanellus*	14,67	1100		50	550
Wigeon	*Anas penelope*	7,00	525		50	263
Dunlin	*Calidris alpina*	3,73	280		50	140
Oystercatcher	*Haematopus ostralegus*	1,65	124		50	62
Shelduck	*Tadorna tadorna*	1,11	84		50	42
Curlew	*Numenius arquata*	2,93	220		50	110
Golden plover	*Pluvialis apricaria*	2,93	220		50	110
Grey plover	*Pluvialis squatarola*	1,22	92		50	46
Teal	*Anas crecca*	2,27	170		50	85

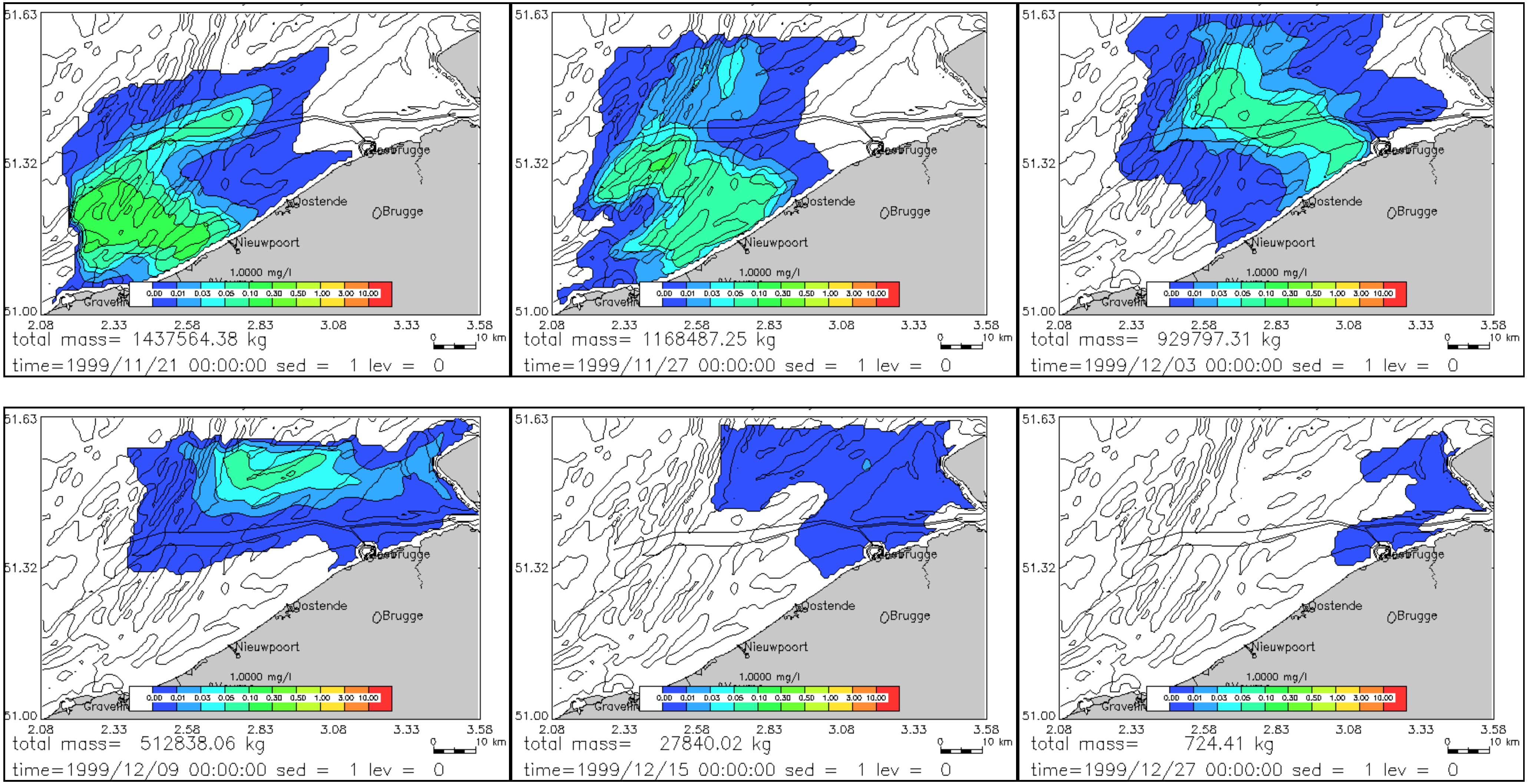
Annex 4.12: Simulation of behaviour of acetone cyaonohydrin (Mackay model)



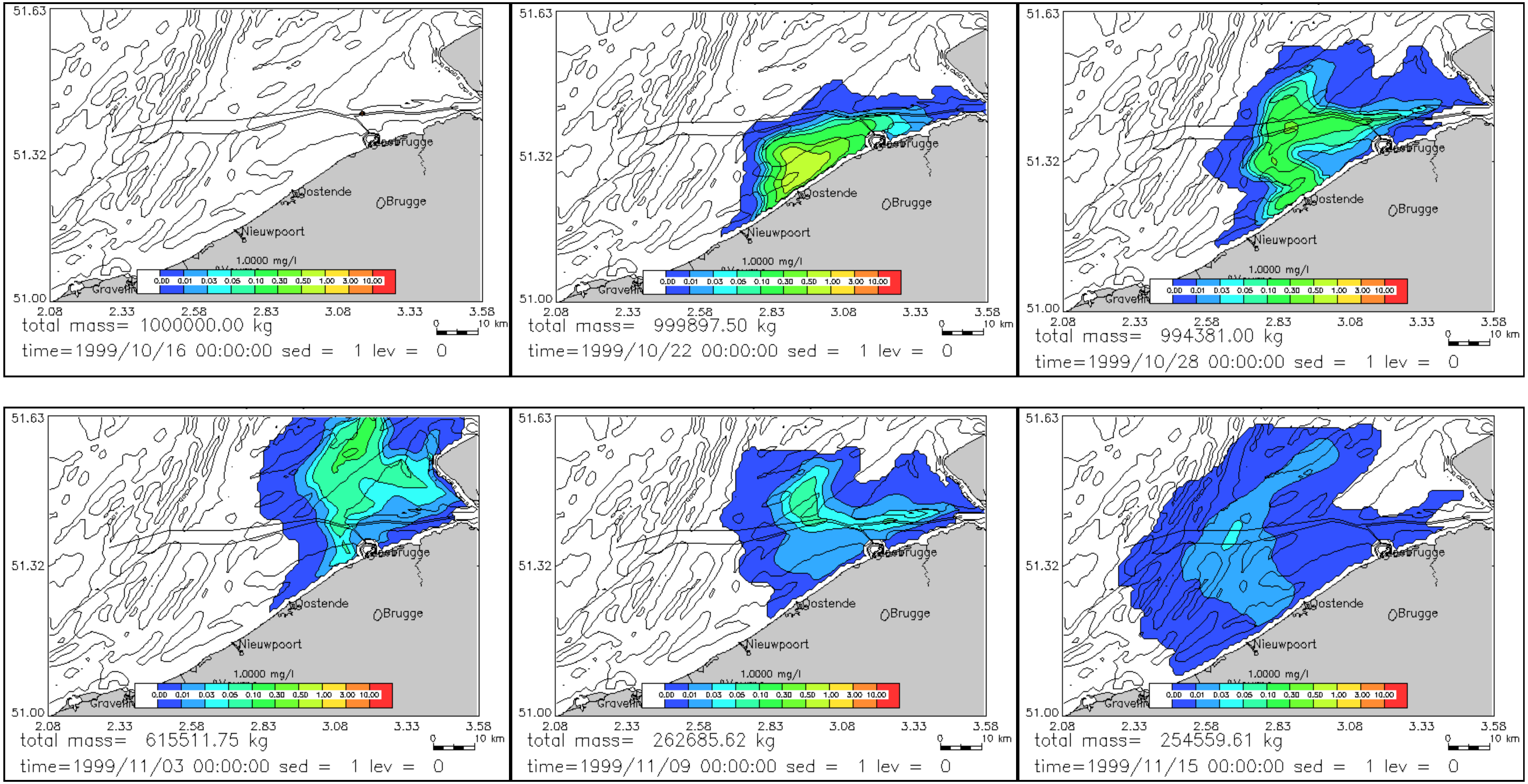
Annex 4.13: Acetone cyanohydrin simulation of 8.000 ton spill (time periode: 75 days) (Executed by MUMM, 2006)



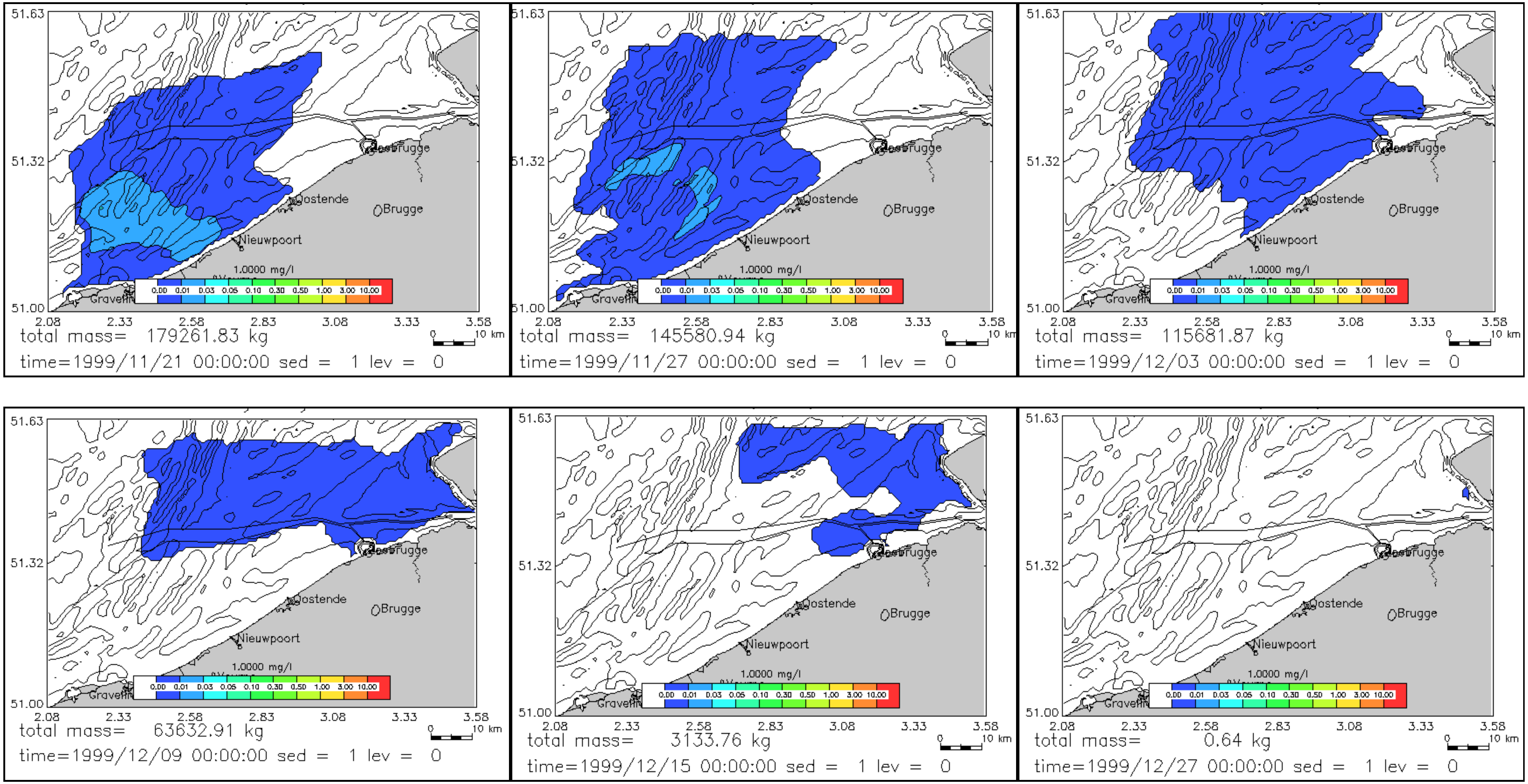
Annex 4.13: Acetone cyanohydrin simulation of 8.000 ton spill (time periode: 75 days) (Executed by MUMM, 2006) (continued)



Annex 4.14: Acetone cyanohydrin simulation of 1.000 ton spill (time periode: 75 days) (Executed by MUMM, 2006)

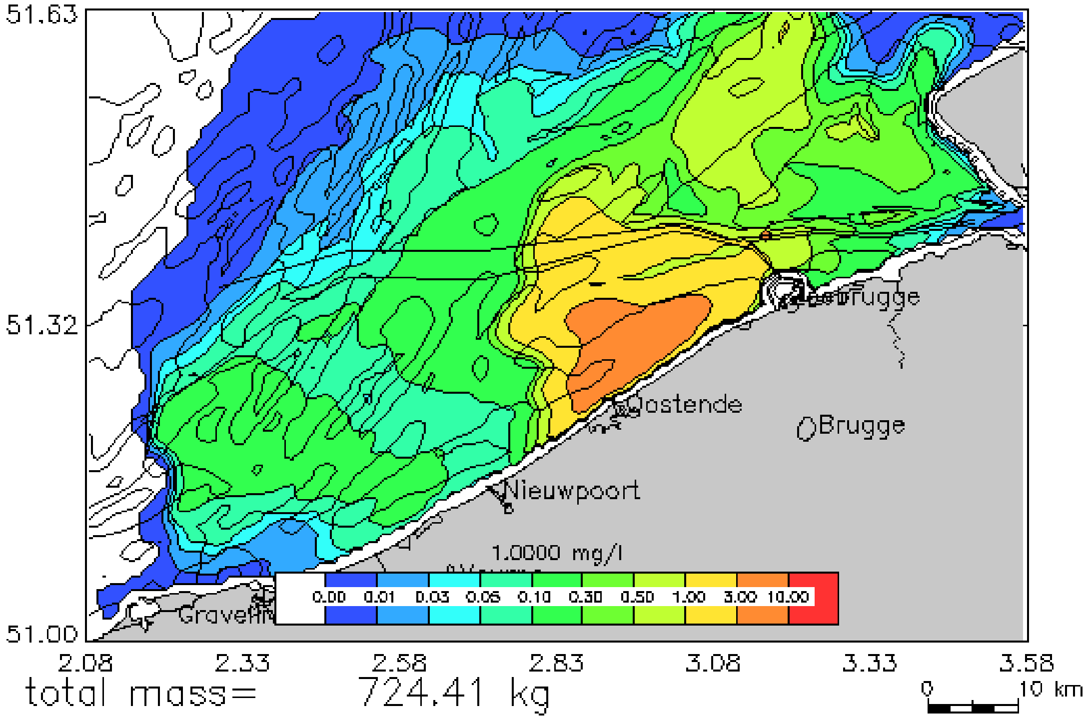


Annex 4.14: Acetone cyanohydrin simulation of 1.000 ton spill (time periode: 75 days) (Executed by MUMM, 2006) (continued)

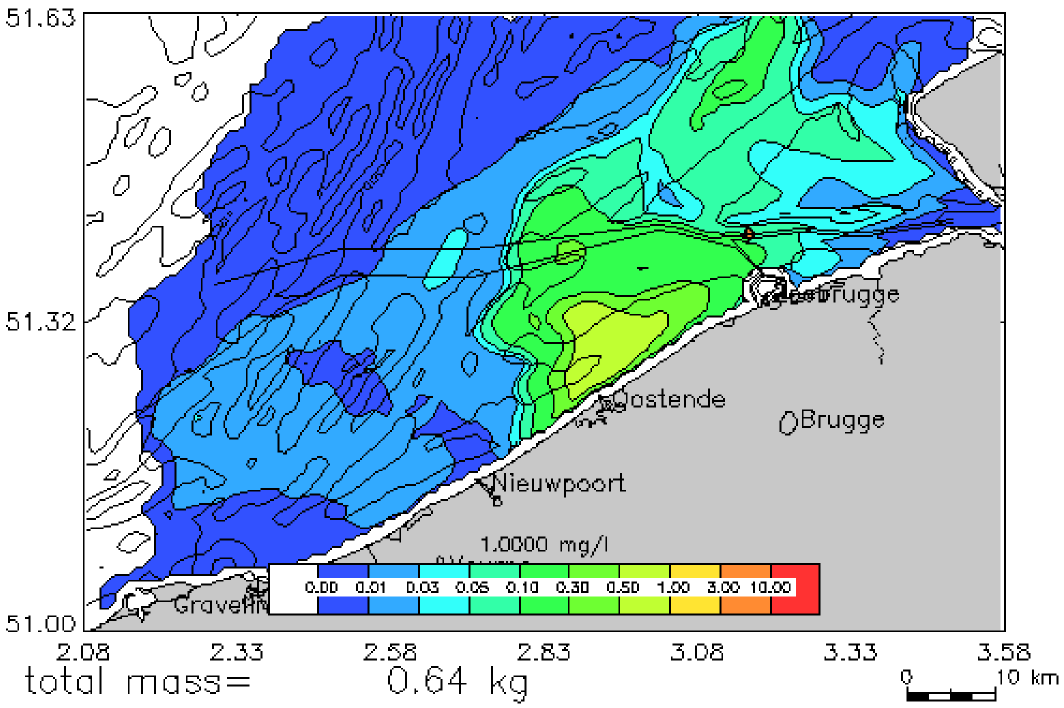


Annex 4.15: Maximum concentration (mg/l) acetone cyanohydrine on BPNS (result simulation 75 days) (MUMM, 2006)

Result of simulation of 8.000 ton/accident



Result of simulation of 1.000 ton/accident



Annex 6.1: Examination and proposals for improvement of existing contingency plans