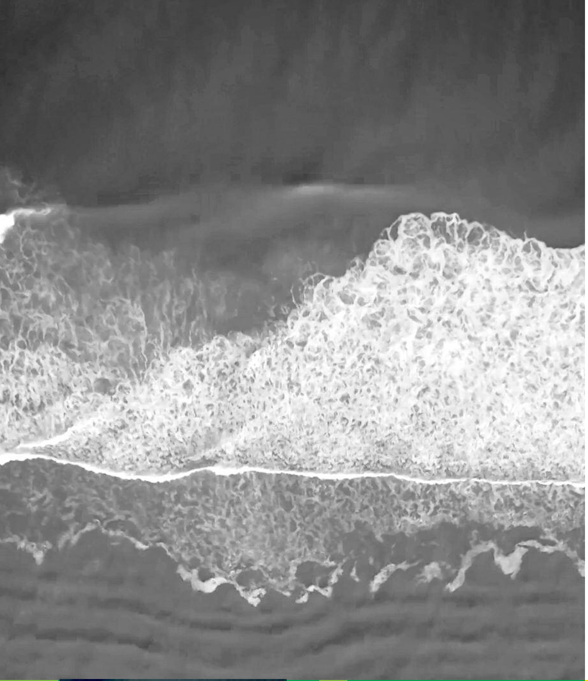


República Islamique de
Mauritanie

Honneur-Fraternité-Justice

Ministère de l'Environnement et du Développement Durable

Direction du Contrôle Environnemental

République du
Sénégal

Un peuple-Un but-Une foi

Ministère de l'Environnement et du Développement Durable

Direction de l'Environnement et des Établissements Classés

Greater Tortue / Ahmeyim
Phase 1 Gas Production Project

Environmental and Social Impact Assessment

Consolidated Final Report Including Regulatory Reviews from Mauritania and Senegal

June 2019

Volume 5 of 7

bp

In partnership with

KOSMOS ENERGY PETROSEN SMHPM

ESIA report produced by

GOLDER CSA Ocean Sciences Inc. Ecodev TROPICA ENVIRONMENTAL CONSULTANTS

The report on the environmental and social impact assessment for the Greater Tortue/Ahmeyim Phase 1 Gas Production Project is divided into 7 volumes as follows:

The present document is **Volume 5** which contains:

APPENDIX K : WATER DISCHARGES CALCULATIONS AND PRODUCED WATER MODELING REPORT

Appendix K
Water Discharges Calculations and Produced Water Modeling Report

APPENDIX CONTENTS

APPENDIX K-1 : WATER DISCHARGES CALCULATIONS

DISCHARGES FROM PREPARATION, CONSTRUCTION AND INSTALLATION

Nearshore Hub							
Vessel	**Number of Vessels**	**Days Used**	**POB**	**(m^3) Daily - Grey**	**(m^3) Daily - Black**	**(m^3) Total - Grey**	**(m^3) Total - Black**
Dredger	2	90	20	7	5	637	443
Rock dumper	2	130	50	18	12	2 301	1 599
Support boat	6	660	6	6	4	4 206	2 922
Crane barge	3	130	20	11	7	1 381	959
HLD barge	1	65	60	11	7	690	480
Anchor vessel	3	20	15	8	6	159	111
Tug boat	4	20	6	4	3	85	59
Project patrol vessel	1	660	7	1	1	818	568
Standby vessel	1	660	15	3	2	1 752	1 218
Supply vessel	2	220	15	5	4	1 168	812
Crew boat	2	110	4	1	1	156	108
Flotel	1	210	250	44	31	9 293	6 458
Piling vessel	1	540	30	5	4	2 867	1 993
Sum				***125***	***87***	***25 513***	***17 729***

FPSO Hook Up and Commissioning							
Vessel	**Number of Vessels**	**Days Used**	**POB**	**(m^3) Daily - Grey**	**(m^3) Daily - Black**	**(m^3) Total - Grey**	**(m^3) Total - Black**
Anchor vessel	3	36	16	8	6	306	213
Tug boat	4	30	10	7	5	212	148
Project patrol vessel	1	60	7	1	1	74	52
Standby vessel	1	60	14	2	2	149	103
Supply vessel	2	20	14	5	3	99	69
Crew boat	2	110	4	1	1	156	108
Derrick barge	1	18	50	9	6	159	111
Multi Service Vessel (MSV)	1	36	25	4	3	159	111
Sum				***39***	***27***	***1 315***	***914***

DISCHARGES FROM PREPARATION, CONSTRUCTION AND INSTALLATION

Subsea Installation							
Vessels							
Vessel	**Number of Vessels**	**Days Used**	**POB**	**(m^3) Daily - Grey**	**(m^3) Daily - Black**	**(m^3) Total - Grey**	**(m^3) Total - Black**
S-Lay vessel	1	120	300	53	37	6 372	4 428
J-Lay vessel	1	90	200	35	25	3 186	2 214
Heavy Lift Vessel	1	290	60	11	7	3 080	2 140
ROV survey vessel	1	50	50	9	6	443	308
Pipe Carrier vessel	1	160	80	14	10	2 266	1 574
Dive support vessel	1	16	80	14	10	227	157
Multi Service Vessel	1	180	25	4	3	797	554
Supply vessel	1	30	22	4	3	117	81
Umbilical Installation Vessel	1	34	50	9	6	301	209
Project patrol vessel	1	56	7	1	1	69	48
Sum				***155***	***108***	***16 856***	***11 714***
Pipeline Discharges							
Source		**Total Volume**	**Volume Factor**				**Total (m^3)**
Production Flowline		16,245.6 m^3	16 246				16 246
Gas Export Pipeline		18,315 m^3	18 315				18 315
Gas Export Risers		45 m^3	45				45
MEG Pipeline		1,004 m^3	1 004				1 004
Sum							***35 610***

DISCHARGES FROM PREPARATION, CONSTRUCTION AND INSTALLATION

Drilling							
Vessels							
Vessel	**Number of Vessels**	**Days Used**	**POB**	**(m^3) Daily - Grey**	**(m^3) Daily - Black**	**(m^3) Total - Grey**	**(m^3) Total - Black**
Drillship	1	700	200	35	25	24 780	17 220
Supply vessel	1	81	30	5	4	430	299
Standby vessel	1	81	20	4	2	287	199
Sum				***44***	***31***	***25 497***	***17 718***
Other Drilling-Related Discharges							
Source	**Specifica-tions**	**Single Albian Well (m^3)**	**6 Albian Wells (m^3)**	**Single Cenomanian Well (m^3)**	**6 Cenomanian Wells (m^3)**		**Total (m^3)**
Drill cuttings/well	12 wells	683	4098	641	3846		7 944
Drill muds/well	12 wells	316	1896	297	1782		3 678
	Specifica-tions	**Units/Period**	**Total (bbl)**				
Bilge water (drillship)	79	bbl/wk	7900				1 264
Bilge water (support vessels)	48	bbl/day	7776				1 244
Ballast (drillship)	620	bbl/day	434000				69 440
Sum							***71 948***

Note: In several cases, days used are presented in Section 2 as ranges; the higher (most conservative) usage is presented in these calculations

Factors (m^3/person/day)	
0.3 m^3/person/day	
Grey	Black
0,177	0,123

DISCHARGES FROM OPERATIONS

Hub and FPSO

Vessel	Number of Vessels	Days Used/Year	POB	(m^3) Daily - Grey	(m^3) Daily - Black	(m^3) Total/Year - Grey	(m^3) Total/Year - Black
Vessels							
Tug boat	4	182,5	10	7	5	1 292	898
Supply vessel	2	182,5	22	8	5	1 421	988
Crew boat	3	182,5	4	2	1	388	269
LNGC	1	36,5	22	4	3	142	99
Condensate carrier	1	5,6	22	4	3	22	15
Mooring Line vessel	3	182,5	4	2	1	388	269
Project patrol vessel	2	365	7	2	2	904	629
Sum				***29***	***20***	***4 557***	***3 167***

Other Discharges

Source	Specifications	Total Volume	Volume Factor	Total/Day	Notes		Total/Year
FPSO Produced water		99 m^3/day	99		365 days/year		36 135
FPSO Cooling and Desal water		96,000 m^3/day	96 000		365 days/year		35 040 000
FPSO Deck Drains		21.9 m^3/day	21,9		30 days/year		657
FPSO Wastewater/Food Waste		25 m^3/day	25		365 days/year		750
			FPSO	*96 146*			
FLNG Cooling water	54,000 m^3/hr	1,296,000 m^3/day	1 296 000		365 days/year		473 040 000
FLNG brine	7.2 m^3/hr	172.8 m^3/day	173		365 days/year		63 072
QU Wastewater	0.3 m3/person/day	48 m3/day	48		365 days/year		17 520
QU Deck drainage	(Estimated)	5 m^3/day	5		30 days/year		150
			FLNG/QU	*1 296 226*			
Sum							***508 198 284***

Note: In several cases, days used per year are presented in Section 2 as ranges; the higher (most conservative) usage is presented in these calculations

Factors (0.3 m^3/person/day)	
Grey	Black
0,177	0,123

DISCHARGES FROM DECOMMISSIONING

Vessel	Number of Vessels	Days Used	POB	(m^3) Daily - Grey	(m^3) Daily - Black	(m^3) Total - Grey	(m^3) Total - Black
FPSO and SPS							
Vessels							
Drillship	1	21	200	35	25	743	517
Standby vessel	1	24	20	4	2	85	59
Supply vessel	1	24	22	4	3	93	65
ROV survey vessel	1	15	50	9	6	133	92
Tug boat	2	10	10	4	2	35	25
Crew boat	1	90	4	1	0,5	64	44
Multi-service vessel	2	24	25	9	6	212	148
Sum				***65***	***45***	***1 366***	***949***

Factors (0.3 m^3/person/day)	
Grey	Black
0,177	0,123

Vessel	Number of Vessels	Days Used	POB	(m^3) Daily - Grey	(m^3) Daily - Black	(m^3) Total - Grey	(m^3) Total - Black
Hub - FLNG, QU Platform							
Vessels							
Supply vessel	1	24	22	4	3	93	65
Standby vessel	1	24	20	4	2	85	59
Anchor vessel	2	64	15	5	4	340	236
Crane vessel	2	64	20	7	5	453	315
Tug boat	6	80	10	11	7	850	590
Crew boat	1	90	4	1	0,5	64	44
Multi-service vessel	2	24	25	9	6	212	148
Sum				***40***	***28***	***2 097***	***1 457***

Factors (0.3 m^3/person/day)	
Grey	Black
0,177	0,123

WASTEWATER FACTORS (m^3/person/day)

Phase	Grey Water	Black Water	Total
Decommissioning - Hub	0,177	0,123	0,3
Decommissioning - FPSO, SPS	0,177	0,123	0,3
Installation & Operation	0,177	0,123	0,3

Notes:

BP cites wastewater generation at 0.3 m^3/person/day, maximum

USEPA (1993) cites 185 liters/person/day - 110 liters (grey water)/person/day and 75 liters (black water)/person/day

0.3 m^3/person/day used for installation, operations, and decommissioning at FPSO and SPS, consistent with BP documentation

0.3 m^3/person/day used for decommissioning at the Hub, correcting BP documentation

Division of grey water and black water (per USEPA, 1993 proportions):

Grey water: 110/185 = 0.59

Black water: 75/185 = 0.41

For 0.3 m^3:

grey water: 0.177 m^3/person/day (0.3 x 0.59)

black water: 0.123 m^3/person/day (0.3 x 0.41)

PIPELINE INSTALL/COMMISSIONING
(Flood, hydrotest, leak test, dewater;
Table 2-26)

Production flowline	2 472	
Production flowline	210	
Production flowline	156	
Production flowline	2,6	
Production flowline	223	
Production flowline	13 182	16 246 sum
Gas export pipeline	2 968	
Gas export pipeline	252	
Gas export pipeline	253	
Gas export pipeline	14 842	18 315 sum
Gas export risers	45	45 sum
MEG pipeline	162	
MEG pipeline	14	
MEG pipeline	15	
MEG pipeline	813	1 004 sum

Discharges and Vessel Usage Source Documents

The following source documents were used to compile this appendix.

Drilling-Related Chemicals and Drilling Fluids/Muds:

1. Environmental Impact Assessment for Exploratory Drilling, Saint-Louis Offshore Profond and Cayar Offshore Profond Blocks, Offshore Senegal; prepared for Kosmos, 2015.
2. Drill Cuttings Volume Worksheet Tortue Dev Cenomanian 28th July 2017
3. Drill Cuttings Volume Worksheet Tortue Dev Albian 28th July 2017

Other Chemicals:

1. Functional FPSO Specifications/MS002-EM-PE-010-03001 B02
2. Waste_Discharge_Inventory_revGBA.pdf

Effluents and Wastes:

1. Project Discharges and Waste Inventory B01
2. J7047-BP-TE-T-002 Operations - Effluents and Wastes
3. J7047-BP-TE-T-002 Operations - Effluents and Wastes, Rev1
4. Tortue Concept Select BOD/J7018-BP-TB-B-001, Rev0
5. Produced Water Modelling Report/MS002-EV-REP-000-03001 A01
6. Produced Water Modelling Report/MS002-EV-REP-000-03001 B02
7. J7047-BP-TE-T-006 Commissioning and Start-up - Effluents and Wastes Rev0

Vessels and Vessel Usage:

1. Vessel description-04012017
2. Energy Usage and Air Emissions Forecast/MS002-EV-REP-010-01002 B02

APPENDIX K-2 : PRODUCED WATER MODELING REPORT

Security Classification: General	Mauritania & Senegal Region	KBR
bp	Tortue Phase 1	

TORTUE DEVELOPMENT PROJECT

Produced Water Modelling Report

B02	Issued for Use	28/03/2018	Paul Page PP	Richard Pawson /Steve Cousins SJ Cousins	David Cowie	KBR DMG
A01	Issued for Review	17/01/2018	Paul Page	Richard Pawson /Steve Cousins	David Cowie	KBR DMG
Rev.	Reason for Issue	Date	Author	Checker	Approver	DMG QA

Refresh Cycle Code (Years):	Not Applicable

Unique Identifier:	Not Applicable	MS002-EV-REP-010-03001	Rev.
RD Type:	Not Applicable		B02

Uncontrolled when printed or stored locally

Revision History*

Revision Date	Revision Number	Approver	Revision
21st Dec 2017	A01	Paul Page	1st Draft Issued for checking and review
05th Jan 2018	B01	Paul Sutherland Steve Cousins	Issued for Use
20th March 2018	B01-01	Paul Page	Issued for review - Report updated to include mercury contaminants in the PW discharges
26th March 2018	B02	Paul Sutherland Steve Cousins	Issued for Use - Report updated to include mercury contaminants in the PW discharges

* history prior to front page.

Operating Management System (OMS)

OMS Sub-element	OMS Sub-element Title	Relevant Section(s) of this Document
3.6	Environment	
7.1	Regulatory Compliance	

Hold References

Hold Reference	Description / Reason for Hold	Relevant Section(s) of this Document
<HOLD01>		
<HOLD02>		

This is an optional table and can be removed if it is not required. It is intended to list all items in the document that are held, and the reason for the hold. A single 'hold' may apply to more than one section of the document. When holds are released, the relevant entry in the table should be deleted as well as being removed from the body of the text.

Reviewers

Name	Role	Type of Review	Date Reviewed
Steve Cousins	Environmental Advisor - Mauritania and Senegal, GPO - Tortue		

Related Documents

GPO Document Number / Identifier	RD Identifier (If Applicable)	Document Name	Location

Unless stated otherwise in the content of this document, reference to the documents above is for information. Specific sections of the referenced documents will be given in the content of this document if conformance is required.

Contents

1 Executive summary

This report describes the findings of a modelling study conducted to assess the potential ecological exposure risks associated with various offshore produced water (PW) discharge scenarios from the Tortue Development Floating Production Storage and Offloading (FPSO) vessel. In accordance with the Basis of Design, it has been assumed that free oil separation has been performed using hydro cyclones /induced gas flotation. The study has been carried out to support the Environmental and Social Impact Assessment (ESIA) for Tortue Phase 1A.

The purpose of the modelling was to:

- Simulate anticipated continuous discharge flow rates and effluent compositions over a 45 day period;
- Provide a quantitative assessment of the environmental risk to the marine environment associated with various discharge scenarios.
- Establish the relative contribution of key contaminants to the environmental exposure risk
- Understand the sensitivity of the risk to changes in hydrocarbon component concentrations and production chemicals in the PW discharge as well as ambient conditions (background current speed etc.).

The methodology used in this study is aligned with OSPAR Recommendation 2012/5 for a Risk Based Approach (RBA) to the Management of Produced Water Discharges from Offshore Installations (1) and the OSPAR Guidelines in support of Recommendation 2012/5 (2).

The OSPAR RBA was developed specifically for the offshore environment and follows the internationally recognised principles of ERA already in place in Europe (ECHA – Technical Guidance documents (3, 4)) and is currently being implemented in the North East Atlantic region.

The OSPAR risk assessment process follows the standard data collection, hazard assessment, exposure assessment and risk characterization steps, which are described in more detail below. The risk characterization step is based on the same widely accepted principle of comparing a Predicted Environmental Concentration (PEC) for each chemical compound discharged into the receiving environment to a Predicted No Effect Concentration (PNEC). When PEC is larger than the threshold PNEC, there may be a risk for damage. When the PEC is lower than the PNEC threshold, the risk for damage is considered to be “acceptable”.

A Substance Based Approach (SBA) was used to estimate the PW effluent toxicity associated with each discharge scenario. The approach involves estimating the concentration of each Naturally Occurring Substance (NOS) and production chemical additive in the PW discharge and gathering eco toxicological information and physical-chemical properties data for each contaminant present. The eco toxicological information is used to estimate PNEC values for each substance.

The Dose-related Risk and Effect Assessments Model (DREAM) was then used to calculate the dispersion of PW discharges and to calculate the Environmental Impact Factor (EIF). The EIF represents the aggregation of PEC/PNEC ratios for all contaminants in the discharge into a single integrated risk value, which is related to the probability of damage. One EIF unit represents a volume of water (defined as 10^5 m^3) which has the potential to harm $\geq$ 5% of the marine species in the receiving environment, if they become exposed to harmful substances arising from the discharge.

The EIF approach has the advantage that it provides a quantitative measure of the environmental risks involved when produced water discharges are released into the sea. In addition, when the risk characterisation follows a SBA, the EIF method is able to quantify the EIF contribution from each contaminant in the discharge and is thus able to provide a basis for reduction of exposure risk in a systematic and a quantitative manner.

Eight PW discharge scenarios were modelled to investigate the sensitivity of ecological risk to Benzene, Toluene Ethyl-benzene and Xylene (BTEX) concentrations in the effluent (Base Case and "High" BTEX case), both with and without production chemical additives in the PW discharge. The purpose of this approach was to identify the change in the total risk following inclusion of the added chemicals; as the management options for NOS and added chemicals will normally be very different.

DREAM modelling was carried out under a range of ambient current conditions (lowest and highest current velocities) selected from a 3-year hindcast 3D hydrodynamic dataset (2009 – 2011) to assess the sensitivity of exposure risk to the prevailing metocean conditions in the vicinity of the release location. The discharge rate of produced water used in the modelling was 625 bpd.

Substance level modelling of both naturally occurring substances and added chemicals in the Tortue FPSO PW discharge showed that ≥ 90% of the environmental exposure risk is attributable to the presence of corrosion inhibitor in the discharge, with minor contributions from Benzene (3%-6%), and the chemical flocculent (2%-3%)

The highest maximum and mean EIF values obtained when modelling PW profiles that only contained substance level data for NOSs were 2.12 and 1.03 respectively, indicating that contribution of NOSs to the PW toxicity is negligible. The highest time-averaged maximum exposure risk and mean EIF values of 64% and 1.03 respectively were associated with the High BTEX concentration case / lowest ambient current velocity scenario. A mean EIF of 1.03 is equivalent to a maximum volume of water which experiences an exposure risk ≥ 5% of 1.03×10^{-4} km^3

For the NOS only base case, the maximum distance from the release location where the exposure risk was ≥ 5% for all time steps ranged from 1.93 km to 3.20 km for the low and high ambient current cases respectively.

The High BTEX case scenarios gave maximum and mean EIFs ranging from 51% - 66% greater than those for the corresponding BTEX Base case scenarios.

The predicted EIFs were higher when production chemicals were included in the PW profile. The highest maximum and mean EIF values of 39.6 and 15.6 were associated with the High BTEX concentration case + production chemicals / lowest ambient current velocity scenario. A maximum EIF of 39.6 is equivalent to a maximum volume of water which experiences an exposure risk ≥ 5% of 3.96×10^{-3} km^3. The modelling results for the High BTEX case scenarios with production chemicals included gave mean EIFs only 5% - 6% greater than those for the corresponding NOS Base case scenarios with production chemicals, indicating once again that the contribution of NOSs to the PW toxicity is minor.

For all BTEX scenarios with production chemicals, the increase in dispersion under high ambient current conditions reduced the calculated maximum and mean EIF by 45% - 49% and 38% respectively.

For the NOS base case with production chemicals, the maximum distance from the release location where the exposure risk was ≥ 5% for all time steps ranged from 5.31 km to 8.47 km for the low and high ambient current cases respectively.

Although the results suggest that added chemicals are the main contributor to environmental exposure risk, it must be stressed that this is in part due to the assessment (safety) factor (AF) approach included in the EIF methodology. The variability in quality and quantity of toxicity data for the different substance groups causes a large range in applied AFs that account for extrapolation uncertainty. For example the PNEC values for Ethylbenzene and Benzene were derived using AFs of 10 and 100 respectively, because comprehensive chronic toxicity data is available (7). In contrast, AFs of 1,000 were applied to production chemicals as there is limited acute toxicity data available for 3 species at 3 different trophic levels (algae, zooplankton, and fish) (3). It is important that the extrapolation uncertainty “hidden” in AFs is taken into account when defining risk reduction measures; otherwise it could result in the wrong prioritization of mitigation options.

Thus in the case of PW discharges from the Tortue FPSO, the first priority before considering any other risk mitigation options, should be establish whether acquiring chronic toxicity test data for the corrosion inhibitor will allow a less conservative AF of 100, or 50 to be used in EIF calculations thereby reducing the overall EIF and contribution from the CI chemical.

Although it is not advisable to compare EIFs from different installations because of differences in the nature and scale of discharges and different environmental conditions, the highest maximum and mean EIF values of 39.6 and 15.6 predicted for the Tortue FPSO PW discharge are small when compared to the limited published PW EIF data for North Sea installations. In 2002 Statoil published EIF data for the discharge of PW from 25 fields in the North Sea. The values ranged from 0 (zero) to 15,000, with an EIF of 100 or less for seven fields, and EIF of approximately 1,000 for the majority of the fields and an EIF of >5,000 for three fields.

2 Introduction

This report describes the findings of a modelling study conducted to assess the potential ecological exposure risks associated with various offshore produced water (PW) discharge scenarios from the Tortue Development Floating Production Storage and Offloading (FPSO) vessel. In accordance with the Basis of Design, it has been assumed that free oil separation has been performed using hydrocyclones /induced gas flotation. It has also been assumed that there will be no comingling of thermal effluents in the PW discharge stream and so is not included in the scope of this study.

The study has been carried out to support the Environmental and Social Impact Assessment (ESIA) for Tortue Phase 1A.

2.1 Background

Development of the Tortue field is expected to be performed in two phases. Phase 1A targets first gas production during 2021 from 4 wells across a number of drill centres, and will be incrementally developed with additional wells and drill centres. Phase 1A will provide ~480 MMscfd of sales gas production, generate ~2.5 MTPA of LNG and deliver a domestic supply of 35 MMscfd each to Mauritania and Senegal.

The Phase 1A FPSO, which is located in 100-130 m of water, will process up to 505 MMscfd of inlet gas from the subsea wells by separating condensate from the gas stream and exporting conditioned gas to a hub, where LNG processing and export will occur. The Hub, which is located in shallow water (30-33 m water depth) on the Mauritania and Senegal maritime border, comprises a breakwater to protect marine operations, including LNG processing and carrier loading. A single Floating LNG (FLNG) vessel will condition the gas for LNG export. Domestic gas pipeline connections will be available on the trestle riser platform.

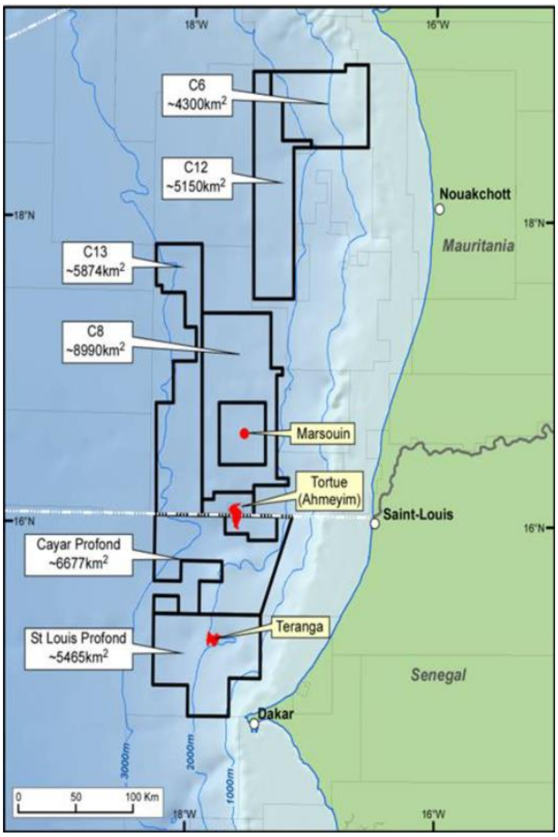
A map showing the field location is provided in Figure 2.1

The modelling of PW discharges has been completed using the Dose-related Risk and Effect Assessments Model (DREAM) developed by the Foundation for Scientific and Industrial Research (SINTEF). DREAM forms part of SINTEF's Marine Environmental Modelling Workbench (MEMW) v8.0 software package and is a tool used to predict the trajectory, fate and environmental consequences of regular, planned releases to the marine environment.

The purpose of the modelling was to:

- Simulate anticipated continuous discharge flow rates and effluent compositions over a 45 day period;
- Provide a quantitative assessment of the environmental risk to the marine environment associated with various discharge scenarios.
- Establish the relative contribution of key contaminants to the environmental exposure risk
- Understand the sensitivity of the risk to changes in hydrocarbon component concentrations and production chemicals in the PW discharge as well as ambient conditions (background current speed etc.).

Figure 2.1 Tortue Field Location Map



3 Risk assessment methodology

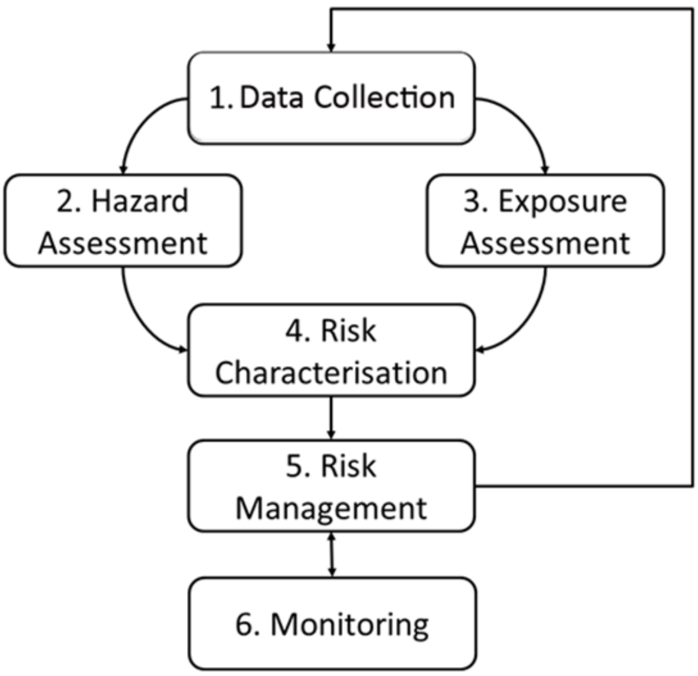
The methodology used in this study is aligned with OSPAR Recommendation 2012/5 for a Risk Based Approach (RBA) to the Management of Produced Water Discharges from Offshore Installations [(1)] and the OSPAR Guidelines in support of Recommendation 2012/5 [(2)].

The OSPAR RBA was developed specifically for the offshore environment and follows the internationally recognised principles of ERA already in place in Europe (ECHA – Technical Guidance documents [(3, 4)]) and is currently being implemented in the North East Atlantic region.

The OSPAR risk assessment process follows the standard data collection, hazard assessment, exposure assessment and risk characterization steps, which are described in more detail below. The risk characterization step is based on the same widely accepted principle of comparing a Predicted Environmental Concentration (PEC) for each chemical compound discharged into the receiving environment to a Predicted No Effect Concentration (PNEC). When PEC is larger than the threshold PNEC, there may be a risk for damage. When the PEC is lower than the PNEC threshold, the risk for damage is considered to be “acceptable

The methodology involves the key steps summarised in Figure 3.1.

Figure 3.1 Diagram summarising the risk-based approach to the management of PW offshore discharges outlined in OSPAR Recommendation 2012/5



3.1 Data Collection

This initial step involves the collection of all relevant information to be able to define the conceptual model, i.e. the PW discharge characteristics, the PW effluent composition, the characterisation of the PW effluent toxicity and the local conditions in the receiving environment including 'meteorological and oceanographic data and the selection of representative sensitive species.

A Substance Based Approach (SBA) was used to estimate the PW effluent toxicity associated with each discharge scenario. The approach involves estimating the concentration of each Naturally Occurring Substance (NOS) and production chemical additive in the PW discharge and gathering eco toxicological information and physical-chemical properties data for each contaminant present. The eco toxicological information is used to estimate PNEC values for each substance as described in the "Hazard assessment" step (see Section 3.2).

The minimum eco toxicological information that should be collected includes short-term (acute) toxicity data for three trophic levels; invertebrates (e.g. crustacean, molluscs, echinoderms), algae (growth inhibition) and fish. If data on the individual substances are not available, the worst case toxicity values for the product are used.

The physical-chemical properties data required includes for each substance, includes, molecular weight, density, solubility, vapour pressure octanol/water partition coefficients (log Pow) and degradation rates.

3.2 Hazard assessment

In this step the reference no-effect concentrations, i.e. the PNECs are derived from laboratory toxicity tests results (i.e. EC_{50}, LC_{50} or NOEC) using appropriate Assessment Factors (AFs) to take into account inherent uncertainties. The application of AFs is based on the `precautionary principle' which is expected to extrapolate to a conservative estimate of the PNEC.

PNECs are developed to protect the marine ecosystem using surrogates of known sensitive species based on the principle that:

- Ecosystem sensitivity depends on the most sensitive species
- Protecting the ecosystem structure protects the community function

3.2.1 PNEC calculation and use of Assessment (Safety) Factors

The OSPAR Guidelines in support of Recommendation 2012/5 for a Risk-based Approach to the Management of Produced Water recommend the continued use of the assessment factors set out in the 1996 ECB EC Technical Guidance Document on Environmental Risk Assessment (3) (see Table 3.1 and Annex A). These assessment factors have been used control chemical discharges from offshore installations for a number of years, and monitoring studies have indicated that they provide an appropriate level of protection to the ecosystem function.

The OSPAR Guidelines noted the fact that the assessment factors set out more recently in the updated ECB EC 2003 Technical Guidance (TGD) (4) and subsequent ECHA Guidance (2008) for Chemical Safety Assessment (5) are overly conservative and have the potential to overestimate the contribution to produced water toxicity from added production chemicals and thereby mask the contribution from natural components. This is a consequence of the introduction of an additional factor of 10 to the assessment factors derived for the marine environment. In a review of the science behind the additional factor, the Scientific Committee on Health and Environmental Risks (SCHER (6)) commented that they did not accept the additional safety factor of 10 as a default for marine ecosystems as being generally justified. In the opinion of SCHER, the use of different approaches for both freshwater and marine ecosystems should be scientifically justified on a case-by-case basis. Therefore to align with OSPAR guidance, a maximum assessment factor of 1,000 has been used in this study, as the ECHA guidance was developed for near-coastal waters and a factor of 10,000 is considered too conservative for offshore waters.

Table 3.1 Assessment factors to derive PNECs (Source: European Chemical Bureau, Technical Guidance Document - Part II, 1996 (3))

	Assessment factor
At least one short-term $L(E)C_{50}$ from each of three trophic levels of the base-set (fish, Daphnia and algae)	1000 [(a)]
One long-term NOEC (either fish or Daphnia)	100 [(b)]
Two long-term NOECs from species representing two trophic levels (fish and/or Daphnia and/or algae)	50 [(c)]
Long-term NOECs from at least three species (normally fish, Daphnia and algae) representing three trophic levels	10 [(d)]
Field data or model ecosystems	Reviewed on a case by case basis[(e)]

For the most common substances in the produced water OSPAR has established and maintained a harmonised set of PNEC values[(7)] (see Annex B). These PNEC values are based on the following prioritisation:

i. Environmental Quality Standards (EQS) derived under the Water Framework Directive (WFD) established for Priority Substances

ii. Reliable PNECs derived from EU Risk Assessment Reports (RARs).

iii. Reliable PNECs or EQS from publicly available literature sources.

3.3 Exposure Assessment

In this step, the predicted fate of produced water in the receiving environment around the vessel is determined by calculating the PECs of all compounds that could impact biota in the receiving environment using a DREAM which is a 3-dimensional dilution/dispersion model.

The output from the substance based exposure assessment is the concentration of each substance discharged with the produced water at any location in the receiving environment (PEC (i) for each component, i).

3.4 Risk Characterisation

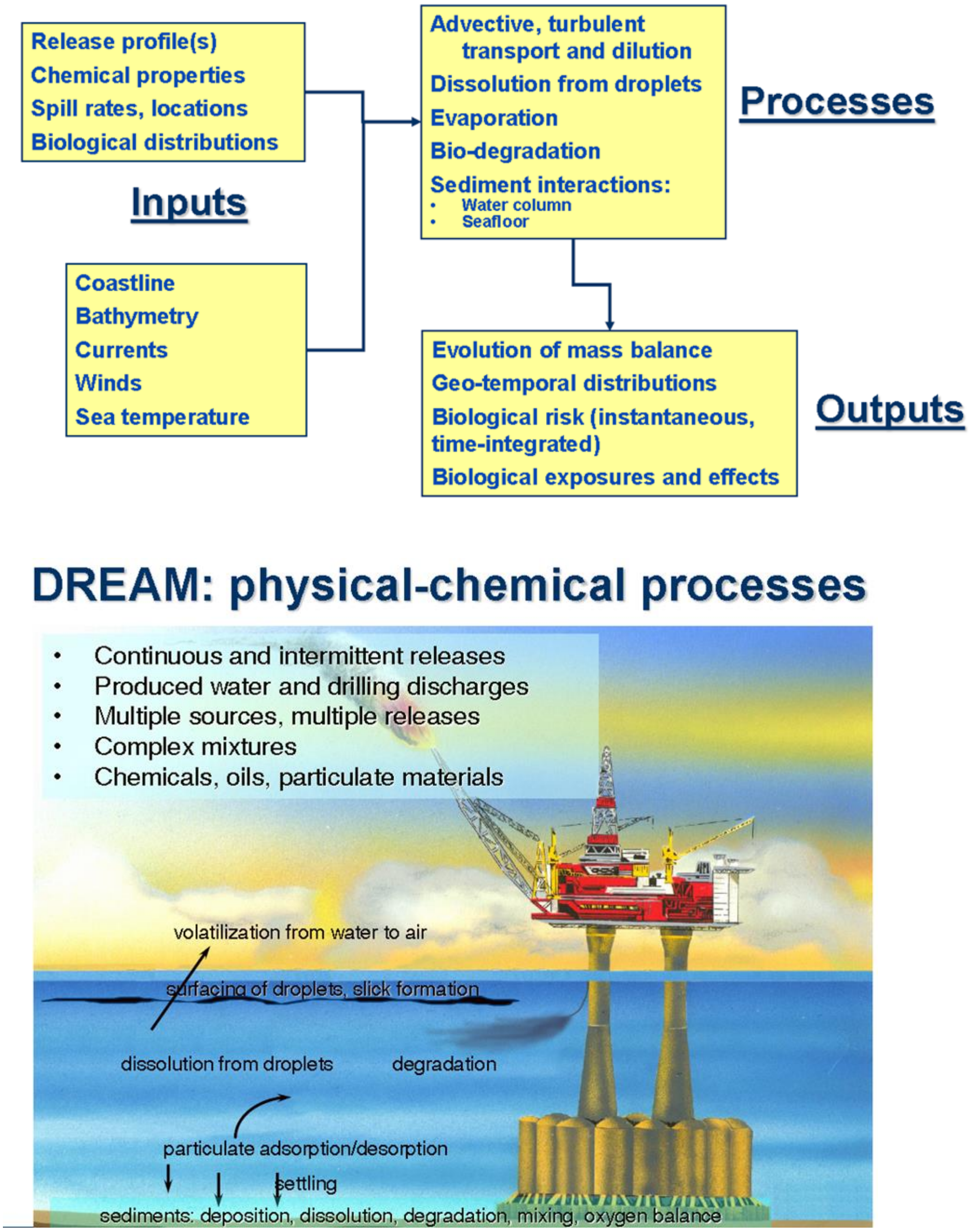
Risk characterisation is the comparison of the PEC of a substance with the no-effect reference concentration, the PNEC, i.e. the calculation of the PEC/PNEC ratio, or Risk Characterisation Ratio (RCR). When the PEC is lower than the PNEC threshold, the risk of injury from that substance is considered to be acceptable. When it is larger, then there is a risk of biological injury.

3.4.1 DREAM/EIF modelling approach

As mentioned above in Section 3.3, the exposure assessment to predict the trajectory and fate of produced water in the receiving environment was conducted using DREAM.

DREAM is a 3-dimensional, time-dependent, multiple-chemical transport, exposure, dose, and effects assessment model. DREAM can account simultaneously for up to 200 chemical components, with different release profiles for 50 or more different sources (Reed et.al. 2001[8]). Each chemical component in the effluent mixture is described by a set of physical, chemical, and toxicological parameters. DREAM incorporates various algorithms to model the processes that govern pollutant fate and effects in the water column, as outlined in the schematic shown in Figure 3.2.

Figure 3.2 General Schematic of the DREAM Model structure and physical-chemical processes governing the behaviour of pollutants.



The model is fully three-dimensional and time variable. It calculates the fate of each compound considered in the receiving environment under the influence of:

- Currents (tidal, residual, meteorological forcing)
- Turbulent mixing (horizontal and vertical)

- Evaporation at the sea surface
- Reduction of concentration due to biodegradation

The algorithms used in the computations, and verification tests of the resulting code, are presented in Reed et al, 2002[9]. The model has also been verified against field measurements (Neff et al, 2006[10]; Durrell et al, 2006[11]).

The ocean current field used in DREAM modelling was based on the global current model (HYCOM) with hourly tidal currents superimposed and is described in more detail in Section 5.2.2. This hindcast current dataset was considered of sufficient quality for use in the initial PW discharge modelling undertaken to inform the ESIA.

a. **Environmental exposure risk and the EIF**

The DREAM model incorporates a risk assessment methodology, the Environmental Impact Factor (EIF) method (Johnsen et. al., 2000[12]). Development of the EIF method is based on a PEC/PNEC approach gives an indication of the likelihood of adverse effects occurring as a result of the anticipated exposure level to a toxic substance. The ratio PEC/PNEC is related to the probability of biological injury according to a method developed by Karman et. al [13], (and also published in Karman and Reerink, 1997 [14]). When the PEC/PNEC ratio = 1, there is a probability of potentially damaging 5% of the marine species in the receiving environment. Figure 3.3 shows the relation between the PEC/PNEC ratio and the probability of injury.

The methodology has been guided by the principle that areas of uncertainty should be resolved in favour of protecting the environment (i.e. conservative environmental assumptions are invoked). The methodology is therefore conservative, in the sense of over-protecting rather than under-protecting the environment.

The EIF method has the advantage over other risk assessment methods in that it can calculate risk contributions from exposure to multiple chemicals and/or natural compounds in the recipient environment. For the total risk associated with multiple chemicals and non-toxic stressors arising from the produced water discharge, the total risk is calculated from the sum of independent probabilities. For two stressors A and B, the total risk is calculated assuming independent action using the equation:

$$P(A+B) = P(A) + P(B) - P(A) * P(B) \qquad \text{(Eq. 1)}$$

Where P(A) and P(B) are the risk probabilities for each stressor at a particular time and spatial location. For small risks (i.e., P(A) and P(B) are both small), or risks from chemicals which are toxicologically similar in their activity, the risks can be considered to be linearly additive, approximately. The method does not account for interactions among chemicals.

For a large number of stressors, the generalized formula for the sum of probabilities is given by the equation:

$$P_{total} = 1.0 - \prod_i^n \quad (1.0 - Pi) \qquad \text{(Eq. 2)}$$

An EIF unit represents a defined volume of water or sediment surface which has the potential to cause harm to ≥ 5% of species in the receiving environment if they become exposed to harmful substances and or non-toxic stressors arising from the discharge.

For the water column, one EIF unit is defined as a water volume of 100 m x 100 m x 10 m (i.e. 10^5 m^3, see Figure 3.4). The total risk resulting from all contaminants in a release is calculated by the DREAM model in 3-dimensional space and time within the model domain by summing the risks (at every point in space at a given time) for each contaminant, using Equation 3 to first convert PEC/PNEC values to risk probabilities as shown in Figure 3.3:

$$Risk\ (\%) = \int_{y=0}^{\ln(PEC:PNEC)} \left\{ \frac{1}{S_m * \sqrt{2\pi}} * e^{\frac{-(\ln PEC:PNECy - x_m)^2}{2 * S_m{}^2}} \right\} \qquad \text{(Eq 3)}$$

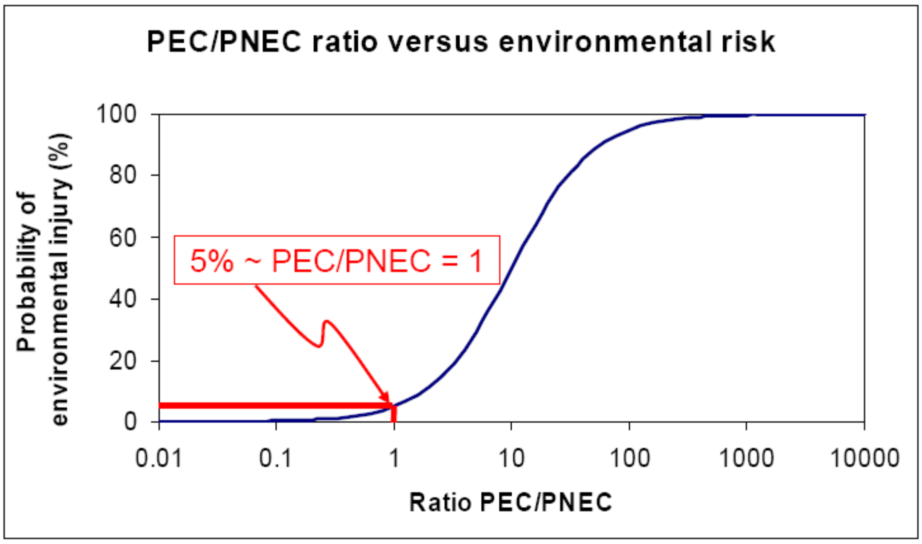
Where:

Risk (%) = probability that a species will be affected

x_m = mean of distribution for which PEC: PNEC ratio = 1; risk = 5%

S_m = the standard deviation of the logarithmically transformed data

Figure 3.3 Relation between the PEC/PNEC level and the risk level (in %) for injury to biota. Based on Karman et. al.[13] . A PEC/PNEC = 1 corresponds to a risk level at which there exists the possibility of injury to 5% of a randomly selected species.

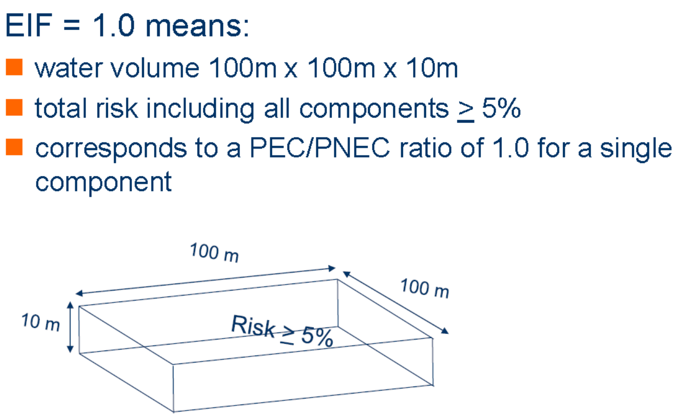


The resultant 3-dimensional risk fields can then be viewed as a time series risk (in percent) map.

Note that although the EIF for a single component, or component group, is related to the recipient water volume where the ratio PEC/PNEC exceeds unity, with a multi-component system, the

PEC/PNEC ratios for each individual contaminant/stressor in the release may be <1, but if the aggregated risk ratios for all stressors exceed 1 (5% risk probability), then the resulting EIF > 0.

Figure 3.4 Definition of the Environmental Impact Factor (EIF) in the water column



The EIF approach has the advantage that it provides a quantitative measure of the environmental risks involved when operational discharges (e.g. produced water, drilling mud and cuttings etc.) are released into the sea, and is thus able to provide a basis for reduction of exposure risk in a systematic and a quantitative manner.

When the risk characterisation follows a SBA, the EIF method is able to discriminate among the various contributors to environmental risk. This capability provides useful information when comparing alternative proposed methodologies for reducing environmental risks associated with a discharge. Thus it is possible to separate a chemical product into its constituents and calculate the EIF contribution from each substance in the product. The results of the calculations can then be used to improve the product in terms of replacing the constituents which contribute most to the EIF.

3.4.2 Advantages and limitations of the risk based approaches

It is important to note that the EIF methodology is guided by the “precautionary principle” and invokes conservative assumptions when addressing areas of uncertainty with the aim of protecting 95% of species present in the receiving environment. It reflects a level of environmental exposure risk and has proven to be a very useful environmental management decision support tool for evaluating and comparing the relative benefits of different risk reduction mitigation options to establish what further measures are justified.

The SBA has the advantage that it can reveal the potentially most harmful compounds present, which is useful for evaluating and implementing mitigation measures, as a part of the design and planning process. Thus it is possible to separate a chemical product into its constituents and calculate the EIF contribution from each of them.

The results of the calculations can then be used to improve the product in terms of substituting the constituents in the product that contain the largest contributions to the EIF. This capability also provides useful information when comparing alternative proposed methodologies for reducing environmental risks associated with a discharge.

A limitation of the SBA is that it does not account for any chemical reactions and by- product formation that the production chemicals might undergo after dosing, or any synergistic/antagonistic effects that might affect toxicity. Each component in the discharge is assumed to be an individual entity which does not interact with other components. In addition, production chemicals are complex mixtures and certain components of the chemical product may have different solubility in oil and water, so that large portions of the modelled chemical may not enter the produced water (PW) stream. This in turn may lead to an overestimation of the concentration and risk associated with these components.

The metocean data used in the modelling was chosen to include conditions giving rise to the minimum dispersion of substances in the discharges, and as such is conservative and not representative of most of the year when dispersion and mixing conditions are enhanced.

4 Produced Water Discharge Scenarios

The produced water discharge scenarios modelled in this study are presented in Table 4.1.

Eight PW discharge scenarios were modelled to investigate the sensitivity of ecological risk to Benzene, Toluene Ethyl-benzene and Xylene (BTEX) concentrations in the effluent (Base Case and "High" BTEX case), both with and without production chemical additives in the PW discharge. The purpose of this approach was to identify the change in the total risk following inclusion of the added chemicals; as the management options for NOS and added chemicals will normally be very different.

Table 4.1 Tortue FPSO Produced Water Discharge Scenarios

Scenario	Concentration of BTEX components in PW discharge	Metocean Ambient current / conditions	Release rate of PW		Release duration (days)	Produced Water Profile Type	Caisson diameter (m)	Release depth below sea surface (m)	Temperature of the release (deg C)	Salinity of the release (ppt)
			(bpd)	(m^3/day)						
1	Base case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	1.000	0	40	0
2	Base case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	1.000	0	40	0
3	High case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	1.000	0	40	0
4	High case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	1.000	0	40	0
5	Base case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	1.000	0	40	0
6	Base case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	1.000	0	40	0
7	High case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	1.000	0	40	0
8	High case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	1.000	0	40	0

The toxicity of produced water and the calculated environmental exposure risk is very much dependent on the metocean conditions that occur at the time of modelling. Periods of low (benign) current conditions can increase the environmental exposure risk as the PW is not diluted and dispersed to PNEC levels. Conversely, during periods of high (energetic) currents, dispersion and dilution of PW can occur more quickly, reducing the environmental risk. Therefore modelling was carried out under a range of ambient current conditions (lowest and highest current velocities) selected from a 3-year hindcast 3D hydrodynamic dataset (2009 – 2011) to assess the sensitivity of exposure risk to the prevailing metocean conditions in the vicinity of the release location.

5 Risk assessment input data

This section outlines the model input data used to characterize the produced water discharge scenarios.

5.1 Outfall Parameters

The geographical coordinates of the Tortue FPSO release site location and other outfall assumptions are summarised in Table 5.1. It is assumed the PW will be released overboard at the sea surface via a 1 m diameter outlet pipe.

Table 5.1 Outfall parameters

Field:		Tortue FPSO
Release Site Location:		
	Geographic Latitude - deg	16
	min	4
	sec	0.072
	North/South	North
	Geographic Longitude - deg	16
	min	53
	sec	9.226
	East / West	West
Water depth:		
	ft	394
	m	120
Depth of release outlet:	locatio	below sea surface
	ft	0
	m	0
Outlet pipe diameter at the release point:		
	m	1.000
	ins	39.370
Angle from north (0=north, 180 = south etc.) deg		0
Angle from vertical (0=up, 180 = down etc.) deg		180
Temperature of release as it leaves the pipe	deg C	40.0
Salinity of release as it leaves the pipe:	ppt	0.0

5.2 Ambient conditions

5.2.1 Bathymetry

The ocean depth database included within the MEMW system uses several internal depth data sources for building depth grids. (Sea Topo 8.0 [15], IBCAO [16])

5.2.2 Hydrodynamic and wind data

The hindcast metocean data used to “drive” pollutant transport in the DREAM model was provided by the Hybrid Coordinate Ocean Model (HYCOM). Daily HYCOM currents were combined with tidal current velocities to generate hourly current vectors, at 31 depth levels ranging from 0 - 5,500 m, at 1/12 degree spatial resolution (@ 9 km x 9 km) across the area of interest over a 3 -year time period

(1^{st} January 2009 - 31^{st} December 2011). The tidal current information, provided by BMT Argoss was obtained from the integration of approximately 5,000 tidal stations and 15 years of satellite radar altimeter into depth averaged global and regional tidal models (2DH model). The tidal model provides tidal currents (u, v components) as well as surface elevation. The vertical structure of the tidal current component was established using a logarithmic profile which provides a reliable representation of tidal currents at different depths.

The 3D current dataset generated covers the area spanned by latitudes 10° - 20° north and longitudes 14.3° - 20° west.

To complement the three dimensional current data, the NCEP Climate System Forecast Reanalysis (CFSR) dataset was interpolated to provide a wind dataset spanning the same area, spatial grid and temporal resolution as the current dataset (see Table 5.2).

The wind data is used in the DREAM model to generate wave height and period information using a fetch calculation, which is subsequently utilized to calculate turbulent mixing on the sea surface.

Table 5.2 HYCOM / NCEP current and wind data

Hydrodynamic Data	HYCOM
Years	2009 - 2011
Horizontal Resolution	1/12 deg (@ 9 km x 9 km)
Depth	3D datasets consist of up 31 depth layers from surface to seabed (0 - 5,500 m) and spread across the water column.
Output Frequency	Daily interpolated to 1 hourly
Tides	Tidal current information is obtained from the integration of approximately 5000 tidal stations and 15 years of satellite radar altimeter into depth averaged global and regional tidal models (2DH model). The tidal model provides tidal currents (u, v components) as well as surface elevation. The vertical structure of the tidal current component established using a logarithmic profile which provides a reliable representation of tidal currents at different depths.
Domain	10^0N- 20^0N, 14.3^0W-20^0W
Wind Velocity Data	**NCEP**
Years	2009 - 2011
Horizontal Resolution	0.5 deg x 0.5 deg (@ 22 km x 22 km)
Height	10 m above sea surface
Output Frequency	1 hourly
Domain	10^0N-40^0N, 5^0W-30^0W

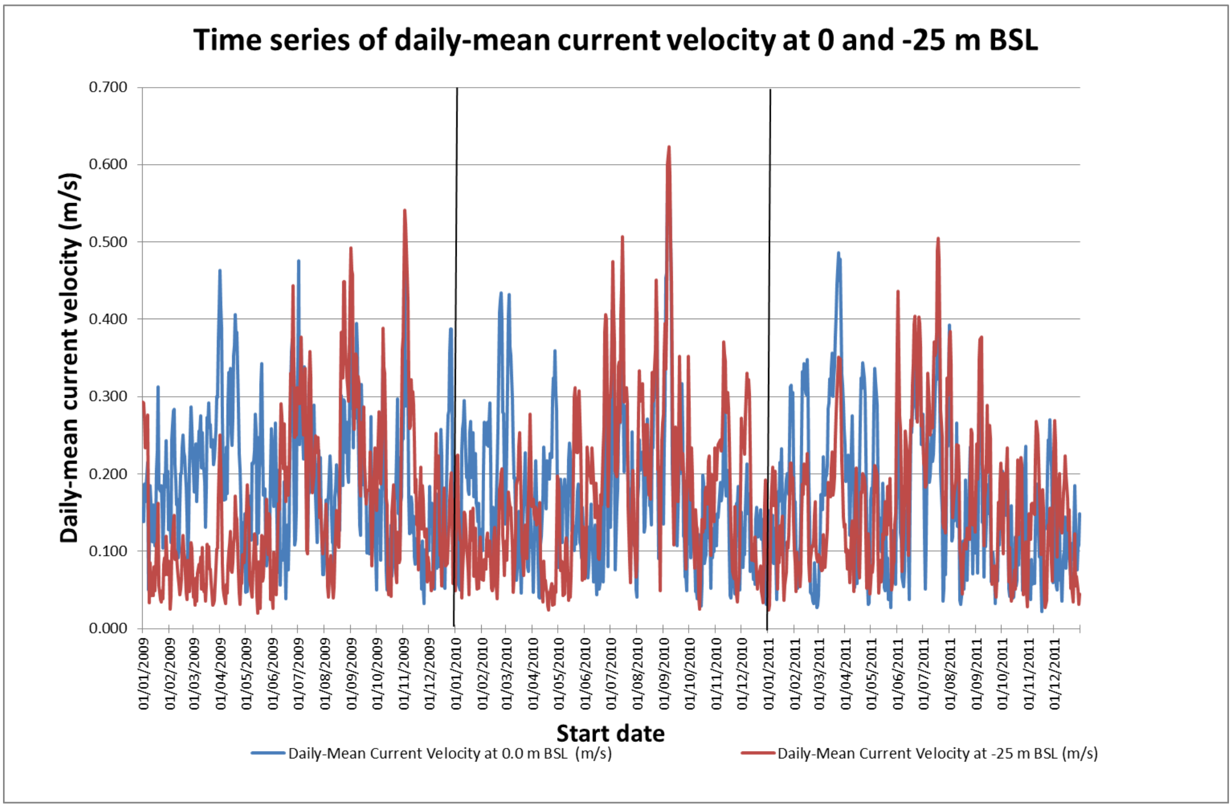
5.2.2.1 Predicted currents at the Tortue FPSO outfall location

Time series ROMS model predictions of daily average current speeds at the sea-surface and -25 m BSL water depths at the proposed Tortue FPSO PW discharge location are presented in Figure 5.1.

Currents assist the thermal and physical dispersion of an effluent in the water column by advection and mixing. Thus the toxicity of produced water and the calculated environmental exposure risk is very much dependent on the metocean conditions that occur at the time of modelling. Periods of low (benign) current conditions can increase the environmental exposure risk as the PW is not diluted and dispersed to contaminant concentrations below the PNECs whereas during periods of high (energetic) currents, dispersion and dilution of PW to concentrations below PNECs can occur more quickly, reducing the environmental risk.

Thus the 3-year hindcast HYCOM current dataset was analysed to find the most benign (highest risk) and energetic (lowest risk) metocean conditions at the PW discharge location averaged over a 45 day period and the associated start dates for these time periods. A 45 day simulation period was chosen to allow the continuous discharge plume to reach a relatively stable state in the water column. Most of the results presented in the report are for the most benign conditions, as it is prudent to conservatively assess the exposure risk, i.e., these conditions represent a minimum degree of dispersion, which is expected to be achieved in relatively calm conditions with low current velocities. However, modelling was also carried out under the highest ambient current conditions to assess the sensitivity of exposure risk to the prevailing metocean conditions in the vicinity of the release location.

Figure 5.1 Time series of HYCOM model daily-mean current speeds at 0 m BSL and -25 m BSL water depths at the Tortue FPSO PW discharge location between 1st Jan 2009 to 31st Dec 2011.

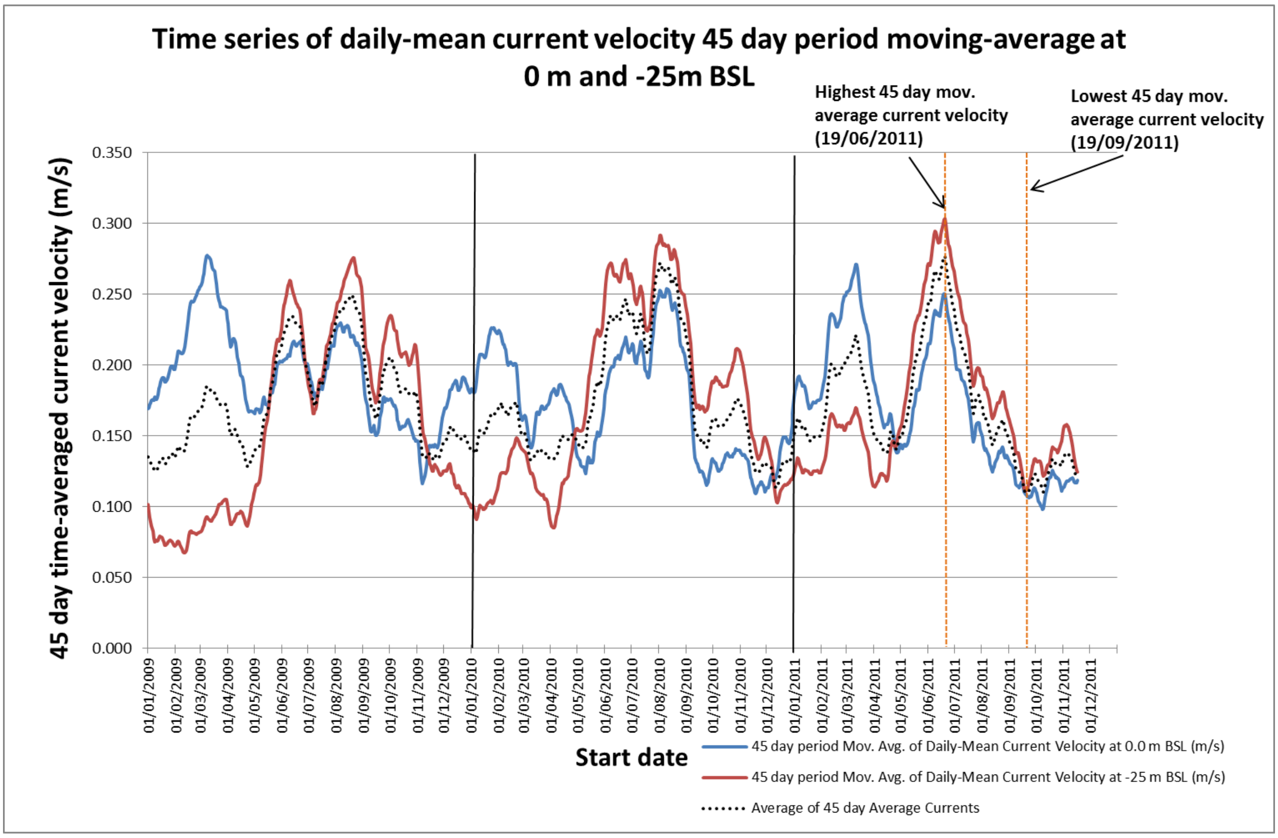


These start dates and the associated current conditions used within the modelling are described below in Table 5.3. Figure 5.2 shows the time-series of 45 day period moving-average of daily-mean current velocities at 0 m BSL and - 50 m BSL at the Tortue FPSO PW discharge location. It should be noted that the highest and lowest current periods were derived from the averaged 45 day period moving-average daily-mean currents at 0 m BSL and - 25 m BSL.

Table 5.3 Start date and current conditions for the periods of minimum (least dispersion) and maximum (most dispersion) mean daily currents averaged over a 45 day period at the Tortue FPSO PW discharge location between 1st Jan 2009 to 31st Dec 2011.

Start Date	Metocean Conditions	45 day time-averaged daily mean current velocity at: 0 m BSL (surface) (m/s)	45 day time-averaged daily mean current velocity -25m BSL (m/s)
19/09/2011	Lowest Current Velocities	0.109	0.111
19/06/2011	Highest Current Velocities	0.251	0.303

Figure 5.2 Time series of daily-mean current velocity 45 day period moving-average at 0 m BSL and -25 m BSL water depths for the Tortue FPSO PW discharge location between 1st Jan 2009 to 31st Dec 2011.



5.2.2.2 Temperature and salinity data

Temperature and salinity data is used within DREAM to calculate the buoyance and trajectory of the effluent plume.

Average monthly temperature and salinity vs. depth profiles for the Cassia platform area were extracted from the National Virtual Ocean Data System (NVODS) server using the World Ocean Atlas 2005 1x1 degree Monthly means dataset[17] (see Figures 6.3 – 6.4).

Figure 5.3 Average monthly seawater temperatures vs. depth profile for the Tortue FPSO location area extracted from the World Ocean Atlas 2005 1x1 degree Monthly means dataset

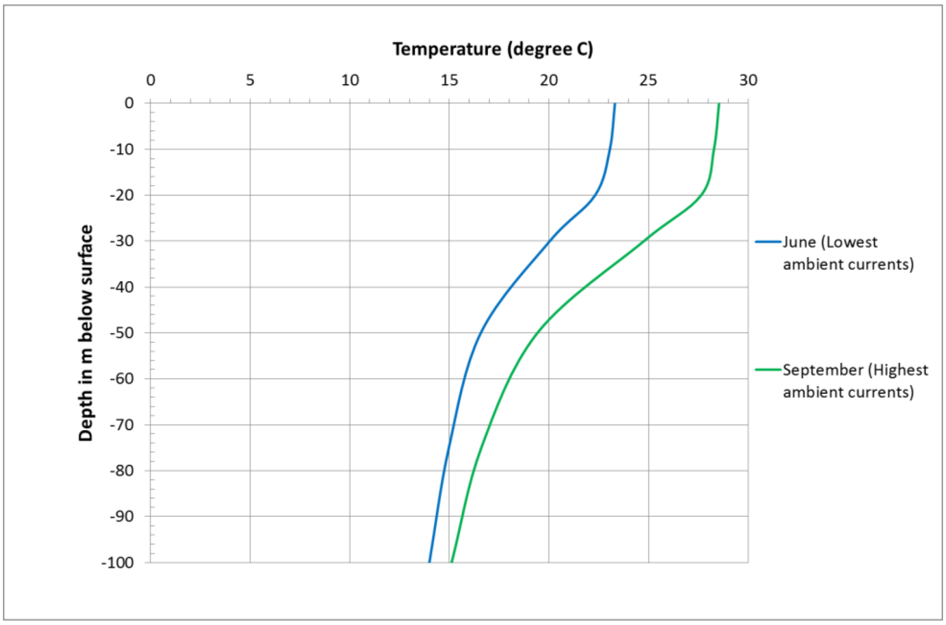
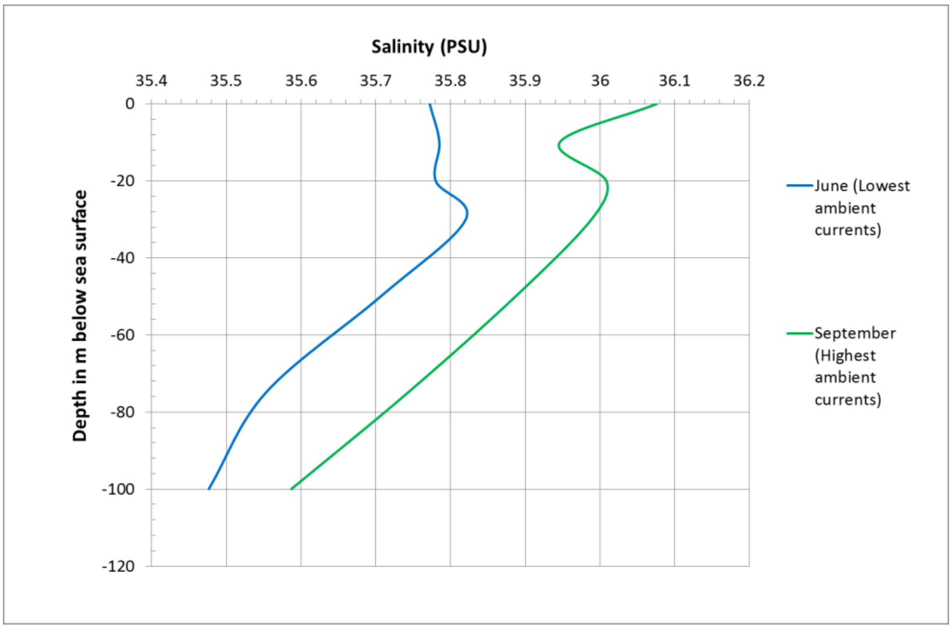


Figure 5.4 Average monthly seawater salinity vs. depth profile for the Tortue FPSO PW discharge location area extracted from the World Ocean Atlas 2005 1x1 degree Monthly means dataset



5.3 Produced water properties – Contaminants of Potential Concern (COPCs)

ProMax and HYSIS chemical process simulators have been used to simulate equipment performance for liquid processing on the Tortue FPSO using topside arrival stream data. Monoethylene glycol (MEG) regeneration has been modelled in line with the requirement to regenerate the MEG to a 90:10 specification. No consideration of Flash Gas Liquid returns and Gas Compression systems was made as they have limited impact on the produced water specification. The overall flow of produced water discharge has been simulated as @ 625 bbl/d, with free oil separation performed using hydrocyclone/induced gas flotation units with no additional tertiary treatment to reduce dissolved oil components.

5.3.1 Naturally occurring compounds

The following substance groups were assumed to be present in the PW discharge:

- Aromatic hydrocarbons (BTEX),
- Dispersed oil
- Phenols
- Metals

Table 5.4 shows the estimated concentration of these components in the produced water discharge for both the Base Case and “High” BTEX Case scenarios. It was assumed that the concentration of dispersed oil in the PW discharge after separation will meet the International Finance Corporation (World Bank Group) effluent level guideline of 29 mg/L [18]. The Table also shows the corresponding recommended PNEC values of each naturally occurring components established by OSPAR[7] that was used for hazard assessment.

Table 5.4 List of naturally occurring substances expected in the Tortue FPSO PW discharge

Component	Concentration in Produced Water (Base Case) (mg/L)	Concentration in Produced Water (High BTEX Case) (mg/L)	PNEC (µg/L) - OSPAR	Component Group
Benzene	**637**	**973**	8.00	**BTEX**
Toluene	**56**	**25**	7.40	
Ethylbenzene	**3**	**3**	10.00	
Xylene	**3**	**2**	8 (PNEC Benzene)	
Dispersed oil	**29.00**	**29.00**	70.5	**Dispersed oil**
Mercury	**0.32**	**0.32**	0.047+Cb2	**Metals**
Phenol (representative for C0-C3 alkyl phenols)	**20**	**20**	7.7	**Phenols C0-C3**

5.3.2 Production chemicals

The estimated concentration, environmental properties and PNEC values of production chemicals expected in the PW effluent stream are presented in Table 6.5.

Although the production chemical supplier is only selected later in the project construction phase, the chemical products used in the simulations are typical representatives for the functional role of each additive (corrosion inhibitor, scale inhibitor etc.).

Table 5.5 List of chemical additives and their estimated concentrations in the Tortue FPSO PW discharge

Production Chemicals									Ecotoxicity Data	
Product name	Percentage of Chemical Components in Product (%)	Function	Product Concentration (mg/l)	No FW - No MPPE Assumed Chemical Concentration in the PW discharge (mg/l)	Specific gravity	Solubility (mg/L)	Bioaccumulation Log P_{ow}	Biodegradation. % 28 days	Worst Aquatic Toxicity Test (mg/l)	PNEC (ppb)
Cortron RN-629	7.01	**Corrosion Inhibitors**	200	14.02	0.92	Complete	N/A	62% (28 days)	1.02	1.02
EC6157A	36.2	**Scale Inhibitor**	20	7.24	1	Complete	-0.1	41% (21) days)	1000	1000
EC6029A	100	**Coagulant Flocculant**	10	10	1.16	Complete	N/A	80% (28 days)	1.3825	1.3825

1-Scale inhibitor: Assumes 100% of injected chemical enters PW.
2-Corrosion inhibitor: Assumes 18% of injected chemical enters PW and injection rate of 32 l/h. CI is assumed to partition 10:1 water:condensate. No allowance is made for CI persistence in MEG during regeneration
3 - Polyacrylamides or Quaternary ammonium co-polymer - Assumed 100% discharge to PW

5.3.3 Model settings and assumptions

The model set-up parameters used in the modelling are summarized in Table 5.6. The spatial grid cell resolutions ranged from 20 m x 20 m to 50 m x 50 m horizontally and 10 m vertically, depending on what was required to accurately map the dilution field

Table 5.6 Model set-up parameters used in DREAM simulations

Model Set-up Parameters		
Number of particles	Liquid / Solid particles	5,000
	Dissolved particles	5,000
The spatial resolution of the Habitat Grid	Resolution in the x-direction (longitude)	20 or 50 m
	Resolution in the y-direction (latitude)	20 or 50 m
The spatial resolution of the concentration grid in the horizontal and vertical	Resolution in the x-direction (longitude)	20 or 50 m
	Resolution in the y-direction (latitude)	20 or 50 m
	Resolution in the z-direction (depth)	5 m
The spatial resolution of the surface grid	Resolution in the x-direction (longitude)	20 or 50 m
	Resolution in the y-direction (latitude)	20 or 50 m
Depth for concentration grid	Min:	0 m
	Max	50 m
Lower concentration limit:		0.01 ppb
Computation time-step and output time-step	Time-step	5 min
	Output interval	12 hr
Simulation period:		45 days

6 Risk Assessment Results

This section summarises the key findings from the exposure assessment and risk characterisation stages of the RBA carried out using DREAM. The complete sets of modelling results are presented in Annex C.

6.1 Assessment of naturally occurring substances only

Table 6.1 summarises the Maximum and Mean EIFs results for PW discharge Scenarios 1 to 4 (which exclude production chemicals, see Section 4 - Table 4.1). The EIF results therefore give an indication of the contribution of NOSs to the overall toxicity and ecological risk associated with potential PW overboard discharges at the Tortue FPSO.

The EIFs for all 4 scenarios were very small ranging from 1.21 to 2.12 for the maximum EIF and 0.62 to 1.03 for the Mean EIFs, indicating that contribution of NOSs to the PW toxicity is negligible. The highest time-averaged maximum exposure risk and mean EIF values of 64% and 1.03 respectively (Scenario 3) were associated with the High BTEX concentration case / lowest ambient current velocity scenario. A mean EIF of 1.03 is equivalent to a maximum volume of water which experiences an exposure risk $\geq$ 5% of 1.03 x 10^{-4} km^3

The High BTEX case scenarios (Scenarios 3 and 4) gave maximum and mean EIFs ranging from 51% - 66% greater than those for the corresponding BTEX Base case scenarios (Scenarios 1 and 2).

Under high ambient current conditions (Scenarios 2 and 4), the PW plume was transported further away from the discharge point before the risk was reduced to <5% resulting in an increase in the maximum spatial extent of the exposure risk footprint over the 45 day simulation. This represents a 66 % (Scenario 2) and 42% (Scenario 4) increase in distance compared to the respective low ambient scenarios (Scenarios 1 and 3).

Figure 6.1 shows snapshot maps of the maximum environmental exposure risk $\geq$ 5% in the water at any location at the time of maximum EIF for the NOS base case at both low and high ambient current velocity conditions (Scenarios 1 and 2). The results showed that the maximum distances from release site where the exposure risk is $\geq$ 5% at the time of maximum EIF are 0.81 km and 2.46 km, for the low and high ambient current cases respectively.

If all time steps are considered, then Figure 6.2 shows the maximum environmental exposure risk predicted at any location in the water column over the 45 day simulation period for Scenarios 1 and 2. The maximum distances from release site where the maximum exposure risk is $\geq$ 5% are 1.93 km and 3.20 km, for the low and high ambient current cases respectively. These maps also show a vertical cross section of risk in the water column along the vector A-B.

The variation in EIF and maximum risk in the water column over the simulation period for the PW NOS base case is shown in Figure 6.3. The increase in dispersion under high ambient current conditions reduced the predicted time-averaged maximum exposure risk by 75% compared to the low ambient current scenario,

Figure 6.4 shows the contribution of each NOS contaminant in the PW water to the EIF for Scenario 1 (NOS base case, low ambient currents). The pie-chart reveals that 96% of the EIF risk in the water column is attributable to Benzene (75%), Mercury (15%) and Toluene (6%). Similar results were obtained under high ambient current conditions (Scenario 2). However, for the “High” BTEX case scenarios (Scenario 3 and 4) the relative contribution of Benzene increased to @ 85% whilst the Mercury and Toluene contributions reduced to @ 10% and 2% respectively.

Figure 6.1 Snapshot maps showing the maximum environmental exposure risk in the water column ≥5% at any location at the time of maximum EIF for the NOS base case at both low and high ambient current velocity conditions (Scenarios 1 and 2). Top - maps same scale, bottom - maps zoomed in).

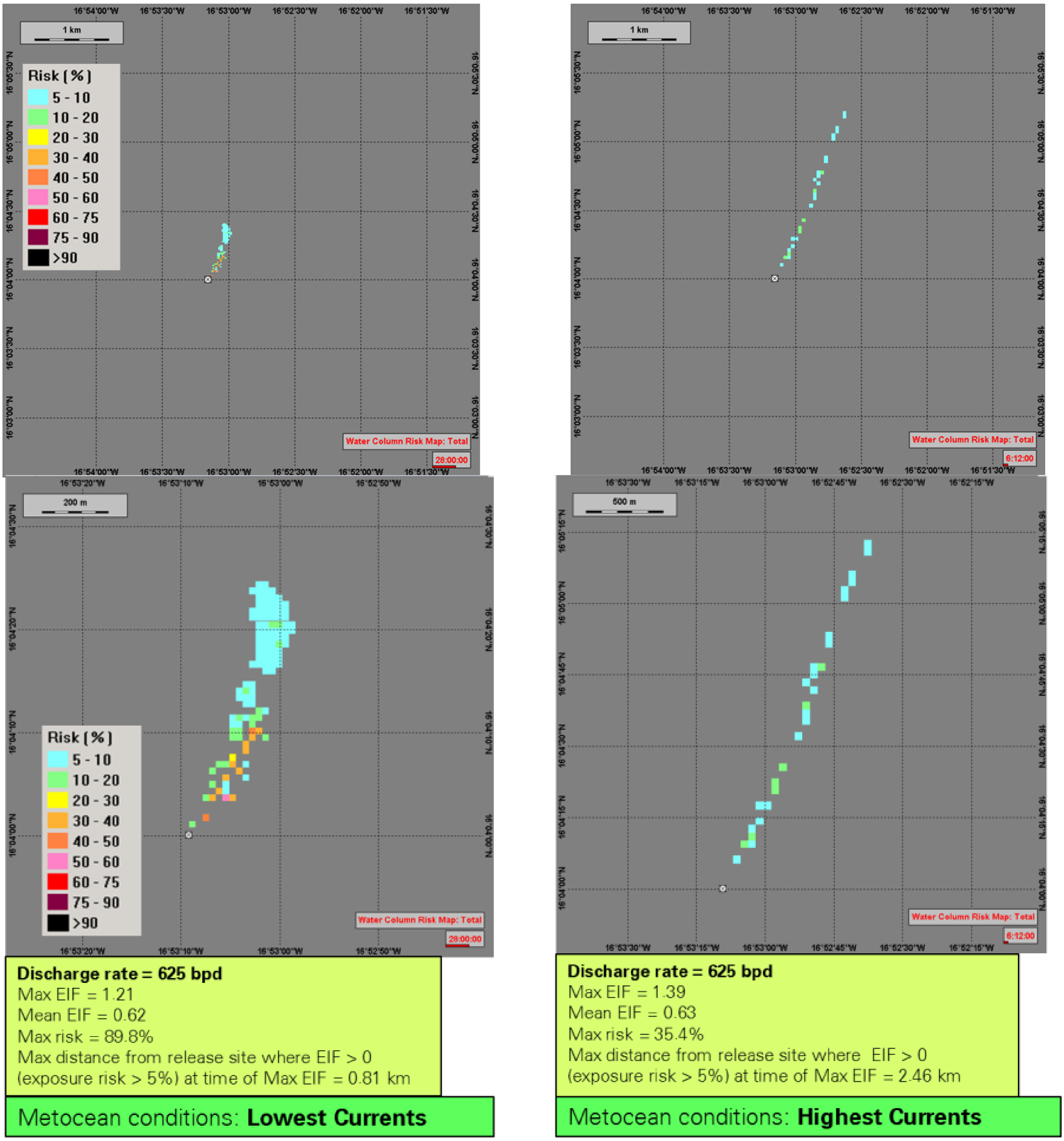


Table 6.1 Summary of the predicted environmental exposure risk arising from NOSs in the PW discharge scenarios for the Tortue FPSO.

Scenario	Concentration of BTEX components in PW discharge	Metocean Ambient current / conditions	Release rate of PW		Release duration (days)	Produced Water Profile Type	Water column EIF									
			(bpd)	(m^3/day)			Maximum exposure risk in the water column over the duration of the simulation (%).	Time-averaged maximum exposure risk in the water column over the duration of the simulation (%).	Lowest maximum exposure risk in the water column over the duration of the simulation (%).	Maximum instantaneous EIF_{wc} over duration of the simulation.	Maximum volume of water whose exposure risk exceeds 5% (EIF_{wc} >0) over the duration of the simulation (km^3).	Time elapsed from the start of the discharge when maximum EIF_{wc} occurs (days)	Maximum distance from release point where WC exposure risk exceeded 5% (i.e. EIF_{wc} > 0) at the time of Max instantaneous EIFwc (km).	Average EIF_{WC} over duration of the simulation.	Average volume of water whose exposure risk exceeds 5% (EIF_{wc} >0) over the duration of the simulation (km^3).	Maximum distance from release point where WC exposure risk exceeded 5% (i.e. EIF_{wc} > 0) over the 45 day simulation (km).
1	Base case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	89.8%	48.8%	20.6%	1.21	0.000121	28.0	0.81	0.62	0.000062	1.93
2	Base case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	35.4%	12.1%	4.7%	1.39	0.000139	6.5	2.46	0.63	0.000063	3.20
3	High case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	97.4%	64.2%	20.3%	2.01	0.000201	4.5	0.31	1.03	0.000103	2.27
4	High case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	47.8%	18.1%	8.2%	2.12	0.000212	35.5	0.43	0.95	0.000095	3.23

Scenario	Concentration of BTEX components in PW discharge	Metocean Ambient current / conditions	Release rate of PW		Release duration (days)	Produced Water Profile Type	Water column EIF																								
			(bpd)	(m^3/day)			Time-averaged maximum exposure risk in the water column over the duration of the simulation (%).	Percentage Change in Time-averaged maximum exposure risk (%)				Maximum instantaneous EIF_{wc} over duration of the simulation.	Percentage Change in Max EIF_{wc} (%)				Maximum distance from release point where WC exposure risk exceeded 5% (i.e. EIF_{wc} > 0) at the time of Max instantaneous EIFwc (km).	Percentage Change (%)				Average EIF_{WC} over duration of the simulation.	Percentage Change in Avg EIF wc(%)				Maximum distance from release point where WC exposure risk exceeded 5% (i.e. EIF_{wc} > 0) over the 45 day simulation (km).	Percentage Change (%)			
1	Base case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	48.8%	0%		0%		1.21	0%		0%		0.81	0%		0%		0.62	0%		0%		1.93	0%		0%	
2	Base case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	12.1%	-75%			0%	1.39	15%			0%	2.46	205%			0%	0.63	2%			0%	3.20	66%			0%
3	High case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	64.2%		0%	32%		2.01		0%	66%		0.31		0%	-61%		1.03		0%	66%		2.27		0%	17%	
4	High case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances	18.1%		-72%		50%	2.12		5%		53%	0.43		37%		-83%	0.95		-8%		51%	3.23		42%		1%

Figure 6.2 Maps showing the spatial extent maximum environmental exposure risk ≥5% predicted at any location in the water column over the 45 day simulation period for the NOS base case at both low and high ambient current velocity conditions (Scenarios 1 and 2).

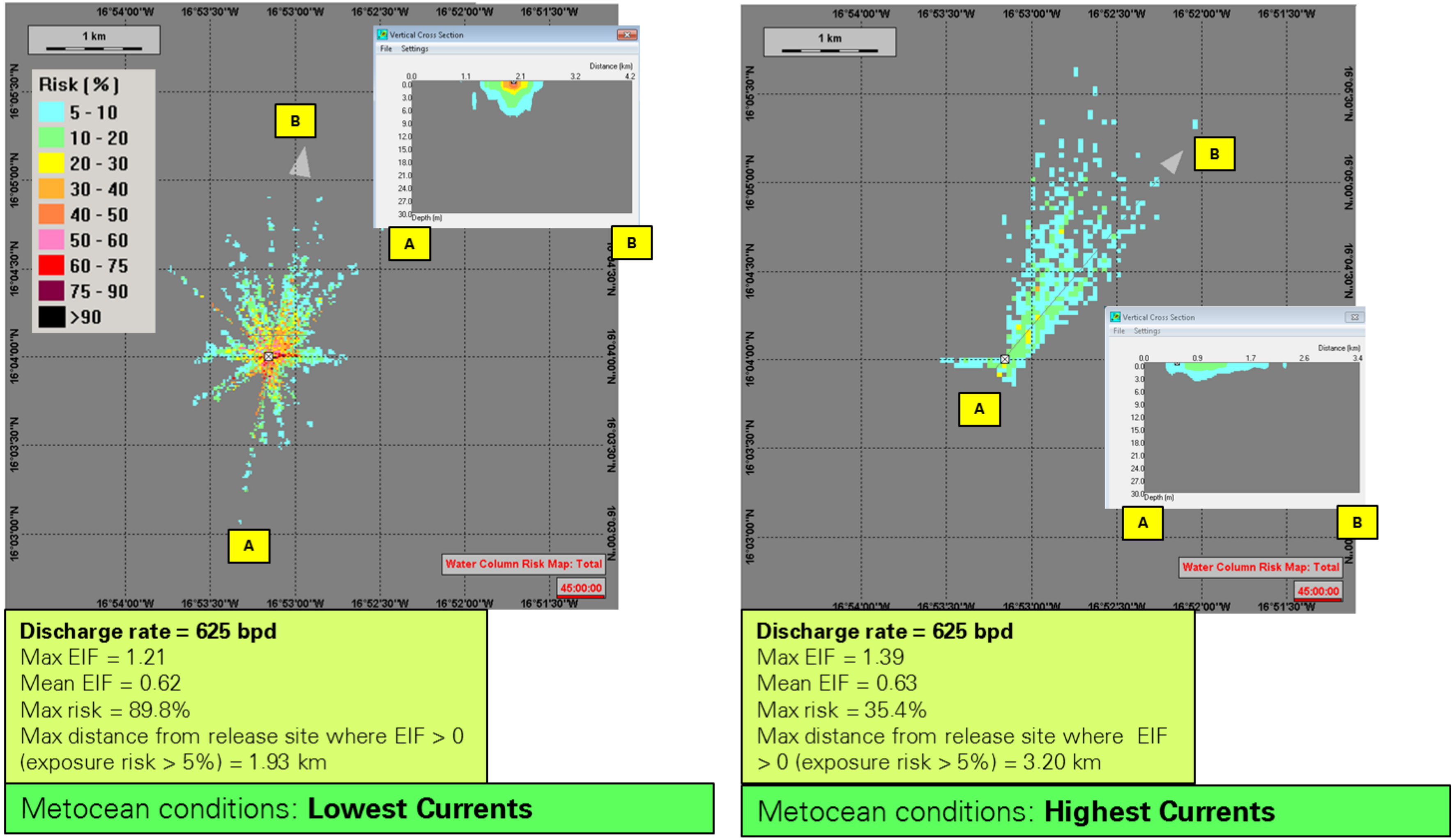
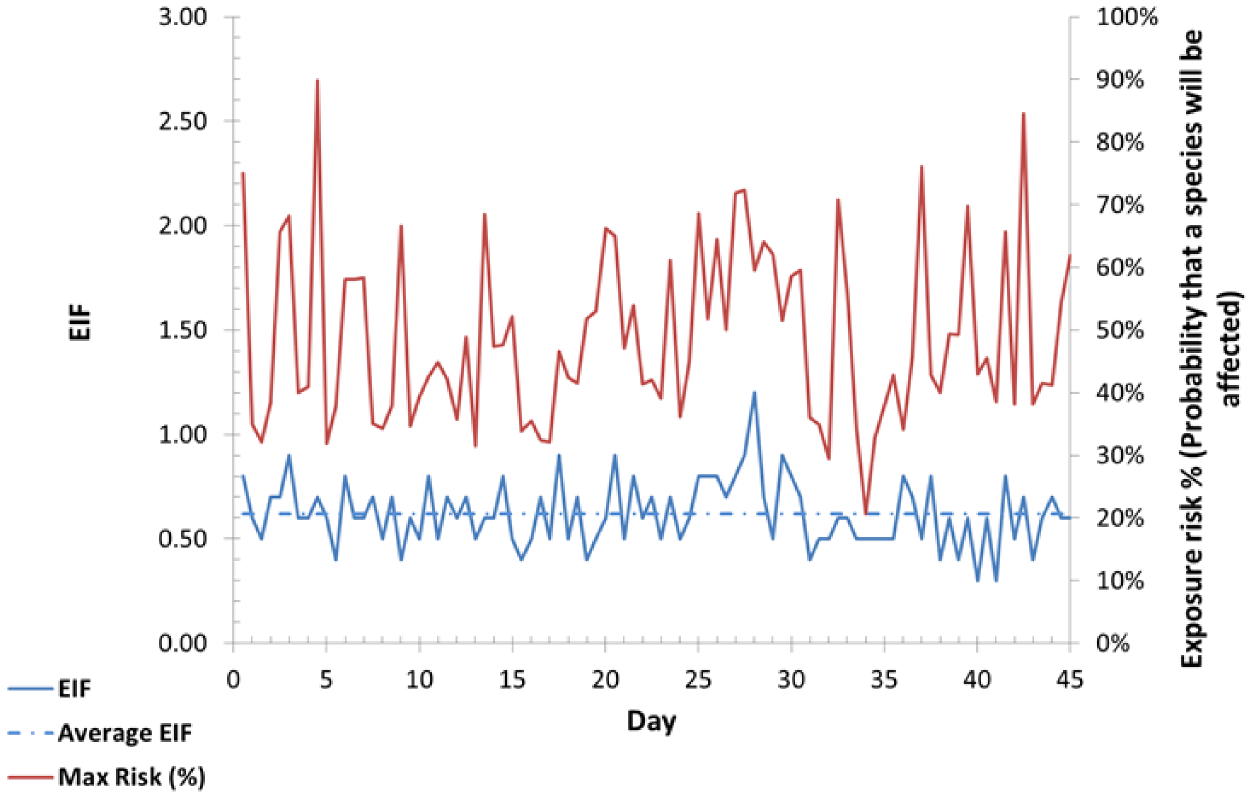


Figure 6.3 **Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column over a 45 day simulation period for the NOS base case at both low (Scenario 1, Top) and high (Scenario 2, Bottom) ambient current velocity conditions.**



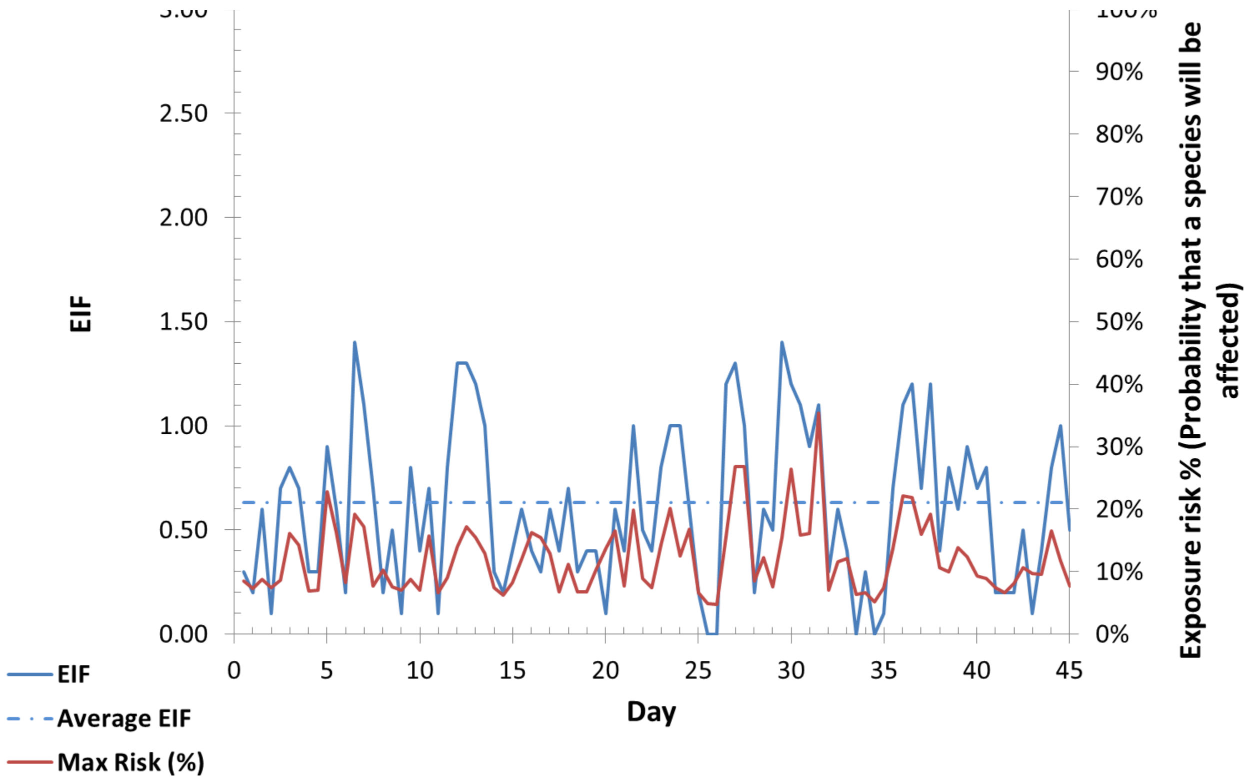
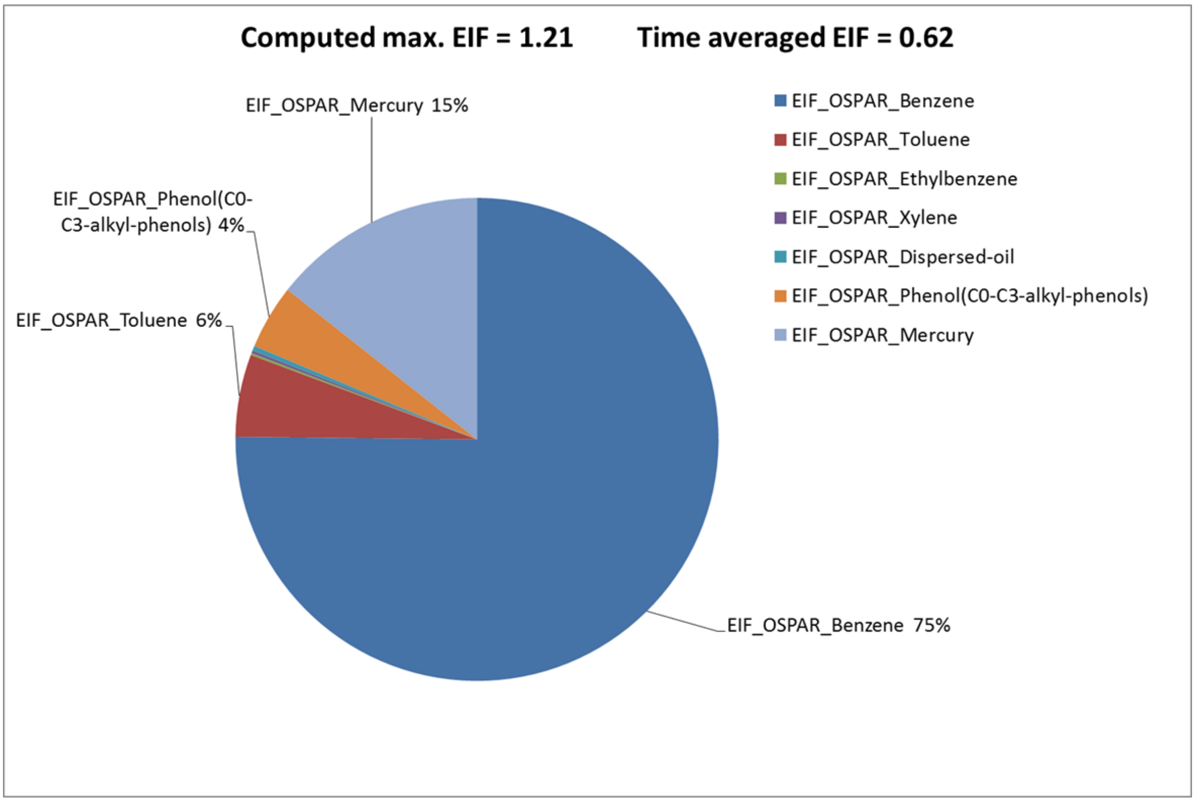


Figure 6.4 Pie-chart showing the contribution of each naturally occurring contaminant towards the EIF for the PW NOS only base case (Scenario 1, low ambient currents)



6.2 Assessment of naturally occurring substances and added Chemicals

Table 6.2 summarises the Maximum and Mean EIFs results for PW discharge Scenarios 5 to 8 (which include production chemicals, see Section 4 - Table 4.1).

The EIFs for all 4 scenarios were much higher than for the scenarios which considered only NOS components indicating that contribution of NOSs to the PW toxicity is minor. The EIFs ranged from 18.9 to 39.6 for the maximum EIF and 9.2 to 15.6 for the Mean EIFs. The highest maximum and mean EIF values of 39.6 and 15.6 respectively (Scenario 7) were associated with the High BTEX concentration case + production chemicals / lowest ambient current velocity scenario. A maximum EIF of 39.6 is equivalent to a maximum volume of water which experiences an exposure risk ≥ 5% of 3.96×10^{-3} km^3

The High BTEX case scenarios with production chemicals included (Scenarios 7 and 8) gave mean EIFs only 5% - 6% greater than those for the corresponding Base case scenarios with production chemicals (Scenarios 5 and 6). For all BTEX scenarios with production chemicals, the increase in dispersion under high ambient current conditions reduced the calculated maximum and mean EIF by 45% - 49% and 38% respectively.

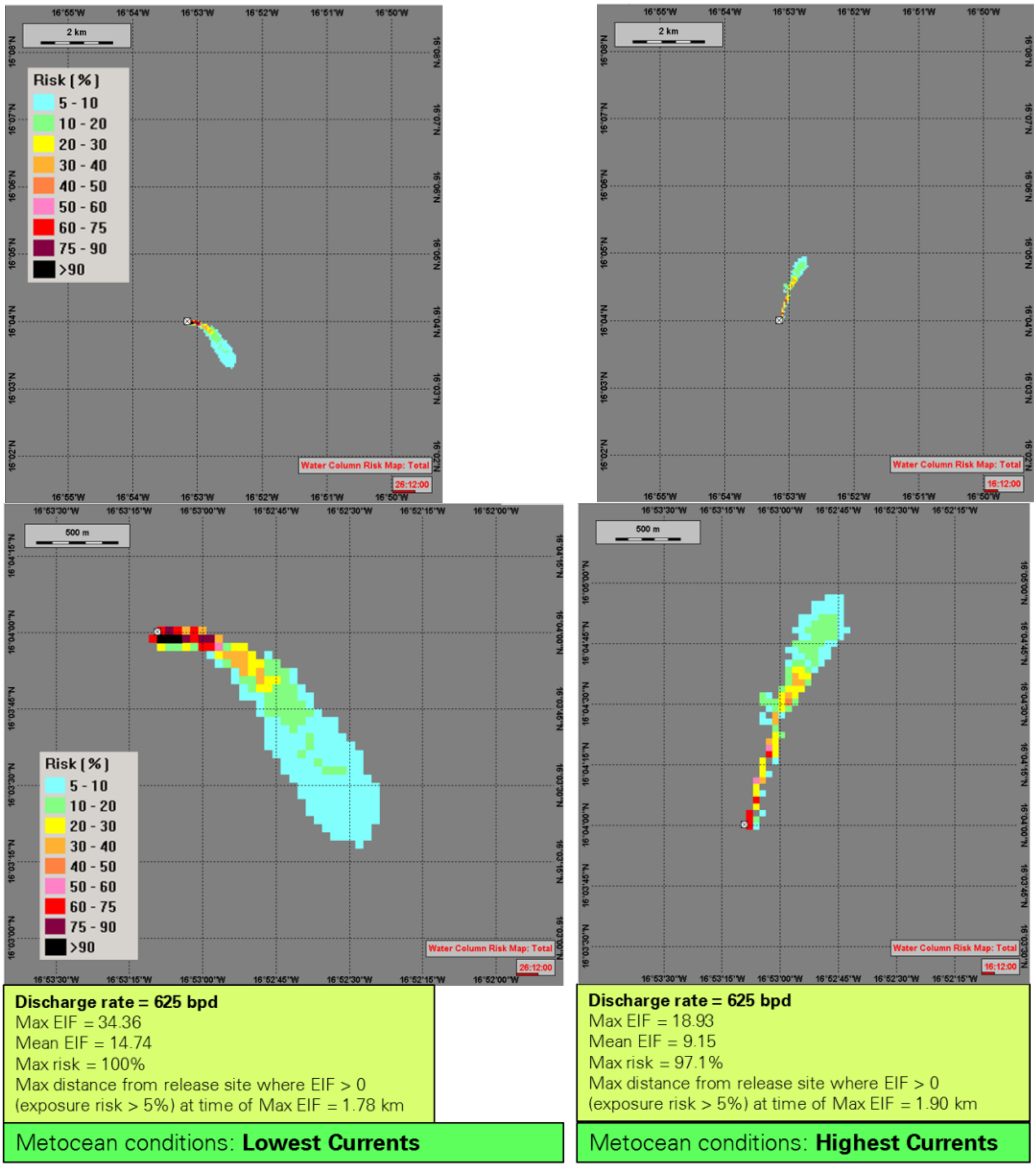
Figure 6.5 shows snapshot maps at the time of maximum EIF in the water column for the NOS base case with production chemicals at both low and high ambient current velocity conditions (Scenarios 5 and 6). The results showed that the maximum distances from release site where the exposure risk is ≥ 5% at the time of maximum EIF are 1.78 km and 1.90 km, for the low and high ambient current cases respectively.

Table 6.2 Summary of the predicted environmental exposure risk arising from NOSs and production chemicals in the PW discharge scenarios for the Tortue FPSO.

Scenario	Concentration of BTEX components in PW discharge	Metocean Ambient current / conditions	Release rate of PW		Release duration (days)	Produced Water Profile Type	Water column EIF									
			(bpd)	(m^3/day)			Maximum exposure risk in the water column over the duration of the simulation (%).	Time-averaged maximum exposure risk in the water column over the duration of the simulation (%).	Lowest maximum exposure risk in the water column over the duration of the simulation (%).	Maximum instantaneous EIF_{wc} over duration of the simulation.	Maximum volume of water whose exposure risk exceeds 5% (EIF_{wc} >0) over the duration of the simulation (km^3).	Time elapsed from the start of the discharge when maximum EIF_{wc} occurs (days)	Maximum distance from release point where WC exposure risk exceeded 5% (i.e. EIF_{wc} > 0) at the time of Max instantaneous EIFwc (km).	Average EIF_{wc} over duration of the simulation.	Average volume of water whose exposure risk exceeds 5% (EIF_{wc} >0) over the duration of the simulation (km^3).	Maximum distance from release point where WC exposure risk exceeded 5% (i.e. EIF_{wc} > 0) over the 45 day simulation (km).
5	Base case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	100.0%	83.1%	45.8%	34.4	0.003436	26.5	1.78	14.7	0.001474	5.31
6	Base case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	97.1%	70.3%	52.2%	18.9	0.001893	16.5	1.90	9.2	0.000915	8.47
7	High case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	100.0%	84.4%	45.8%	39.6	0.003955	26.5	1.76	15.6	0.001563	4.00
8	High case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	97.2%	72.6%	61.6%	20.1	0.002010	16.5	2.08	9.6	0.000963	8.35

Scenario	Concentration of BTEX components in PW discharge	Metocean Ambient current / conditions	Release rate of PW		Release duration (days)	Produced Water Profile Type	Water column EIF																									
			(bpd)	(m^3/day)			Time-averaged maximum exposure risk in the water column over the duration of the simulation (%).	Percentage Change in Time-averaged maximum exposure risk (%)				Maximum instantaneous EIF_{wc} over duration of the simulation.	Percentage Change in Max EIF $_{wc}$(%)				Maximum distance from release point where WC exposure risk exceeded 5% (i.e. EIF_{wc} > 0) at the time of Max instantaneous EIFwc (km).	Percentage Change (%)				Average EIF_{WC} over duration of the simulation.	Percentage Change in Avg EIF wc(%)				Maximum distance from release point where WC exposure risk exceeded 5% (i.e. EIF_{wc} > 0) over the 45 day simulation (km).	Percentage Change (%)			
5	Base case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	84.5%	0%		0%		34.4	0%		0%		1.78	0%		0%		14.7	0%		0%		5.31	0%		0%	
6	Base case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	71.0%	-16%			0%	18.9	-45%			0%	1.90	7%			0%	9.2	-38%			0%	8.47	59%			0%
7	High case	Lowest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	82.9%		0%	-2%		39.6		0%	15%		1.76		0%	-1%		15.6		0%	6%		4.00		0%	-25%	
8	High case	Highest Currents	625	99	Continuous (45 days)	Naturally Occurring Substances + Production Chemicals	71.5%		-14%		1%	20.1		-49%		6%	2.08		18%		9%	9.6		-38%		5%	8.35		109%		-1%

Figure 6.5 **Snapshot maps showing the maximum environmental exposure risk in the water column ≥5% at any location at the time of maximum EIF for the NOS base case with production chemicals at both low and high ambient current velocity conditions (Scenarios 5 and 6). Top - maps same scale, bottom - maps zoomed in).**



If all time steps are considered, then Figure 6.6 shows the maximum environmental exposure risk predicted at any location in the water column over the 45 day simulation period for Scenarios 5 and 6. The maximum distances from release site where the maximum exposure risk is ≥ 5% are 5.31 km and 8.47 km, for the low and high ambient current cases respectively. These maps also show a vertical cross section of risk in the water column along the vector A-B.

The variation in EIF and maximum risk in the water column over the simulation period is for the NOS base case with production chemicals shown in Figure 6.7. The increase in dispersion under high ambient current conditions reduced the predicted time-averaged maximum exposure risk by 16% compared to the low ambient current scenario,

Figure 6.8 shows the contribution of each contaminant in the PW water to the EIF for Scenario 5 (NOS base case + production chemicals, low ambient currents). The pie-chart reveals that 93% of the EIF risk in the water column is attributable to corrosion inhibitor (Cortron RN629) with minor contributions from Benzene (3%), and the chemical flocculent (EC6029A, 3%). Similar results were obtained for the other scenarios although the contribution from Benzene was increased by a few percentage points for the “High” BTEX case scenarios (see Annex C.7, Figure C35, and Annex C.8, Figure C40).

Figure 6.6 **Maps showing the spatial extent of the maximum environmental exposure risk ≥5% predicted at any location in the water column over the 45 day simulation period for the NOS base case with production chemicals at both low and high ambient current velocity conditions (Scenarios 5 and 6).**

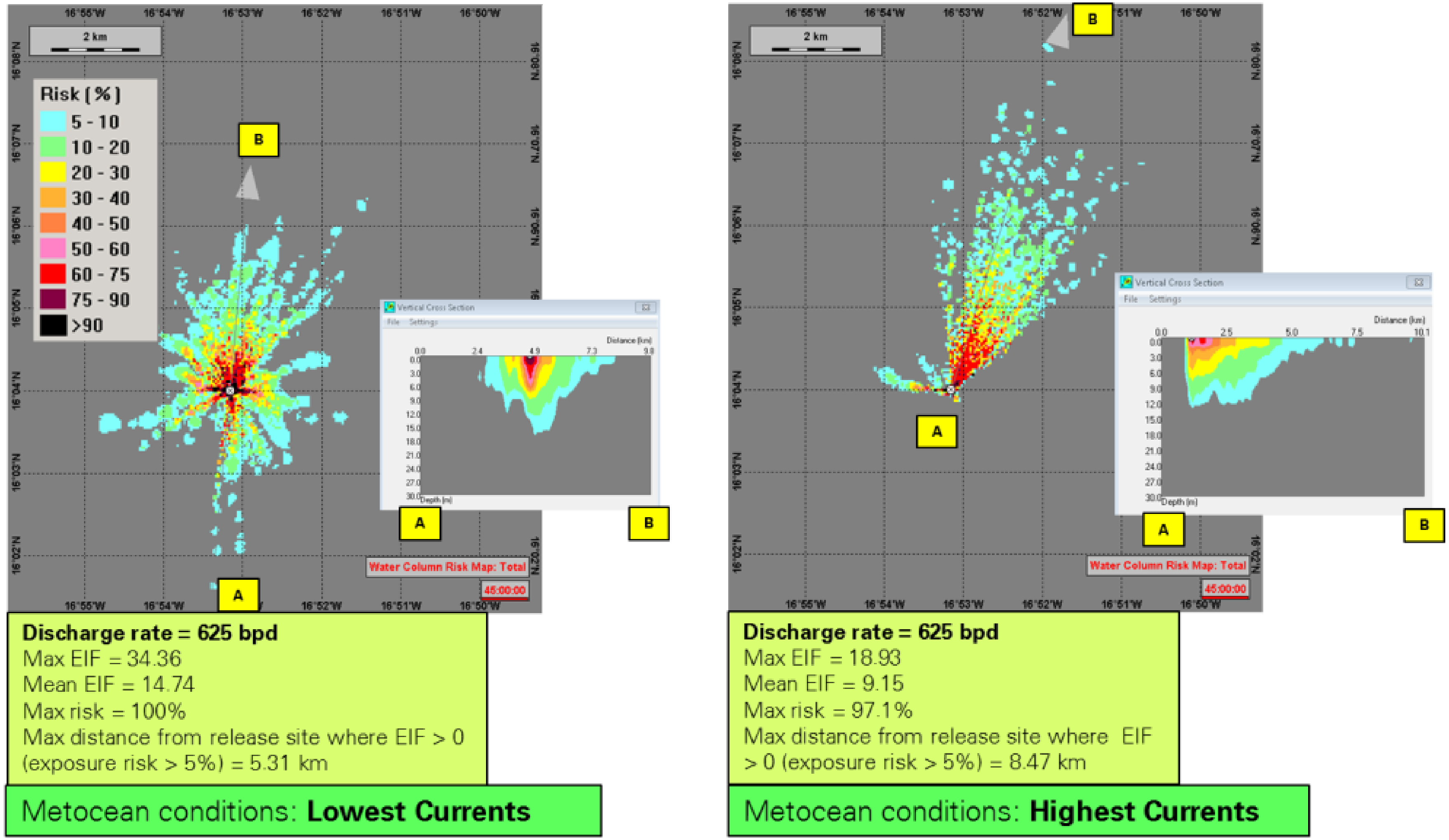
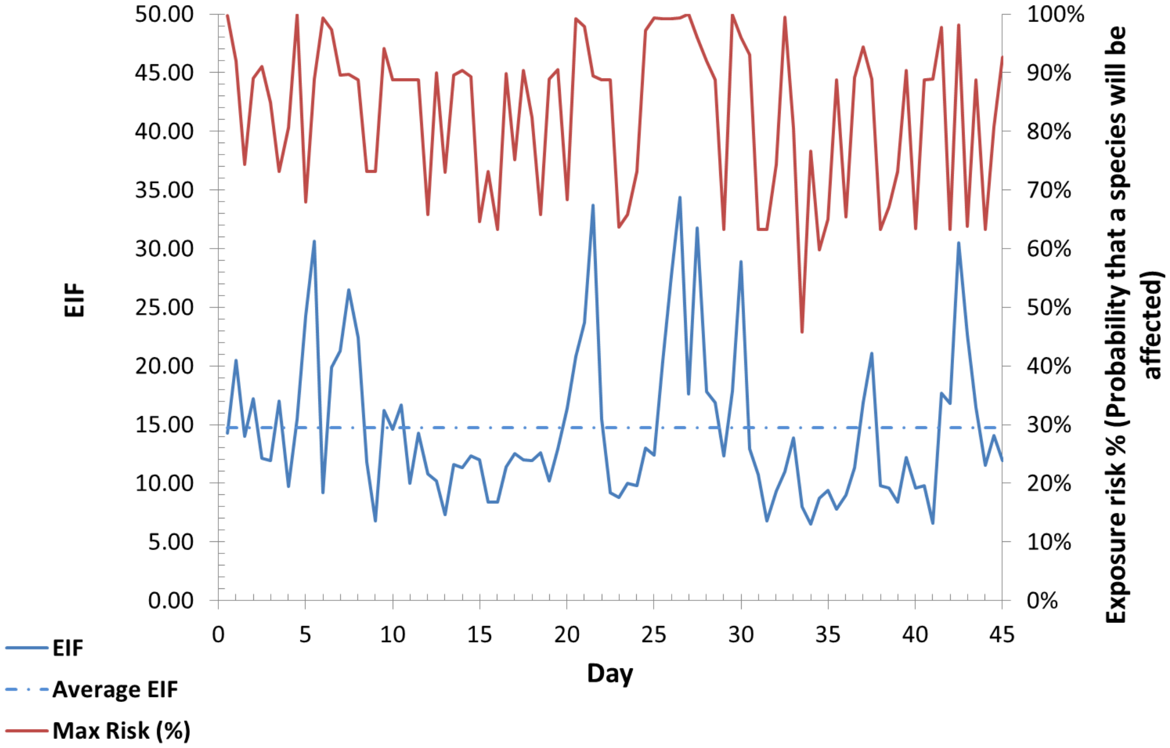


Figure 6.7 Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column over a 45 day simulation period for the NOS base case with production chemicals at both low (Scenario 5, Top) and high (Scenario 6, Bottom) ambient current velocity conditions.



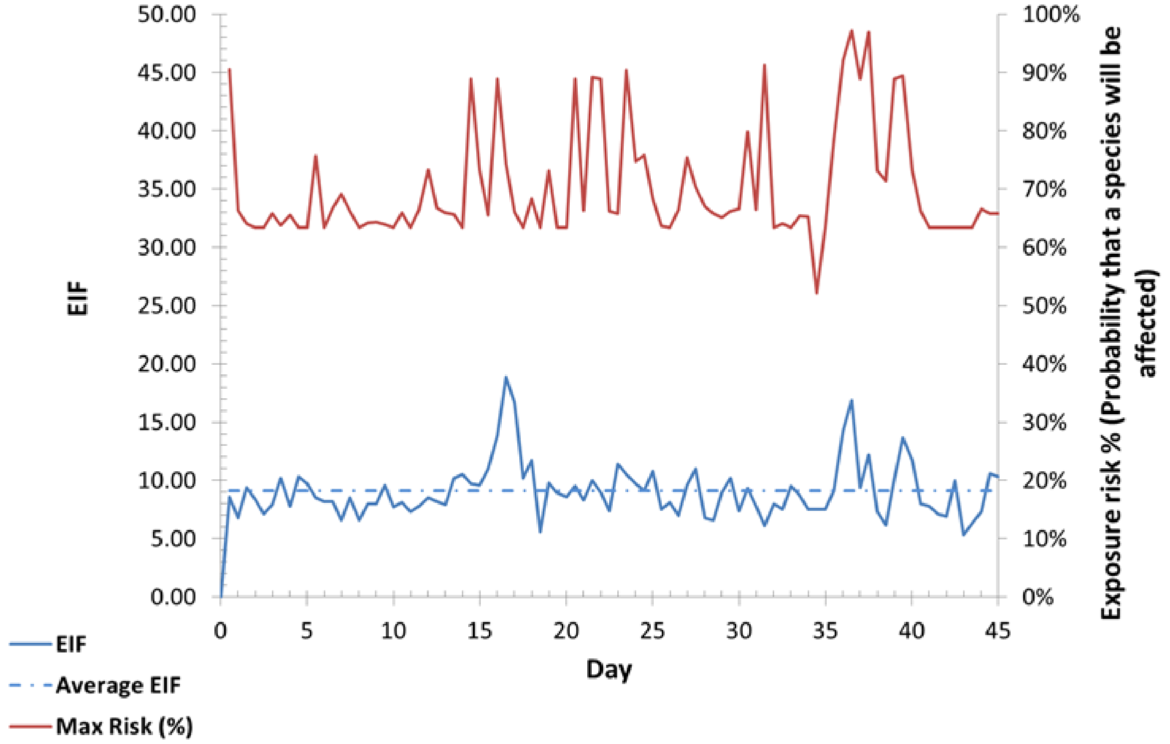
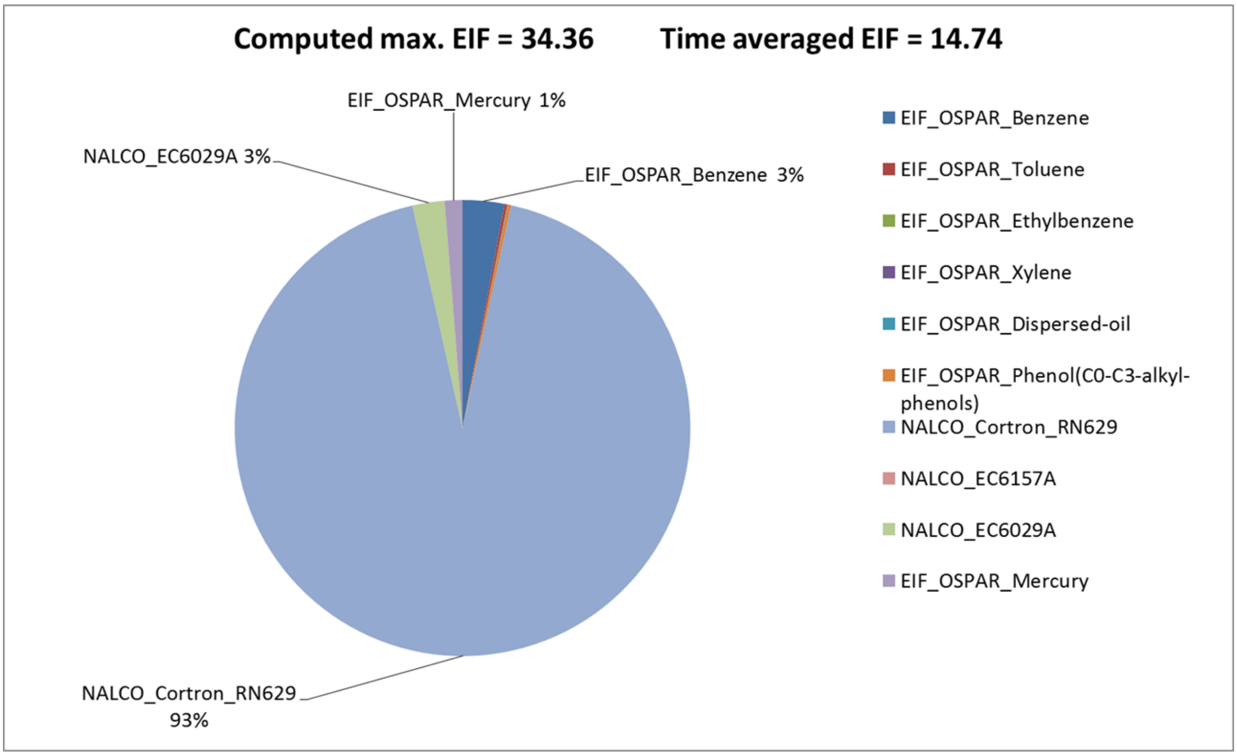


Figure 6.8 Pie-chart showing the contribution of each naturally occurring contaminant towards the EIF for the NOS base case with production chemicals (Scenario 5, low ambient currents)



7 Discussion

Overall, the results show significant variability in the calculated EIFs, which depends on the ambient metocean conditions, the concentration of BTEX components in the PW and whether the PW discharge profiles contain chemical additives.

Although the predicted EIFs were higher when production chemicals were included in the PW profile, which suggests that added chemicals are the main contributor to environmental exposure risk, it must be stressed that this is in part due to the assessment (safety) factor (AF) approach included in the EIF methodology. The variability in quality and quantity of toxicity data for the different substance groups causes a large range in applied AFs that account for extrapolation uncertainty. For example the PNEC values for Ethylbenzene and Benzene were derived using AFs of 10 and 100 respectively, because comprehensive chronic toxicity data is available [(7)]. In contrast, AFs of 1,000 were applied to production chemicals as there is limited acute toxicity data available for 3 species at 3 different trophic levels (algae, zooplankton, and fish) [(3)]. It is important that the extrapolation uncertainty “hidden” in AFs is taken into account when defining risk reduction measures; otherwise it could result in the wrong prioritisation of mitigation options.

Thus in the case of PW discharges from the Tortue FPSO, the first priority before considering any other risk mitigation options, should be establish whether acquiring chronic toxicity test data for the corrosion inhibitor will allow a less conservative AF of 100, or 50 to be used in EIF calculations thereby reducing the overall EIF and contribution from the CI chemical.

Although it is not advisable to compare EIFs from different installations because of differences in the nature and scale of discharges and different environmental conditions, the highest maximum and mean EIF values of 39.6 and 15.6 predicted for the Tortue FPSO PW discharge are small when compared to the limited published PW EIF data for North Sea installations. In 2002 Statoil published EIF data for the discharge of PW from 25 fields in the North Sea. The values ranged from 0 (zero) to 15,000, with an EIF of 100 or less for seven fields, and EIF of approximately 1,000 for the majority of the fields and an EIF of >5,000 for three fields[(12)].

8 References

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Annex A PNEC Calculation and Assessment (Safety) Factors

The selection of the assessment factor for the derivation of the PNEC in the whole effluent approach assessment followed the EC 1996 methodology [(3)] (see Table A1 below).

Table A 1 - Assessment factors to derive a PNEC in an aquatic environment extracted from EC 1996 Technical Guidance Document in support of Commission Directive 93/67/EEC on risk assessment for new notified substances and Commission Regulation (EC) No 1488/94 on risk assessment for existing substances.

	Assessment factor
At least one short-term $L(E)C_{50}$ from each of three trophic levels of the base-set (fish, Daphnia and algae)	1000 [(a)]
One long-term NOEC (either fish or Daphnia)	100 [(b)]
Two long-term NOECs from species representing two trophic levels (fish and/or Daphnia and/or algae)	50 [(c)]
Long-term NOECs from at least three species (normally fish, Daphnia and algae) representing three trophic levels	10 [(d)]
Field data or model ecosystems	Reviewed on a case by case basis[(e)]

NOTES:

(a) The use of a factor of 1000 on short-term toxicity data is a conservative and protective factor and is designed to ensure that substances with the potential to cause adverse effects are identified in the effects assessment. It assumes that each of the above identified uncertainties makes a significant contribution to the overall uncertainty.
For any given substance there may be evidence that this is not so, or that one particular component of the uncertainty is more important than any other. In these circumstances it may be necessary to vary this factor. This variation may lead to a raised or lowered assessment factor depending on the evidence available. Except for substances with intermittent release (see section 3.3.2) under no circumstances should a factor lower than 100 be used in deriving a $PNEC_{water}$ from short-term toxicity data.
Evidence for varying the assessment factor could include one or more of the

- Evidence from structurally similar compounds (Evidence from a closely related compound may demonstrate that a higher or lower factor may be appropriate);
- Knowledge of the mode of action. (Some substances, by virtue of their structure, may be known to act in a non-specific manner. A lower factor may therefore be considered. Equally a known specific mode of action may lead to a raised factor);
- The availability of data from a wide selection of species covering additional taxonomic groups other than those represented by the base-set species;
- The availability of data from a variety of species covering the taxonomic groups of the base-set species across at least three trophic levels.

In such a case the assessment factors may only be lowered if these multiple data points are available for the most sensitive taxonomic group.

There are cases where the base-set is not complete: e.g. for substances which are produced at <1 t/a (notifications according to Annex VII B of Directive 92/32/EEC). At the most the acute toxicity for Daphnia is determined. In these exceptional cases, the PNEC should be calculated with a factor of 1000.
Variation from a factor of 1000 should not be regarded as normal and should be fully supported by accompanying evidence.

(b) An assessment factor of 100 applies to a single long-term NOEC (fish or Daphnia) if this NOEC was generated for the trophic level showing the lowest $L(E)C_{50}$ in the short-term tests.
If the only available long-term NOEC is from a species (standard or non-standard organism) which does not have the lowest $L(E)C_{50}$ from the short term-tests, it cannot be regarded as protective of other more sensitive species using the assessment factors available. Thus the effects assessment is based on the short-term data with an assessment factor of 1000. However, the resulting PNEC based on short-term data may not be higher than the PNEC based on the long-term NOEC available.
An assessment factor of 100 applies also to the lowest of two long-term NOECs covering two trophic levels when such NOECs have not been generated from that showing the lowest $L(E)C_{50}$ of the short-term tests.

(c) An assessment factor of 50 applies to the lowest of two NOECs covering two trophic levels when such NOECs have been generated covering that level showing the lowest $L(E)C_{50}$ in the short-term tests. It also applies to the lowest of three NOECs covering three trophic levels when such NOECs have not been generated from that level showing the lowest $L(E)C_{50}$ in the short-term tests.

(d) An assessment factor of 10 will normally only be applied when long-term toxicity NOECs are available from at least three species across three trophic levels (e.g. fish, Daphnia, and algae or a non-standard organism instead of a standard organism).
When examining the results of long-term toxicity studies, the $PNEC_{water}$ should be calculated from the lowest available no observed effect concentration (NOEC). Extrapolation to the ecosystem effects can be made with much greater confidence, and thus a reduction of the assessment factor to 10 is possible. This is only sufficient, however, if the species tested can be considered to represent one of the more sensitive groups. This would normally only be possible to determine if data were available on at least three species across three trophic levels.

It may sometimes be possible to determine with high probability that the most sensitive species has been examined, i.e. that a further long-term NOEC from a different axonomic group would not be lower than the data already available. In those circumstances, a factor of 10 applied to the lowest NOEC from only two species would also be appropriate. This is particularly important if the substance does not have a potential to bioaccumulate. If it is not possible to make this judgement, then an assessment factor of 50 should be applied to take into account any interspecies variation in sensitivity. A factor of 10 cannot be decreased on the basis of laboratory studies.

(e) The assessment factor to be used on mesocosm studies or (semi-) field data will need to be reviewed on a case-by-case basis.

Annex B PNECs for Naturally Occurring Components of PW

In support of OSPAR 2012/7 guidelines (2), OSPAR Agreement 2014/5 (7) provides PNECs for the naturally occurring components of PW to be included in the RBA assessment. A selected list of PNECs provided in OSPAR Agreement 2014/5 is shown below in Table B1. The document includes a more detailed list of all naturally occurring components and more detailed chemical property information and the Assessment (Safety) Factors used to develop the PNECs.

Table B.1 Selected list of the key naturally occurring constituents of PW and their associated PNECs (OSPAR Agreement 2014/5)

Substance	PNEC (µg/L)	Source	Additional information
BTEX			
Benzene (and xylene)	8	EC, 2013	It is proposed to apply the PNEC for benzene to represent the toxicity of xylene
Toluene	7.4	EU RAR, 2003	
Ethylbenzene	10	EU RAR, 2007	
Naphthalenes			
Naphthalene (and alkyl homologues)	2	EC, 2013	It is proposed to apply the PNEC for naphthalene to represent the toxicity of C1-C3 alkyl homologues of naphthalene
Polycyclic aromatic hydrocarbons (PAHs)			
2-3 ring PAH			
Acenaphthene	0.38	EU RAR CTPHT, 2008	
Acenaphtylene	0.13	EU RAR CTPHT, 2008	
Fluorene	0.25	EU RAR CTPHT, 2008	
Anthracene (and dibenzothiophene and alkyl homologues)	0.1	EC, 2013	It is proposed to apply the PNEC for anthracene to represent the toxicity of dibenzothiophene and C1-C3 alkyl homologues of dibenzothiophene
Phenanthrene (and alkyl homologues)	1.3	EU RAR CTPHT, 2008	It is proposed to apply the PNEC for phenanthrene to represent the toxicity of C1-C3 alkyl homologues of phenanthrene
4 ring PAHs			
Fluoranthene	0.0063	EC, 2013	The $PNEC_{water}$ is back calculated from food standard applying bioconcentration factor [1)]
Pyrene	0.023	EU RAR CTPHT, 2008	
Benz(a)anthracene	0.0012	EU RAR CTPHT, 2008	
Chrysene	0.007	EU RAR CTPHT, 2008	
5-6 ring PAHs			
Dibenzo(a,h)anthracene	0.00014	EU RAR CTPHT, 2008	
Substance	**PNEC (µg/L)**	**Source**	**Additional information**
Benzo(a)pyrene[2] (and Benzo(g,h,i)perylene,	0.00017	EC, 2013	It is proposed to apply the PNEC for benzo(a)pyrene to represent the toxicity of

Benzo[b]fluoranthene, Benzo[k]fluoranthene and Indeno[1,2,3-cd]pyrene)			benzo(g,h,i)perylene, benzo[b]fluoranthene, benzo[k]fluoranthene and indeno[1,2,3-cd]pyrene. The $PNEC_{water}$ is back calculated from food standard for benzo(a)pyrene applying bioconcentration factor for molluscs [1)]
Alternative PNEC value/sources based on aquatic toxicity (µg/L)			
Benzo(a)pyrene	1) 0.022 (5-6 rings PAH EQS draft fact sheet; dossier 20101221) 2) 0.022 (EU RAR CTPHT, 2008) 3) 0.010 (Verbruggen, 2012).		
Benzo[b]fluoranthene,	1) 0.017 (5-6 rings PAH EQS draft fact sheet; dossier 20101221 2) 0.0017 (EU CTPHT RAR, 2008) 3) 0.017 (Verbruggen, 2012).		
Benzo[k]fluoranthene	1) 0.017 (5-6 rings PAH EQS draft fact sheet; dossier 20101221)2) 0.0017 (EU RAR CTPHT, 2008) 3) 0.017 (Verbruggen, 2012)		
Indeno[1,2,3-cd]pyrene)	1) 0.00027 (EU RAR CTPHT, 2008) 2) 0.00027 (Verbruggen, 2012		
Benzo(g,h,i)perylene,	1) 0.00082 (5-6 rings PAH EQS draft fact sheet; dossier 20101221) 2) 0.00082 (EU RAR CTPHT, 2008) 2) 0.00082 (Verbruggen, 2012)		
Dispersed oil			
Dispersed oil	70.5	Smit et al., 2009	No official standard available
Metals			
Arsenic	0.6 +Cb[3]	UKTAG, 2007	No EU standard available.,
Cadmium	0.2+Cb[3]	EC, 2013	
Chromium	0.6+ Cb	UKTAG, 2007	No EU standard available
Copper	2.6	EU RAR, 2008	
Nickel	8.6 +Cb	EC, 2013	
Mercury[4]	0.05+Cb[3]	WFD, 2008	The PNEC does not account for bioaccumulation[1]
Lead	1.3	EC, 2013	
Zinc	3.4+Cb[3]	UKTAG, 2012	
Alkyl phenols			
Phenol (and C1-C3 alkyl phenols)	7.7	EU RAR, 2006	Reliable PNECs are not available for individual C0-C3 alkyl phenols. It is proposed to apply the PNEC for phenol to represent the toxicity of all C0-C3 alkyl phenols
Butylphenol (and other C4 alkyl phenols)	0.64	EU RAR, 2008	Reliable PNECs are not available for individual C4 alkyl phenols. It is proposed to apply the PNEC for butylphenol to represent the toxicity of all C4 alkyl phenols
Substance	**PNEC (µg/L)**	**Source**	**Additional information**
Pentylphenol (and other C5 alkyl phenols)	0.2	EA RAR, 2008	Reliable PNECs are not available for individual C5 alkyl phenols. It is proposed to apply the PNEC for pentylphenol to represent the toxicity of all C5 alkyl phenols

Octylphenol (and C6-C8 alkyl phenols)	0.01	EC, 2013	Reliable PNECs are not available for individual C6-C8 alkyl phenols. It is proposed to apply the PNEC for octylphenol to represent the toxicity of all C6-C8 alkyl phenols
Nonylphenol (and other C9 alkyl phenols)	0.3	EC, 2013	Reliable PNECs are not available for individual C9 alkyl phenols. It is proposed to apply the PNEC for nonylphenol to represent the toxicity of all C9 alkyl phenols

1) For Priority Substances under the WFD with significant bioaccumulation potential or human health effects from consumption of fishery products (e.g. for some PAHs), the PNECwater is derived from food standards applying bioconcentration factors.

2) 5-6 ring PAHs include the carcinogenic substances: benzo[a]pyrene, benzo(g,h,i)perylene, benzo[b]fluoranthene, benzo[k]fluoranthene and indeno[1,2,3-cd]pyrene. It is proposed to apply the PNEC for benzo[a]pyrene for all 5-6 carcinogenic PAHs.

3) Cb: Background concentration (µg/L). Site specific background concentrations are preferred. If not available, ranges for background concentrations can be found in the OSPAR background document (OSPAR, 2004).

4) For mercury, which has bioaccumulation potential, back calculation from food standards is not possible because bioconcentration factors are highly variable. Therefore the PNEC water for mercury based on aquatic toxicity is proposed (WFD, 2008). The PNEC does not account for bioaccumulation/secondary effects and is therefore not protective for marine mammals and birds.

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Annex C Environmental exposure risk modelling results for each release scenario

C.1 Scenario 1

Figure C.1 Scenario 1 - Snapshot map at the time of maximum environmental exposure risk in the water column ≥ 5% (EIF_{WC} = 1.21, 1.21 x 10^{-4} km^3) over the 45 day simulation period for naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions

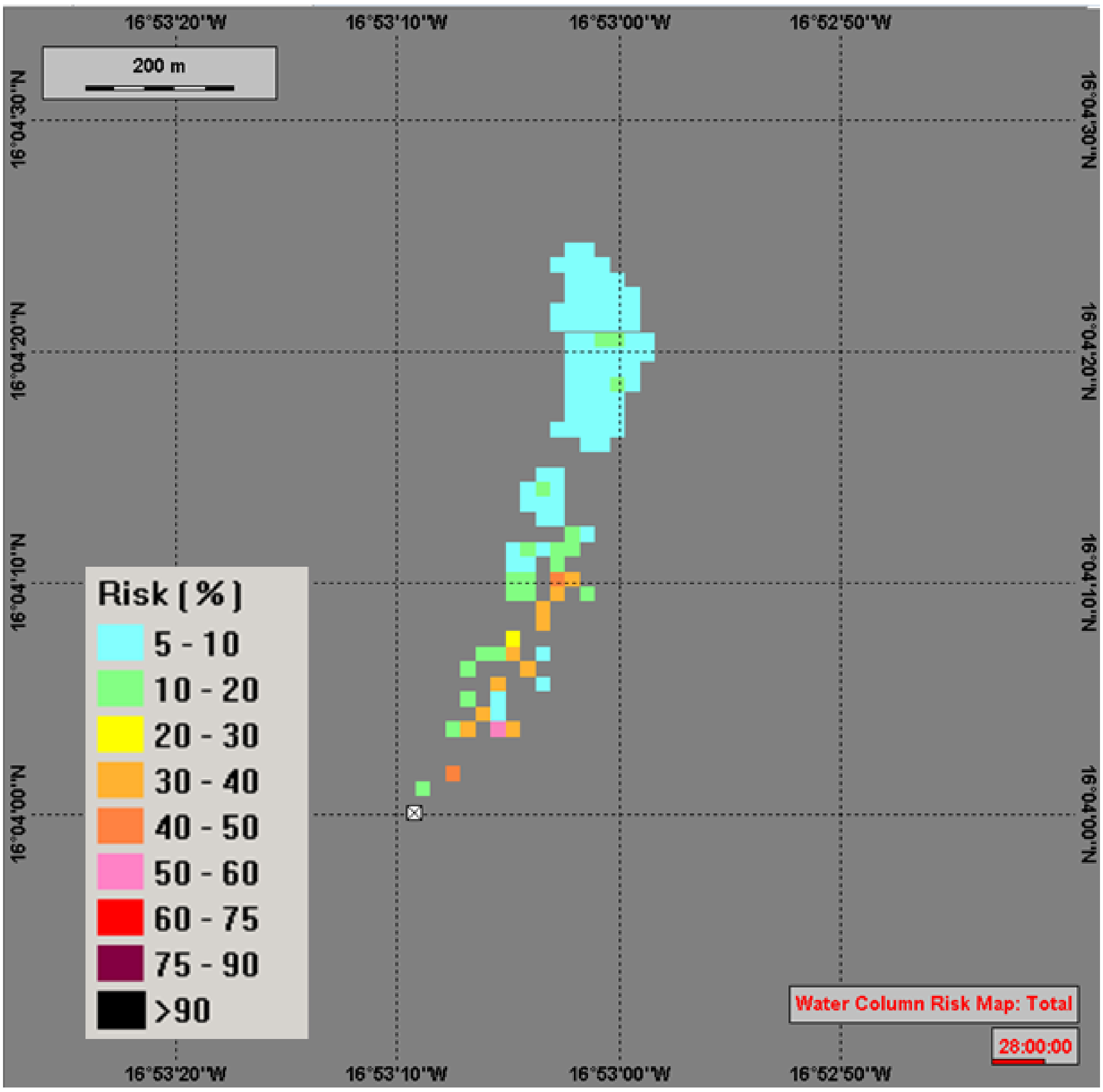


Figure C.2 **Scenario 1 - Time series of EIF_{WC} in the water column, showing the contribution from each component in the continuous release of PW over the 45 day simulation period for naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.**

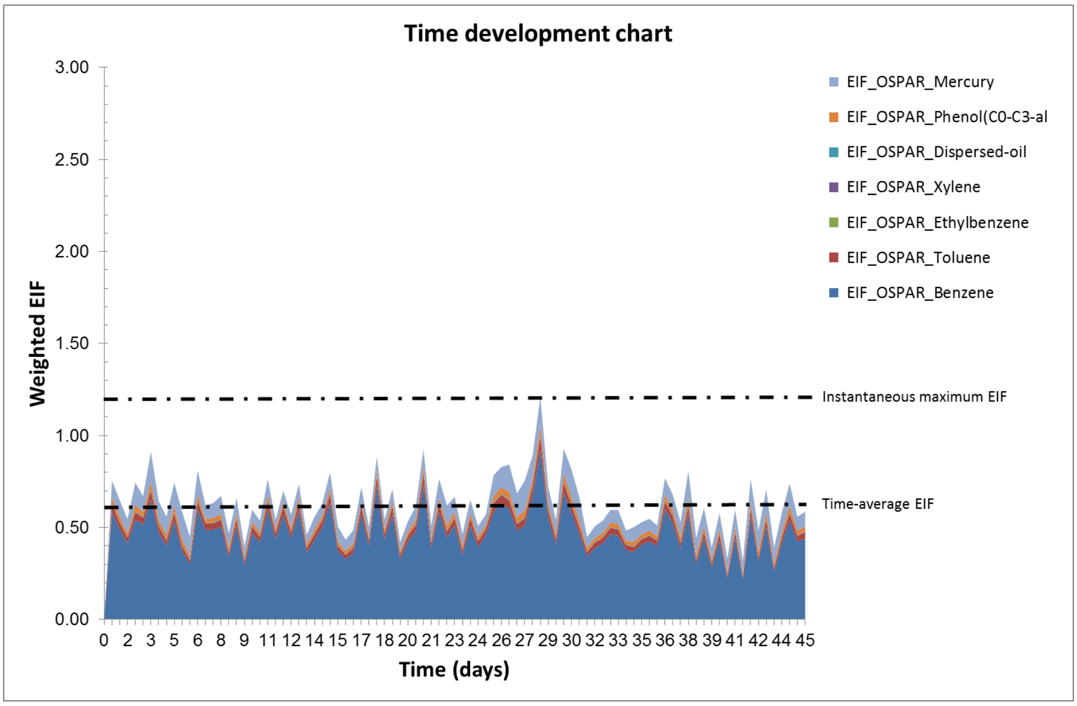


Figure C.3 **Scenario 1 - Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column for the continuous release of PW over the 45 day simulation period for naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.**

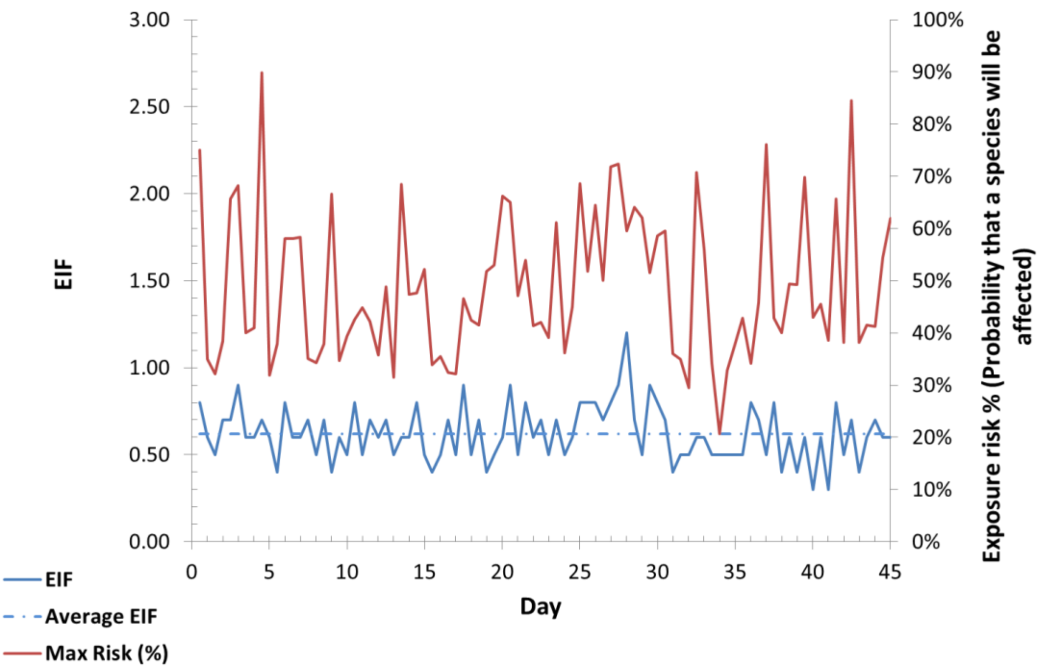


Figure C.4 Scenario 1 - Map showing the spatial extent of the maximum environmental exposure risk at any location in the water column (≥ 5% [EIF_{WC} >0]) over a 45 day simulation period (all time steps integrated) for naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.

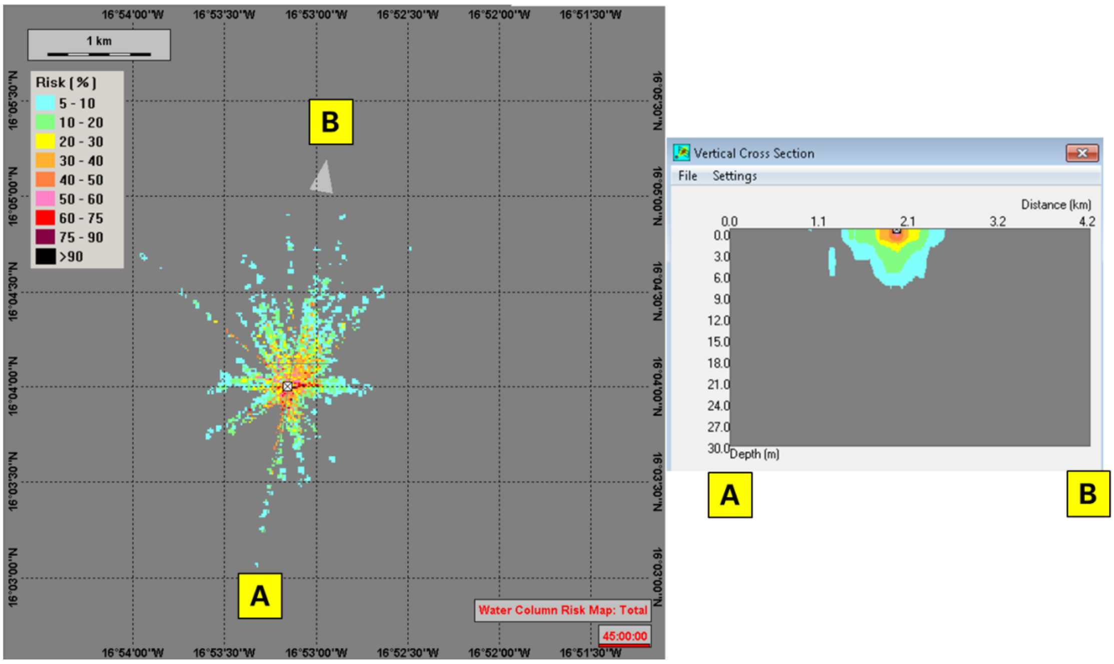
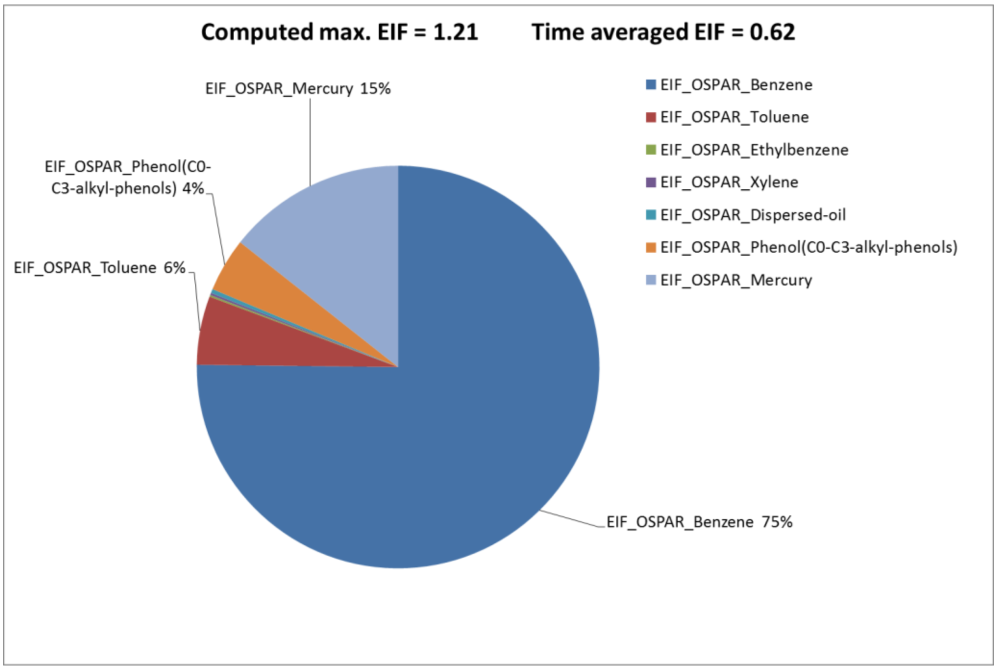


Figure C5 Scenario 1 - Pie-chart showing the contributions to EIF_{WC} of each contaminant in the discharge at the time of maximum EIF_{WC} following the continuous release of PW over the 45 day simulation period for naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.



C.2 Scenario 2

Figure C.6 Scenario 2 - Snapshot map at the time of maximum environmental exposure risk in the water column ≥ 5% (EIF_{WC} = 1.39, 1.39 x 10^{-4} km^3) over the 45 day simulation period for naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions

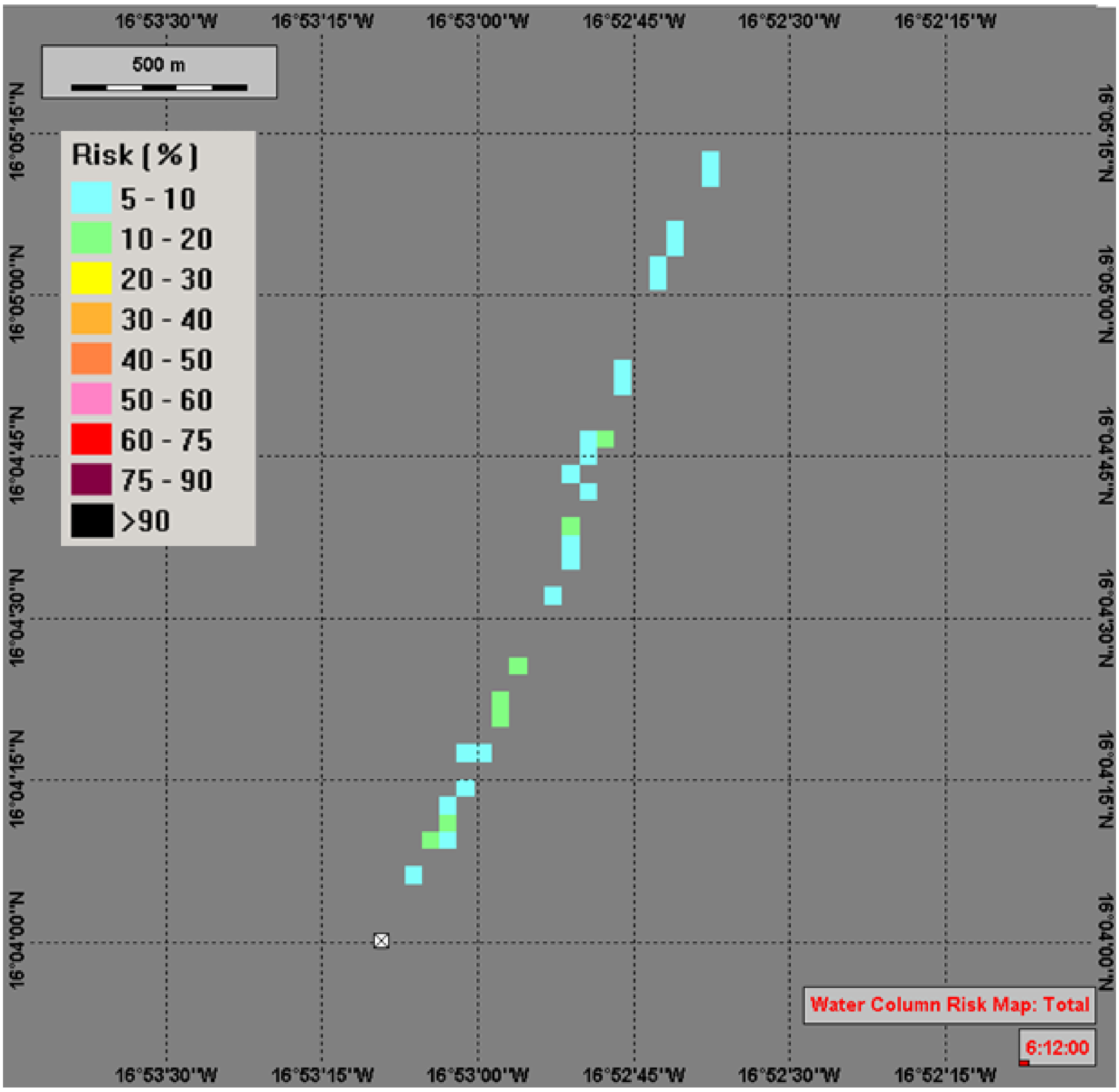


Figure C.7 Scenario 2 - Time series of EIF_{WC} in the water column, showing the contribution from each component in the continuous release of PW over the 45 day simulation period for

naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.

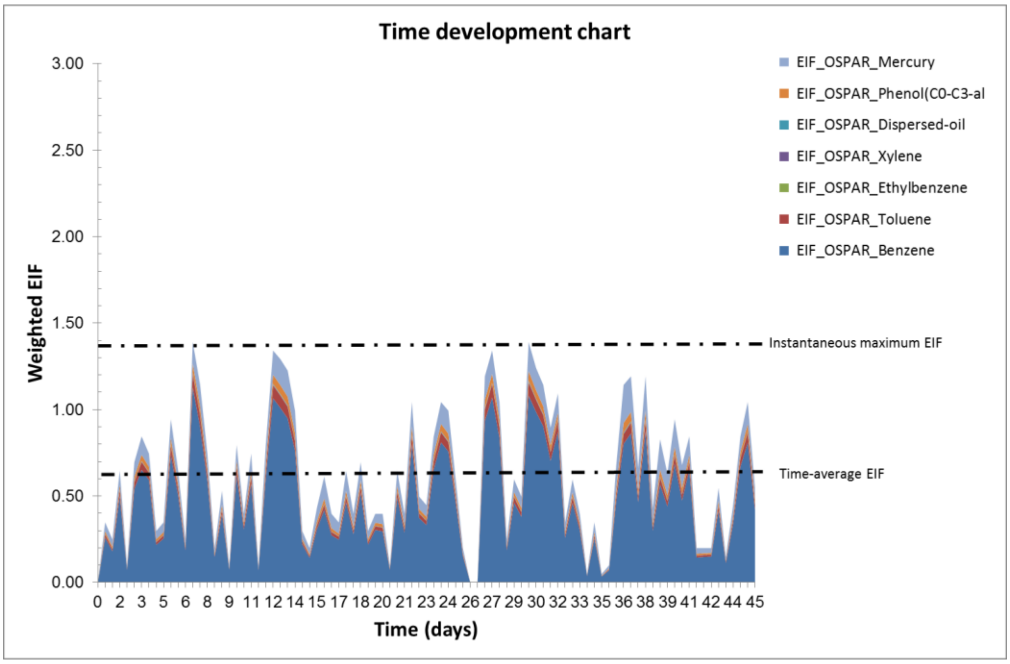


Figure C.8 Scenario 2 - Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column for the continuous release of PW over the 45 day simulation period for naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.

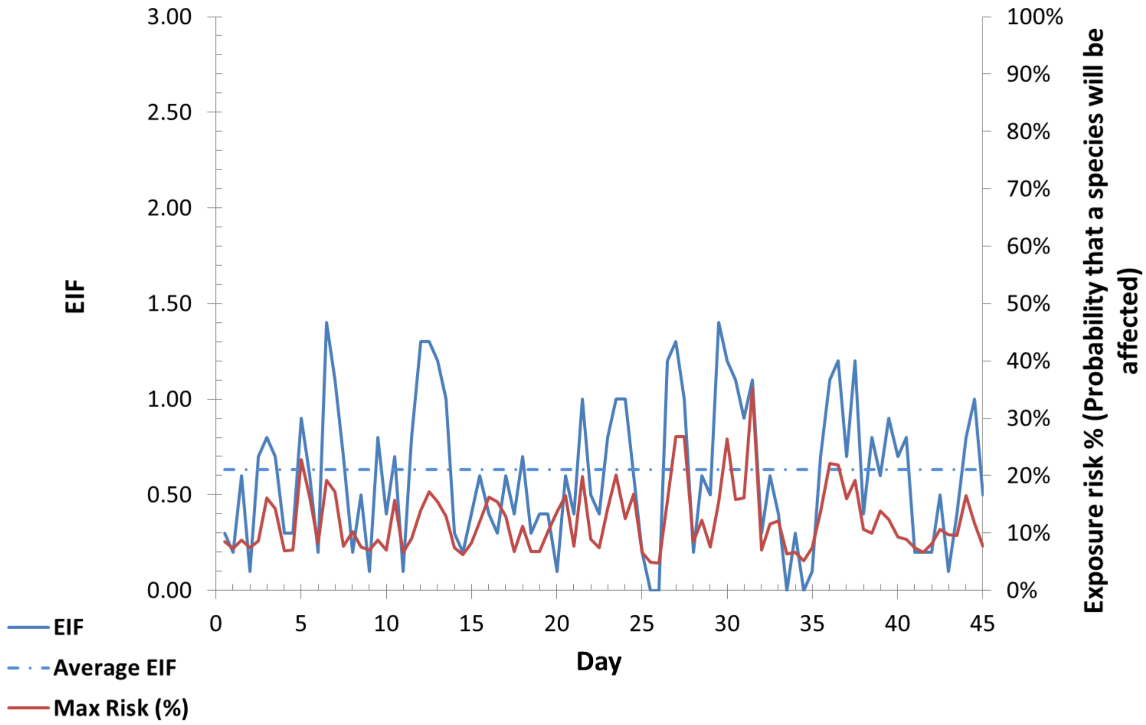


Figure C.9 **Scenario 2 - Map showing the spatial extent of the maximum environmental exposure risk at any location in the water column (≥ 5% [EIF_{WC} >0]) over a 45 day simulation period (all time steps integrated) for naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**

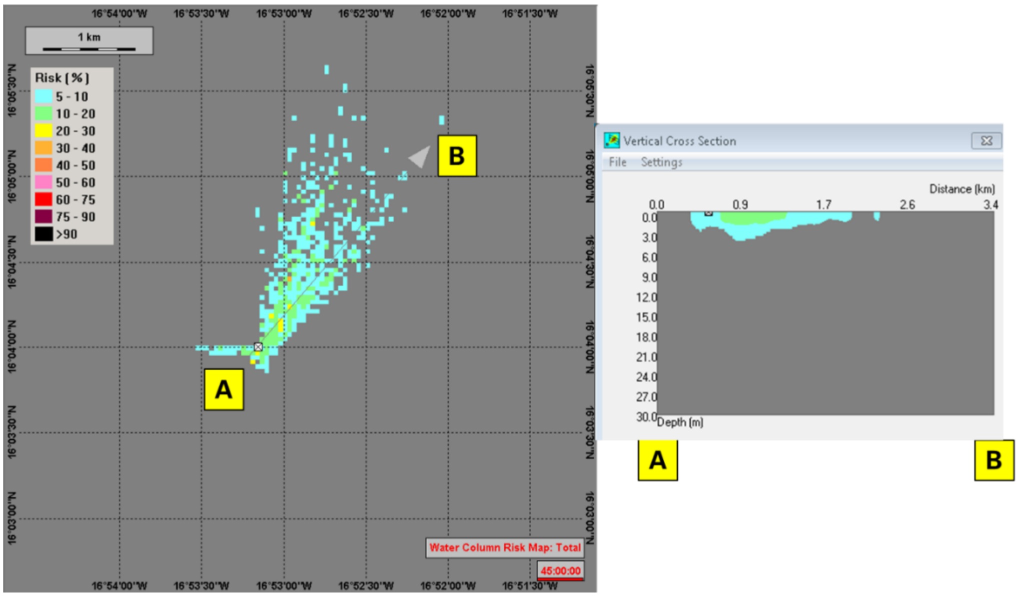
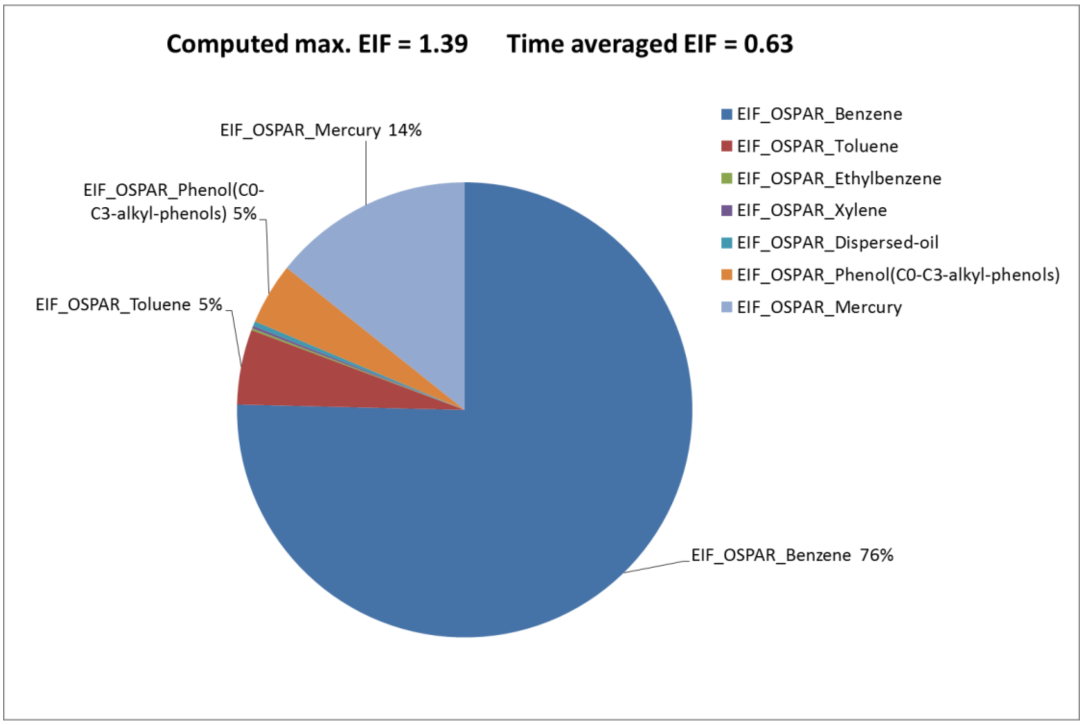


Figure C10 **Scenario 2 - Pie-chart and table showing the contributions to EIF_{WC} of each contaminant in the discharge at the time of maximum EIF_{WC} following the continuous release of PW over the 45 day simulation period for naturally occurring substances only (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**



C.3 Scenario 3

Figure C.11 Scenario 3 - Snapshot map at the time of maximum environmental exposure risk in the water column ≥ 5% (EIF_{WC} = 2.01, 2.01 x 10^{-4} km^3) over the 45 day simulation period for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions

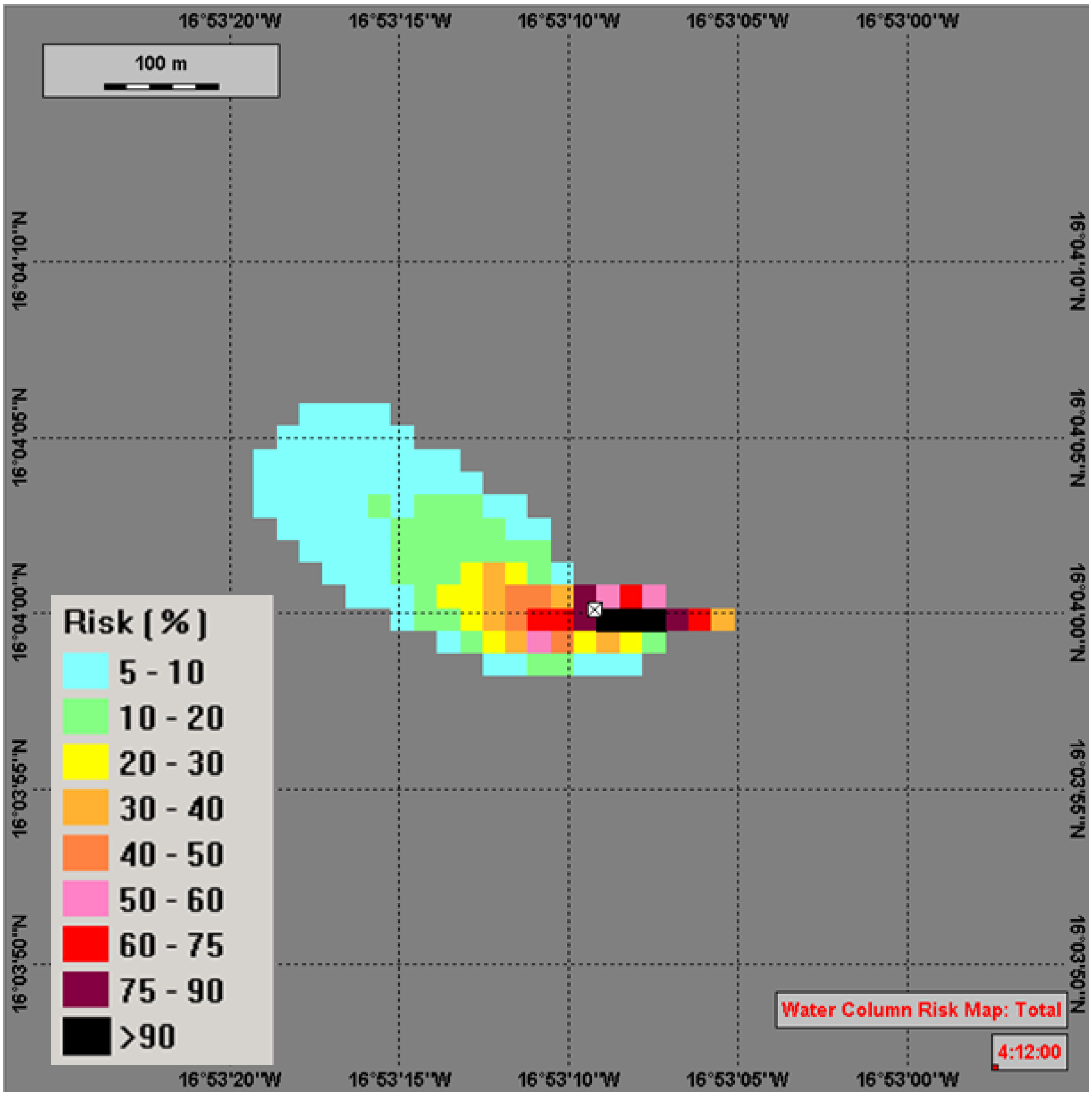


Figure C.12 **Scenario 3 - Time series of EIF_{WC} in the water column, showing the contribution from each component in the continuous release of PW over the 45 day simulation period for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.**

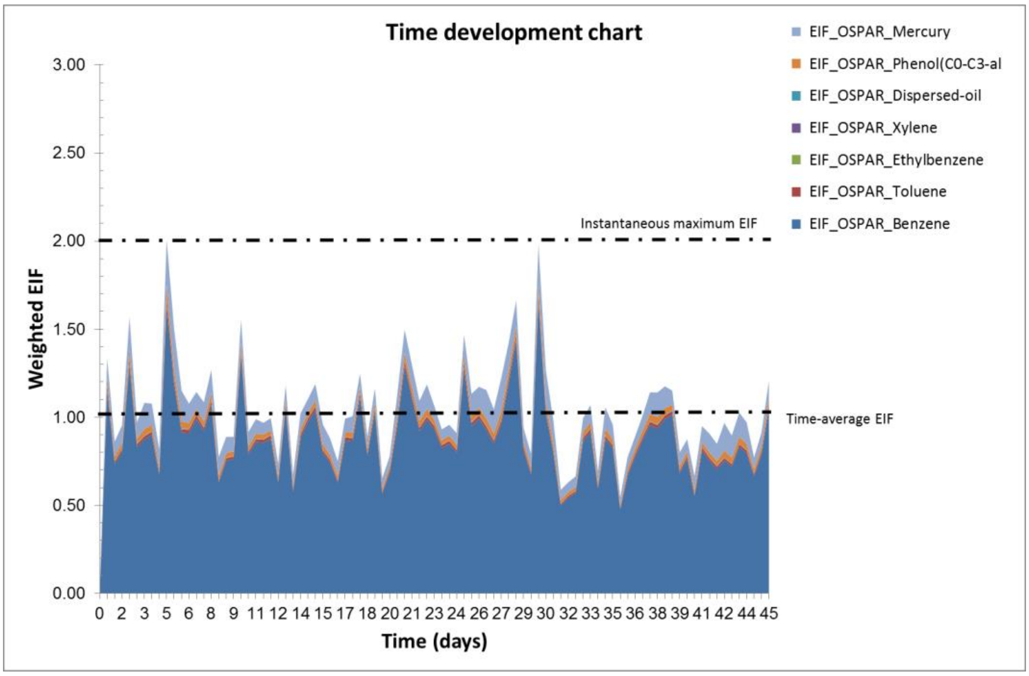


Figure C.13 **Scenario 3 - Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column for the continuous release of PW over the 45 day simulation period for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.**

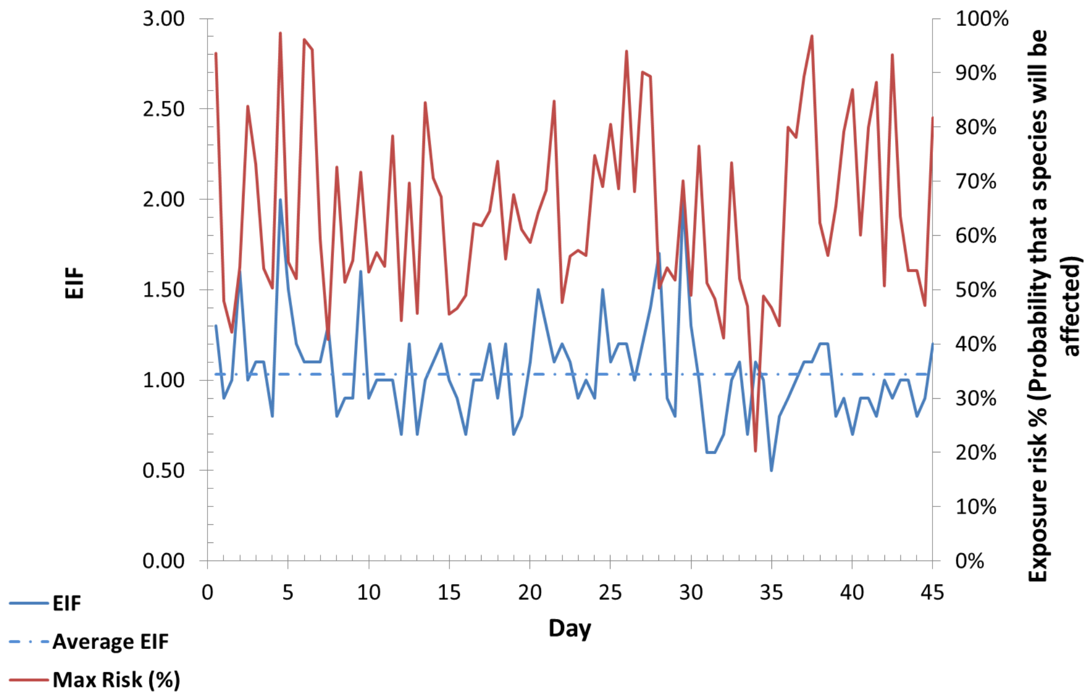


Figure C.14 Scenario 3 - Map showing the spatial extent of the maximum environmental exposure risk at any location in the water column (≥ 5% [EIF_{WC} >0]) over a 45 day simulation period (all time steps integrated) for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.

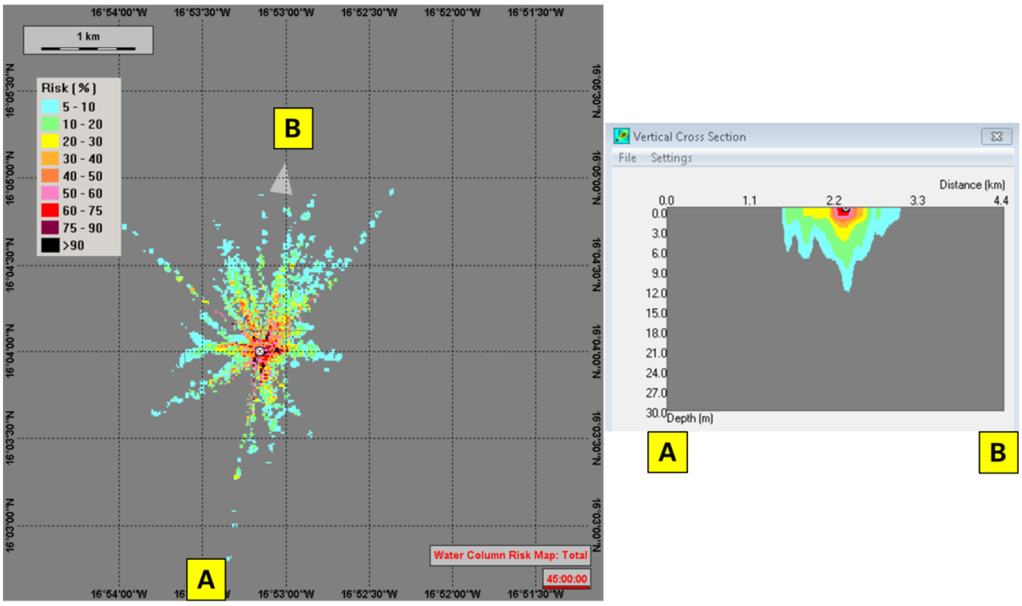
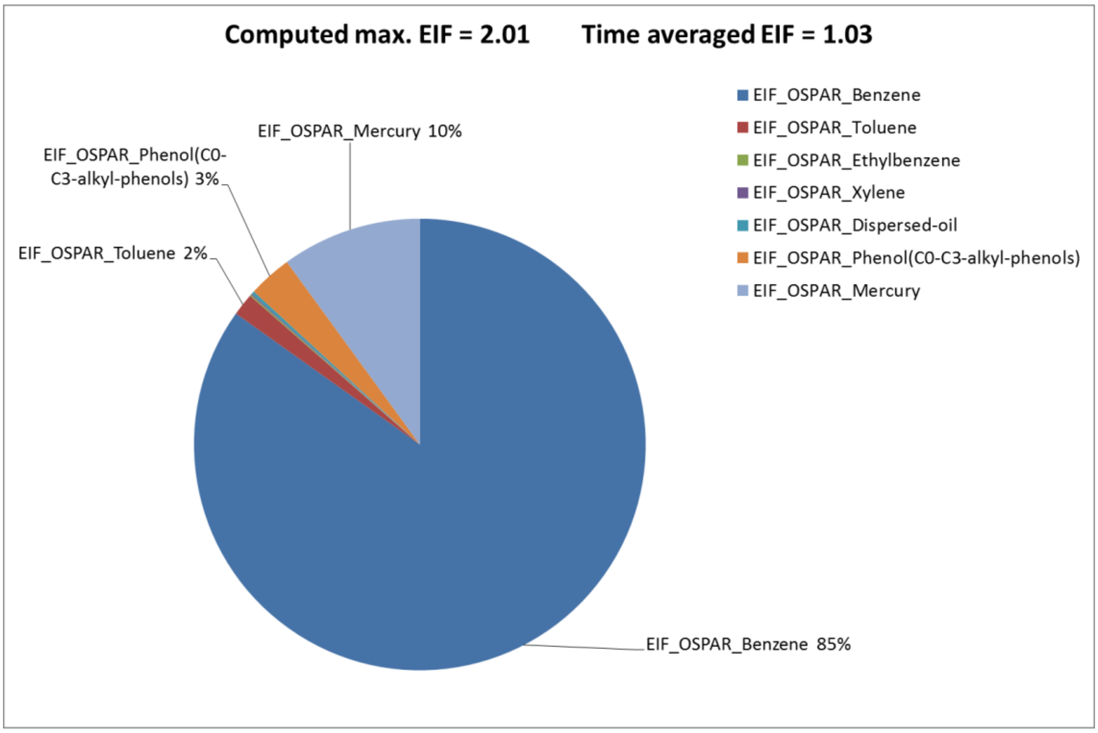


Figure C15 Scenario 3 - Pie-chart and table showing the contributions to EIF_{WC} of each contaminant in the discharge at the time of maximum EIF_{WC} following the continuous release of PW over the 45 day simulation period for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.



C.4 Scenario 4

Figure C.16 Scenario 4 - Snapshot map at the time of maximum environmental exposure risk in the water column ≥ 5% (EIF_{WC} = 2.12, 2.12 x 10^{-4} km^3) over the 45 day simulation period for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions

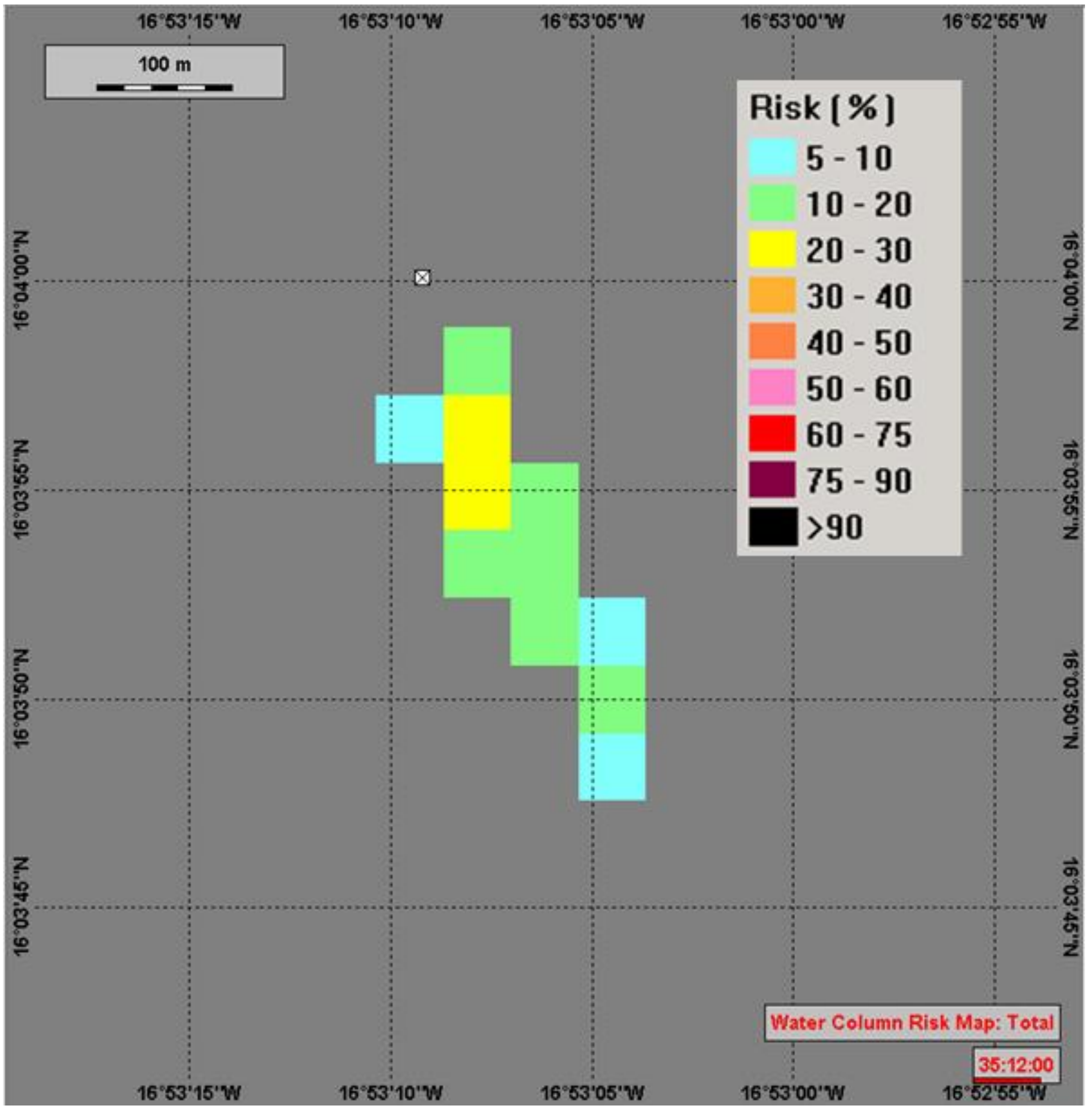


Figure C.17 Scenario 4 - Time series of EIF_{WC} in the water column, showing the contribution from each component in the continuous release of PW over the 45 day simulation period for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.

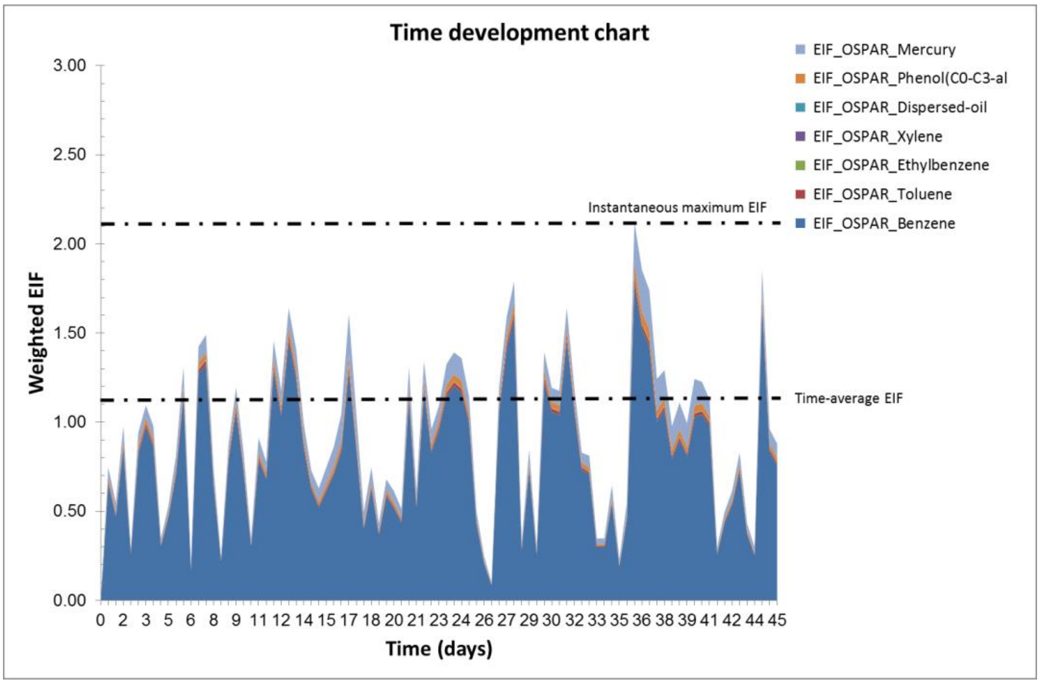


Figure C.18 Scenario 4 - Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column for the continuous release of PW over the 45 day simulation period for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.

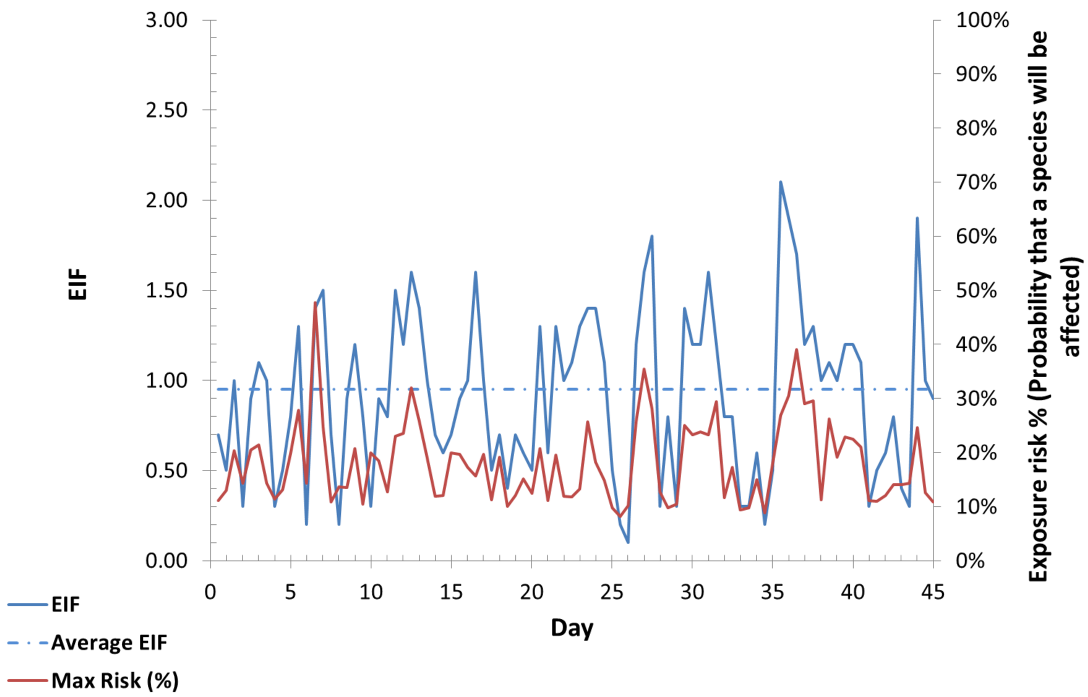


Figure C.19 **Scenario 4 - Map showing the spatial extent of the maximum environmental exposure risk at any location in the water column (≥ 5% [EIF_{WC} >0]) over a 45 day simulation period (all time steps integrated) for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**

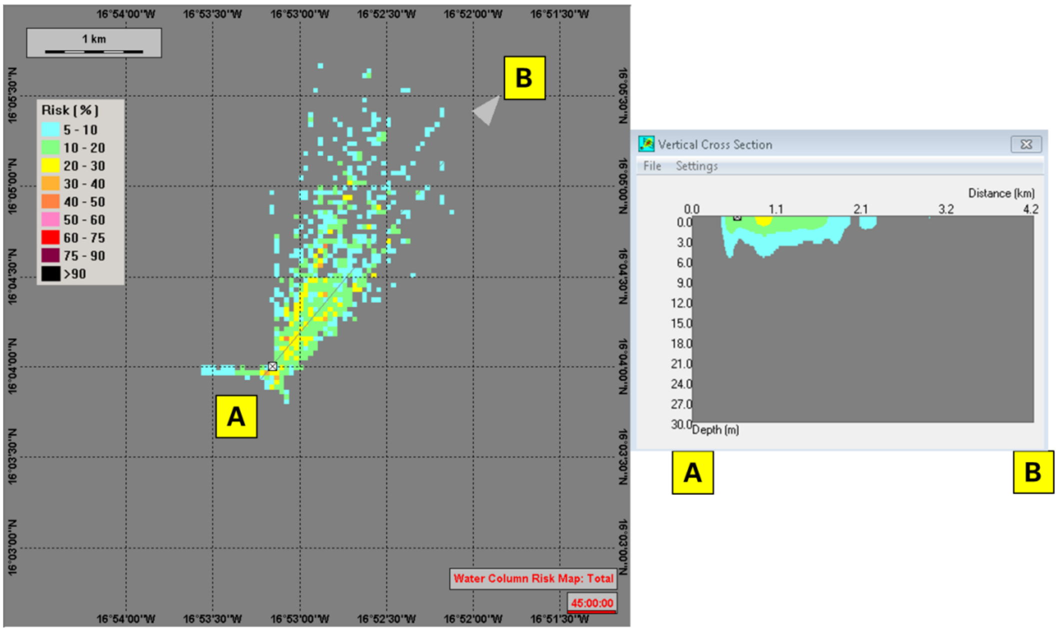
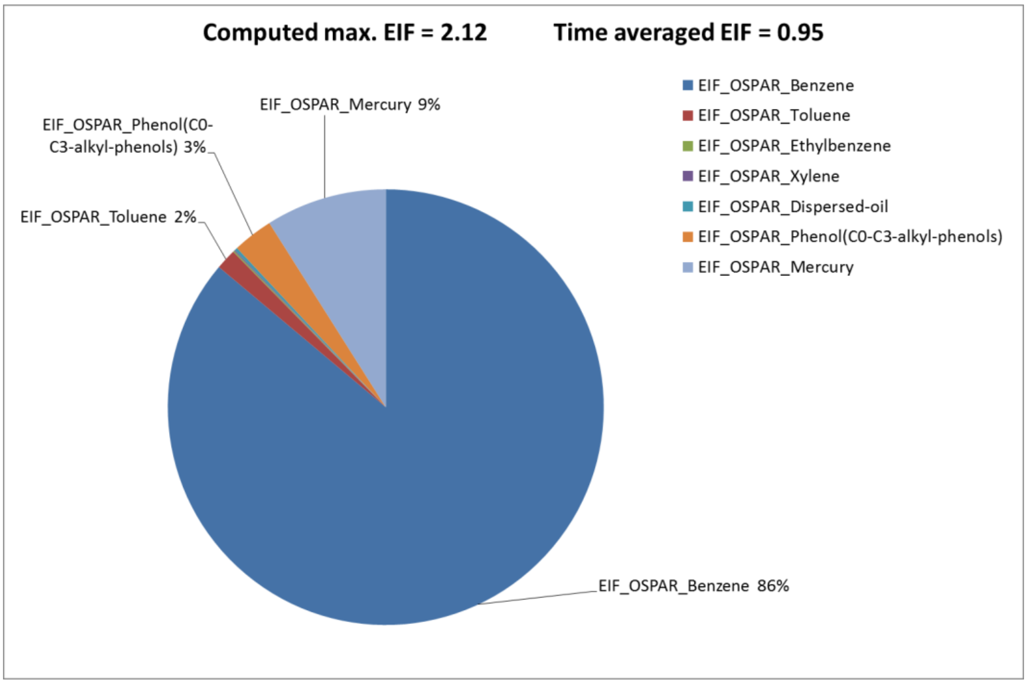


Figure C20 **Scenario 4 - Pie-chart and table showing the contributions to EIF_{WC} of each contaminant in the discharge at the time of maximum EIF_{WC} following the continuous release of PW over the 45 day simulation period for naturally occurring substances only ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**



C.5 Scenario 5

Figure C.21 Scenario 5 - Snapshot map at the time of maximum environmental exposure risk in the water column ≥ 5% (EIF_{WC} = 34.36, 3.436 x 10^{-3} km^3) over the 45 day simulation period for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions

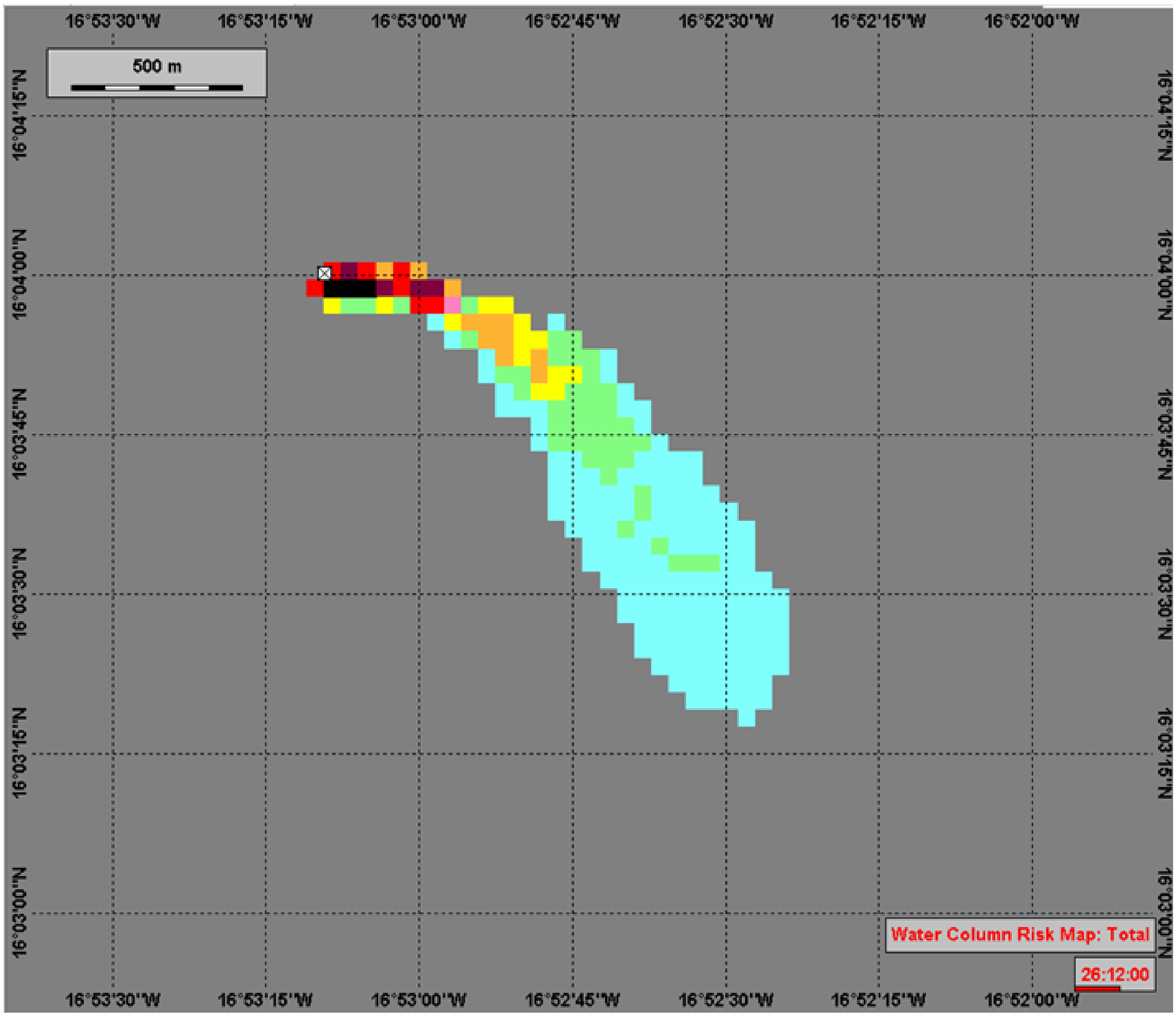


Figure C.22 Scenario 5 - Time series of EIF_{WC} in the water column, showing the contribution from each component in the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.

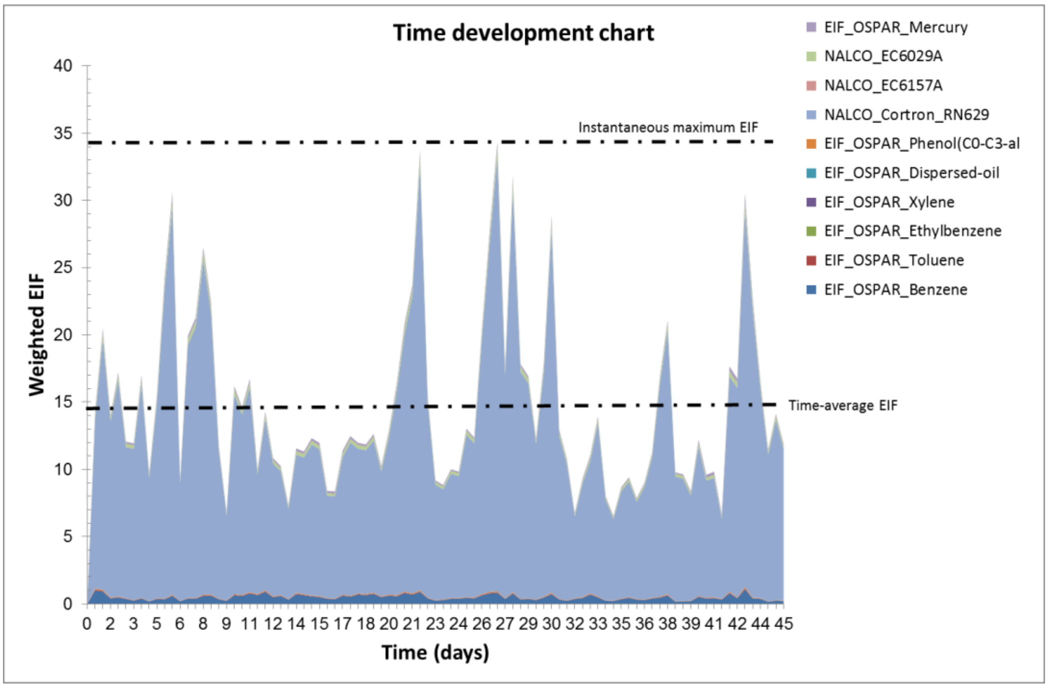


Figure C.23 Scenario 5 - Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column for the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.

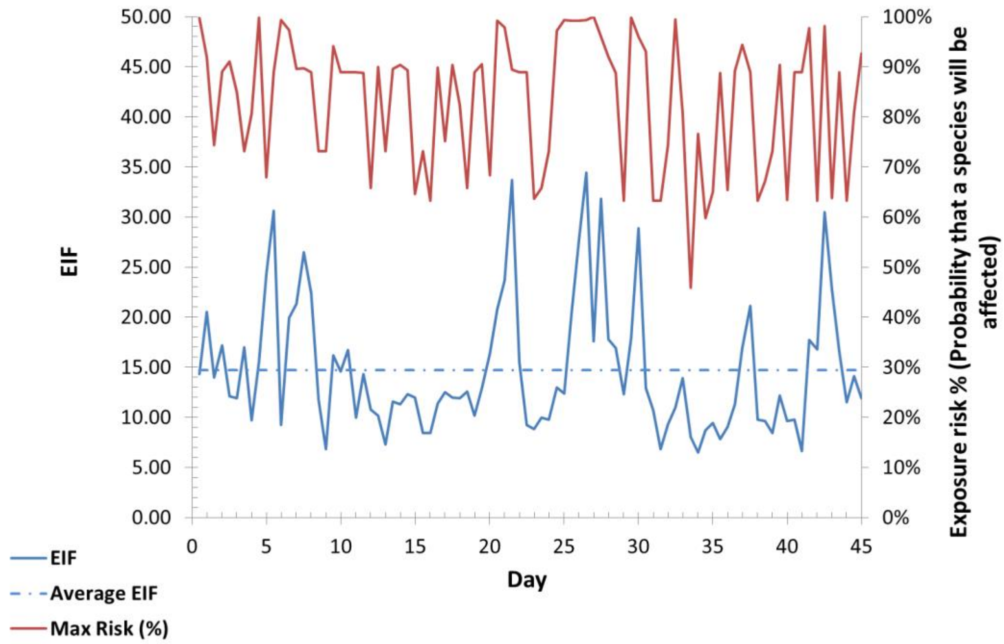


Figure C.24 Scenario 5 - Map showing the spatial extent of the maximum environmental exposure risk at any location in the water column (≥ 5% [EIF_{WC} >0]) over a 45 day simulation period (all time steps integrated) for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.

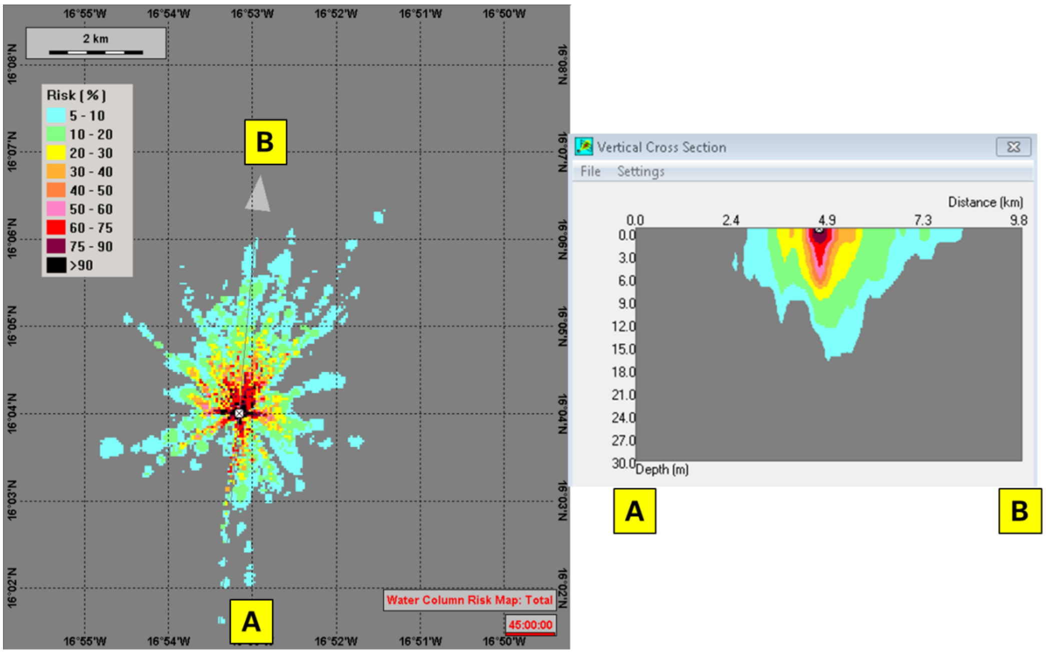
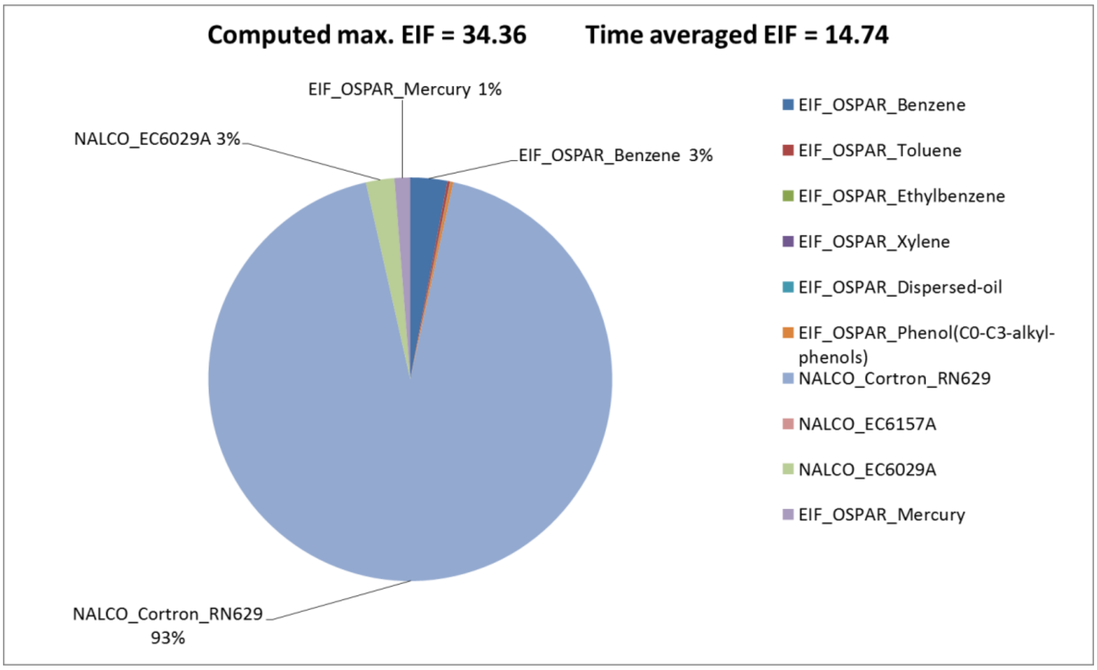


Figure C25 Scenario 5 - Pie-chart and table showing the contributions to EIF_{WC} of each contaminant in the discharge at the time of maximum EIF_{WC} following the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.



C.6 Scenario 6

Figure C.26 Scenario 6 - Snapshot map at the time of maximum environmental exposure risk in the water column ≥ 5% (EIF_{WC} = 18.93, 1.893 x 10^{-3} km^3) over the 45 day simulation period for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.

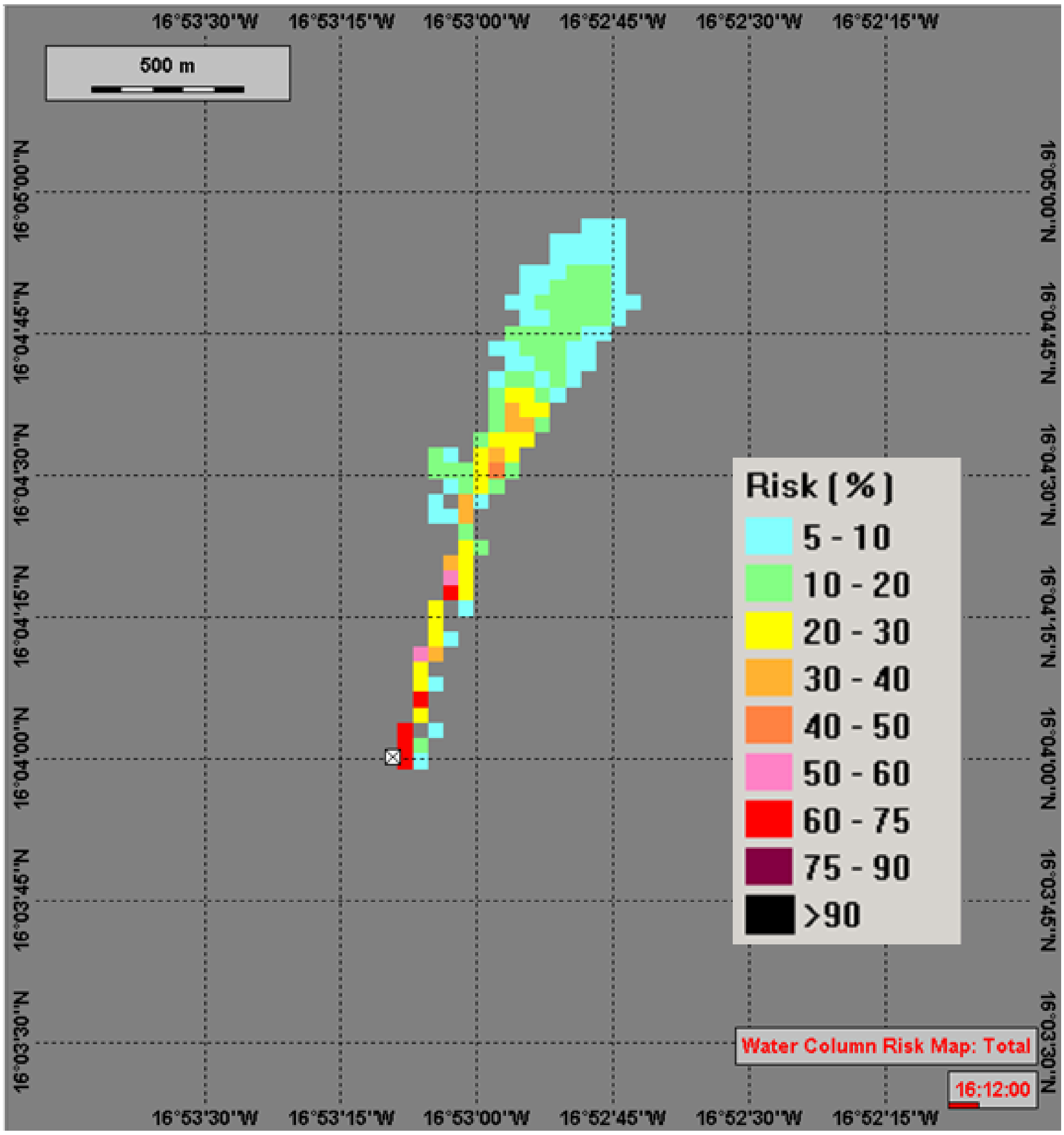


Figure C.27 **Scenario 6 - Time series of EIF_{WC} in the water column, showing the contribution from each component in the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**

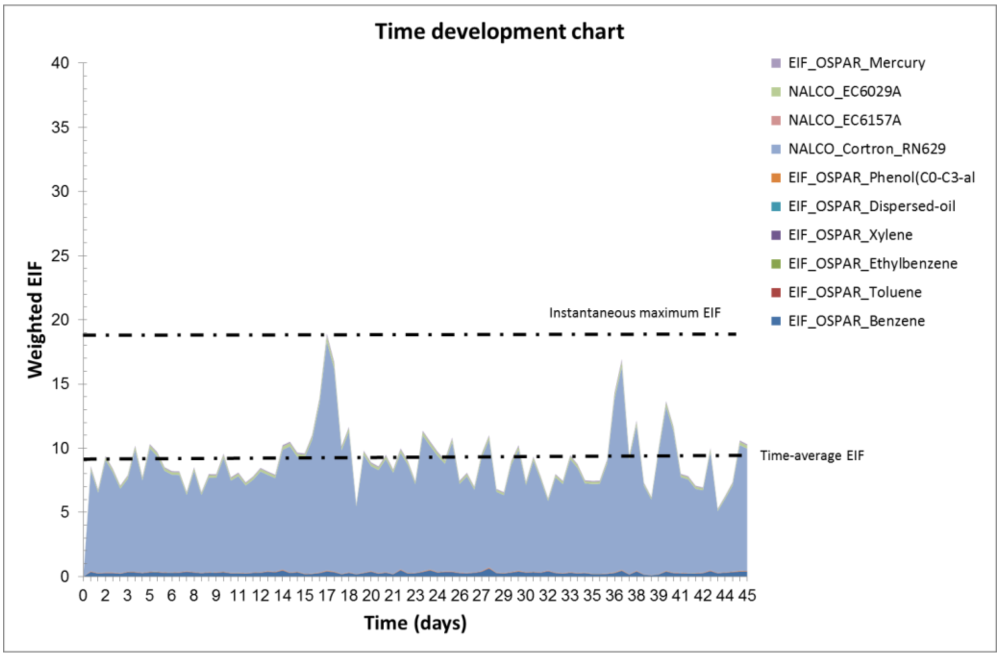


Figure C.28 **Scenario 6 - Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column for the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**

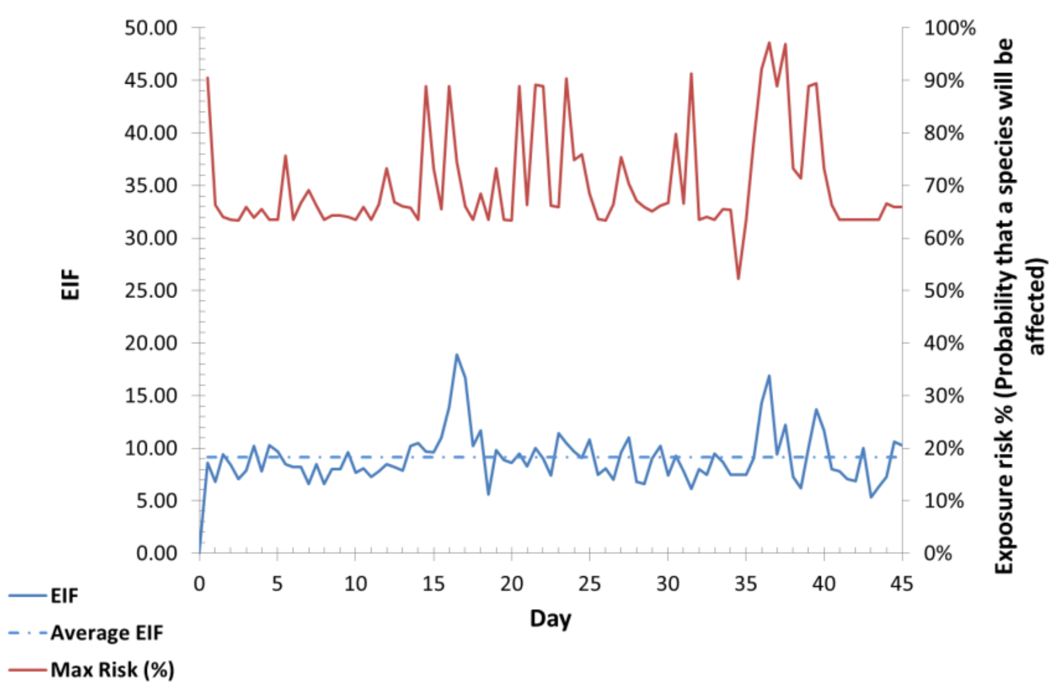


Figure C.29 **Scenario 6 - Map showing the spatial extent of the maximum environmental exposure risk at any location in the water column (≥ 5% [EIF_{WC} >0]) over a 45 day simulation period (all time steps integrated) for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**

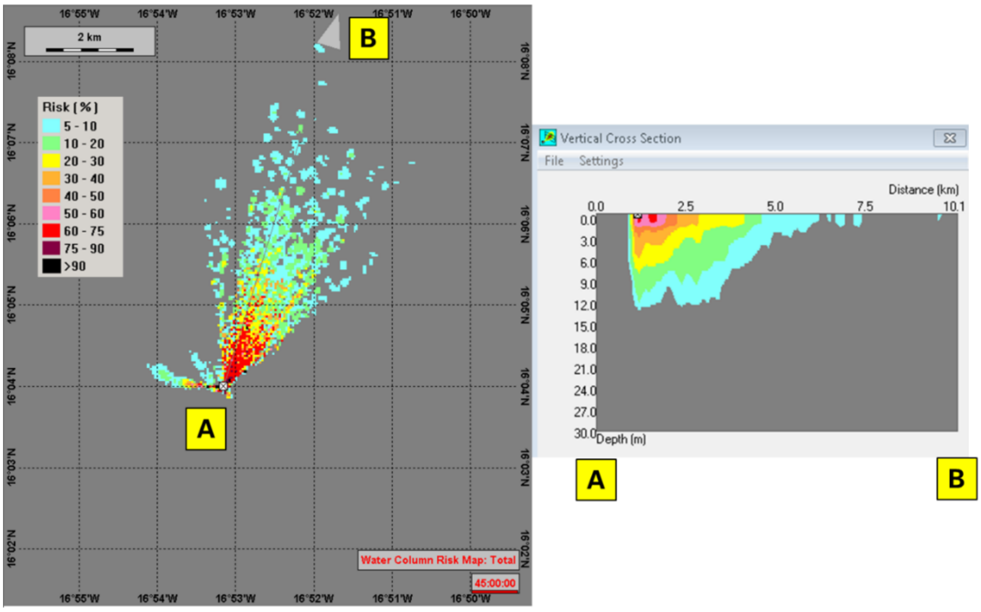
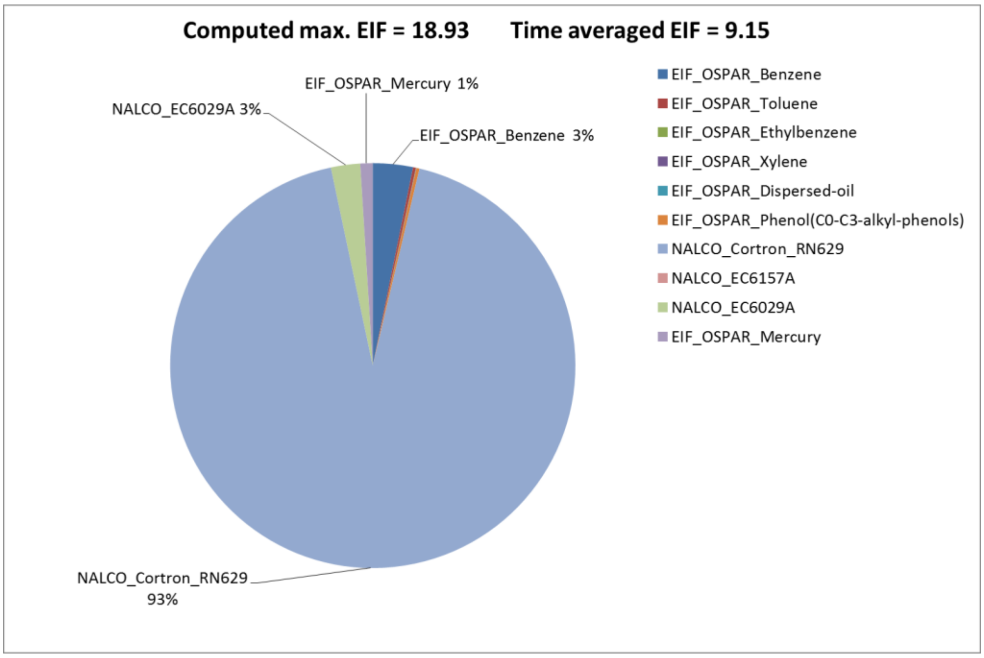


Figure C30 **Scenario 6 - Pie-chart and table showing the contributions to EIF_{WC} of each contaminant in the discharge at the time of maximum EIF_{WC} following the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals (Base Case BTEX concentrations, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**



C.7 Scenario 7

Figure C.31 Scenario 7 - Snapshot map at the time of maximum environmental exposure risk in the water column ≥ 5% (EIF_{WC} = 39.55, 3.955 x 10^{-3} km^3) over the 45 day simulation period for naturally occurring substances and production chemicals (“High” BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions

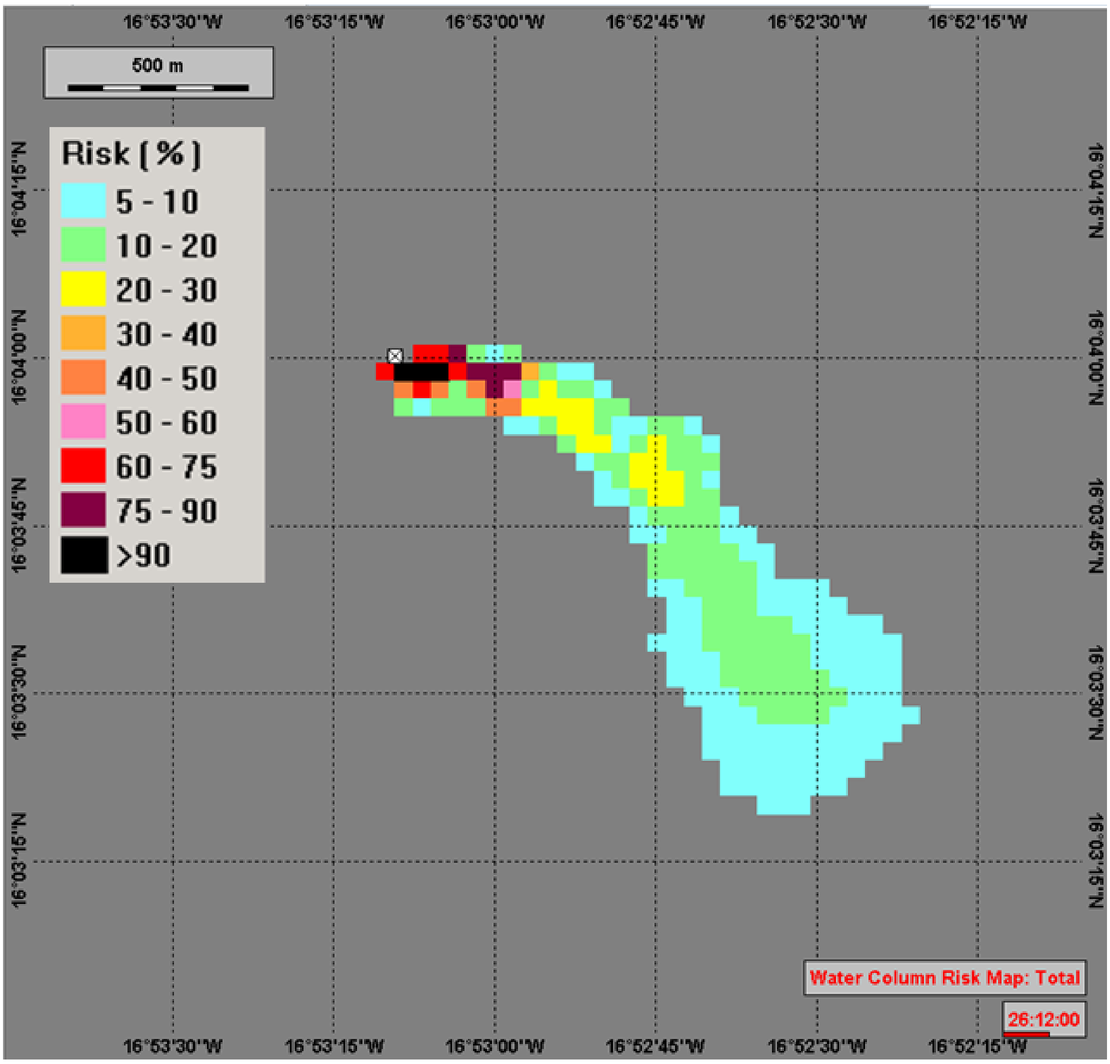


Figure C.32 Scenario 7 - Time series of EIF_{WC} in the water column, showing the contribution from each component in the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.

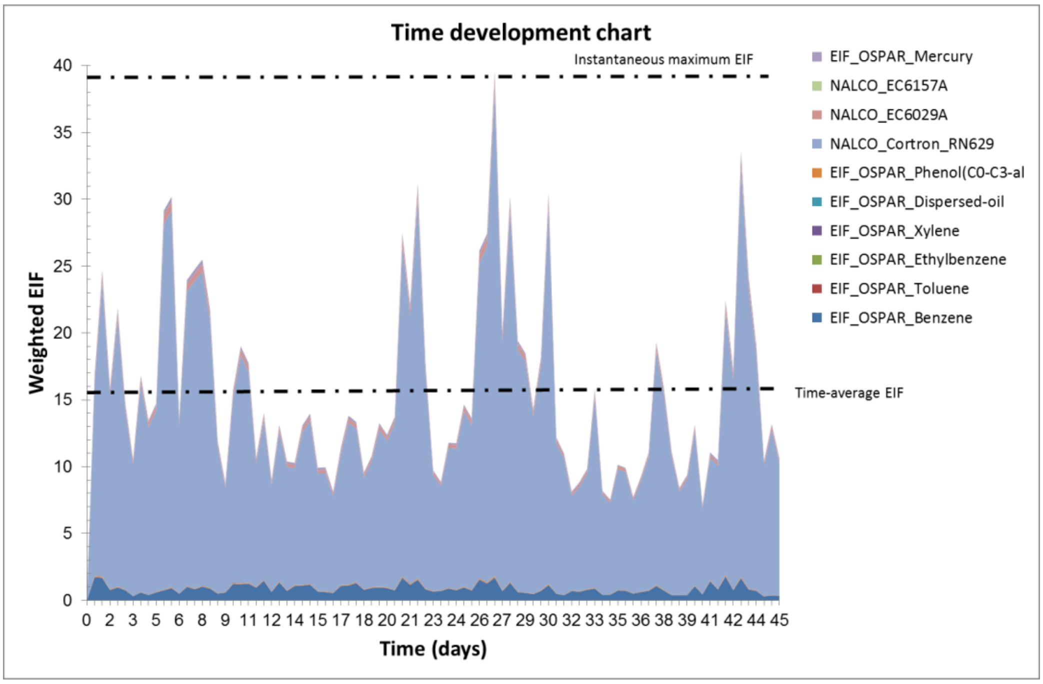


Figure C.33 Scenario 7 - Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column for the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.

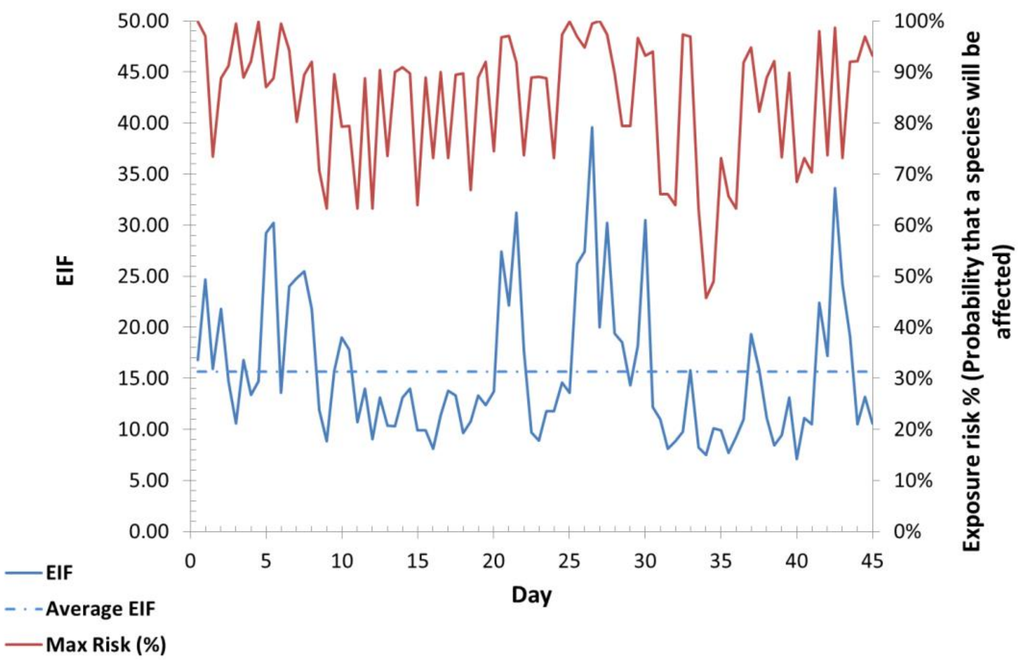


Figure C.34 **Scenario 7 - Map showing the spatial extent of the maximum environmental exposure risk at any location in the water column (≥ 5% [EIF_{WC} >0]) over a 45 day simulation period (all time steps integrated) for naturally occurring substances and production chemicals ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.**

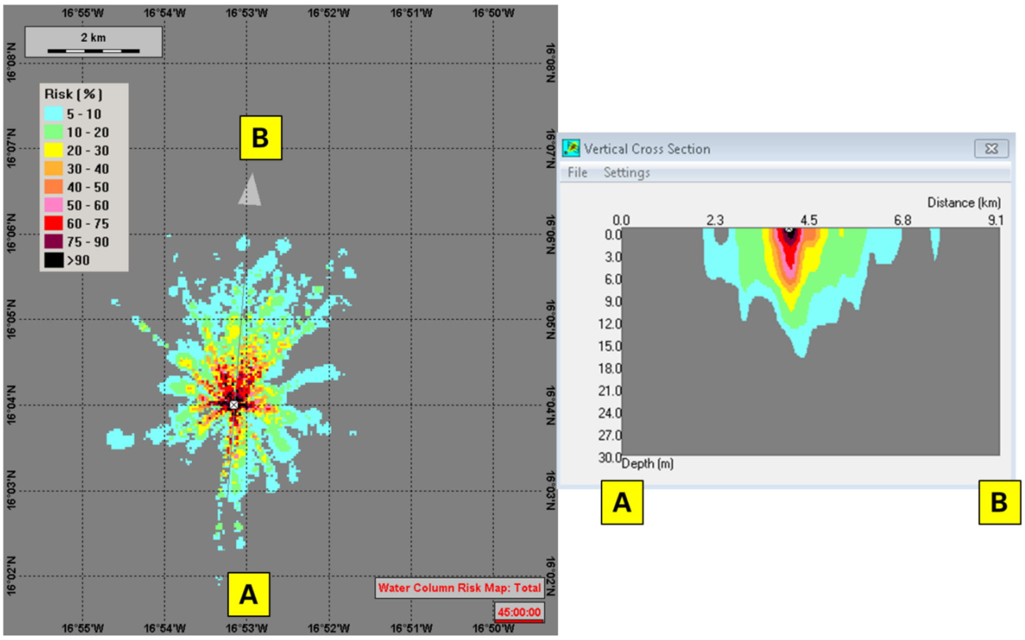
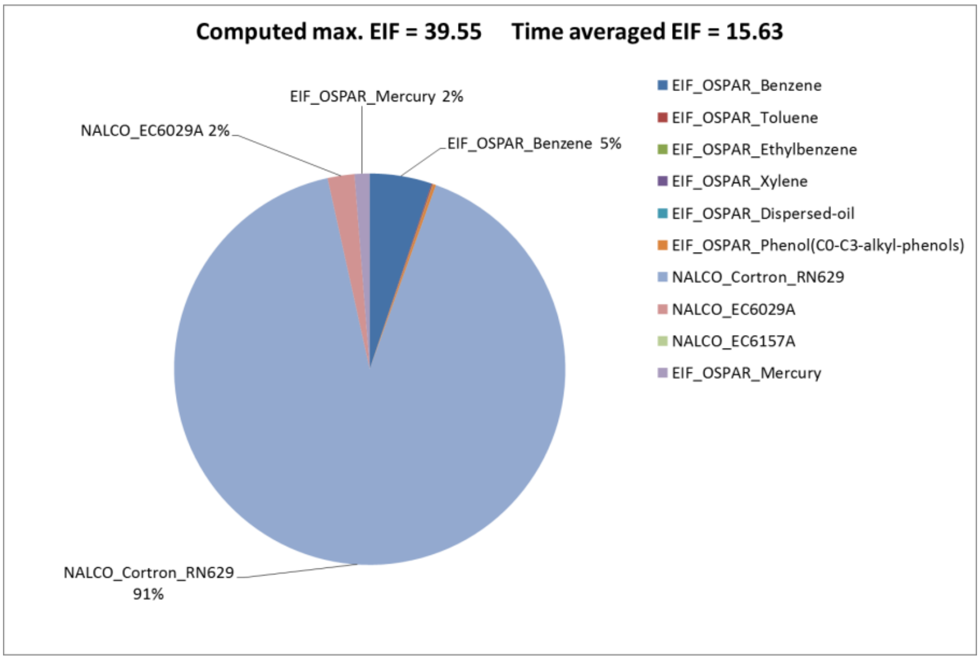


Figure C35 **Scenario 7 - Pie-chart and table showing the contributions to EIF_{WC} of each contaminant in the discharge at the time of maximum EIF_{WC} following the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, lowest ambient current velocity conditions.**



C.8 Scenario 8

Figure C.36 Scenario 8 - Snapshot map at the time of maximum environmental exposure risk in the water column ≥ 5% (EIF_{WC} = 20.10, 2.010 x 10^{-4} km3) over the 45 day simulation period for naturally occurring substances and production chemicals ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions

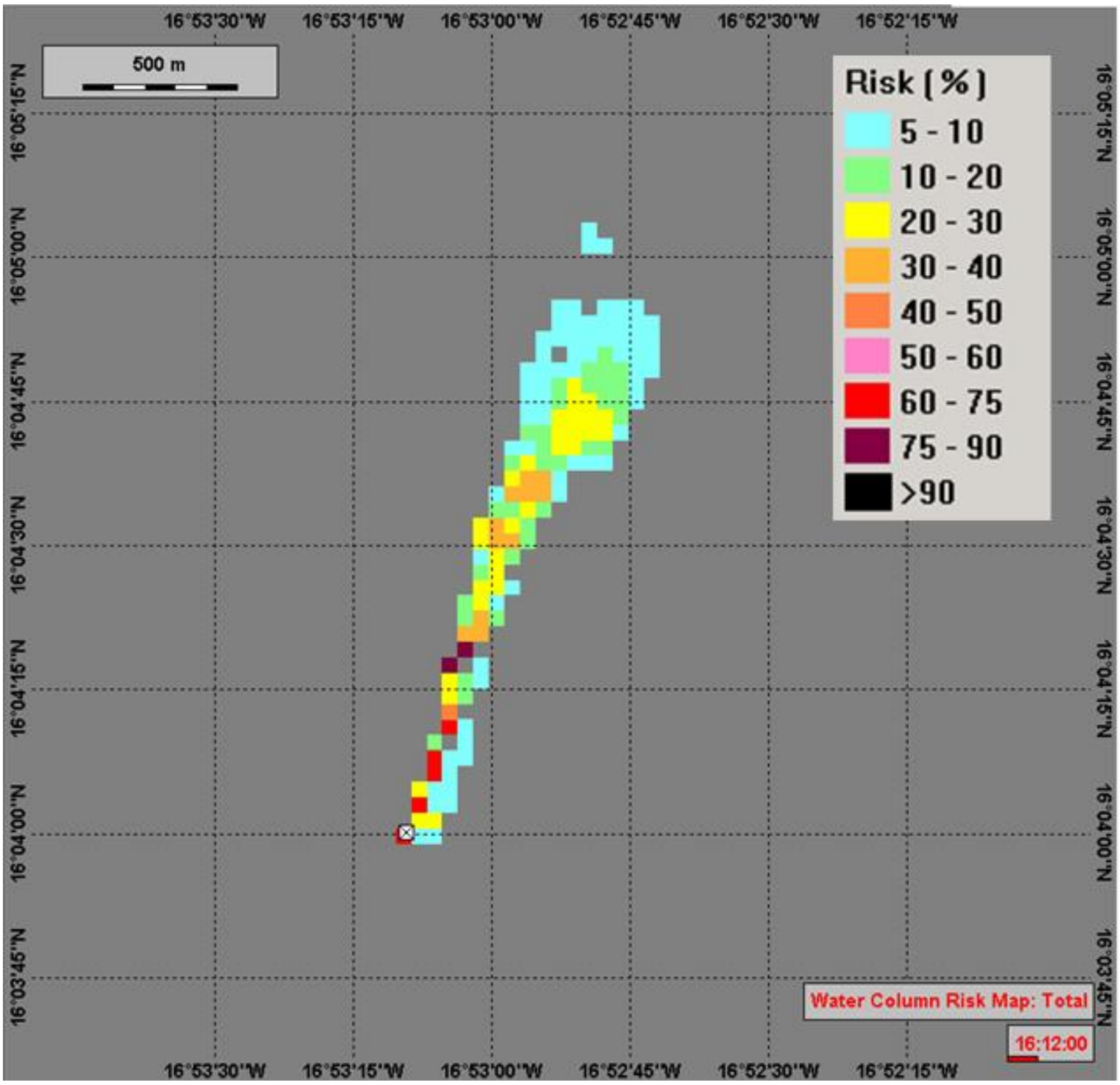


Figure C.37 Scenario 8 - Time series of EIF_{WC} in the water column, showing the contribution from each component in the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.

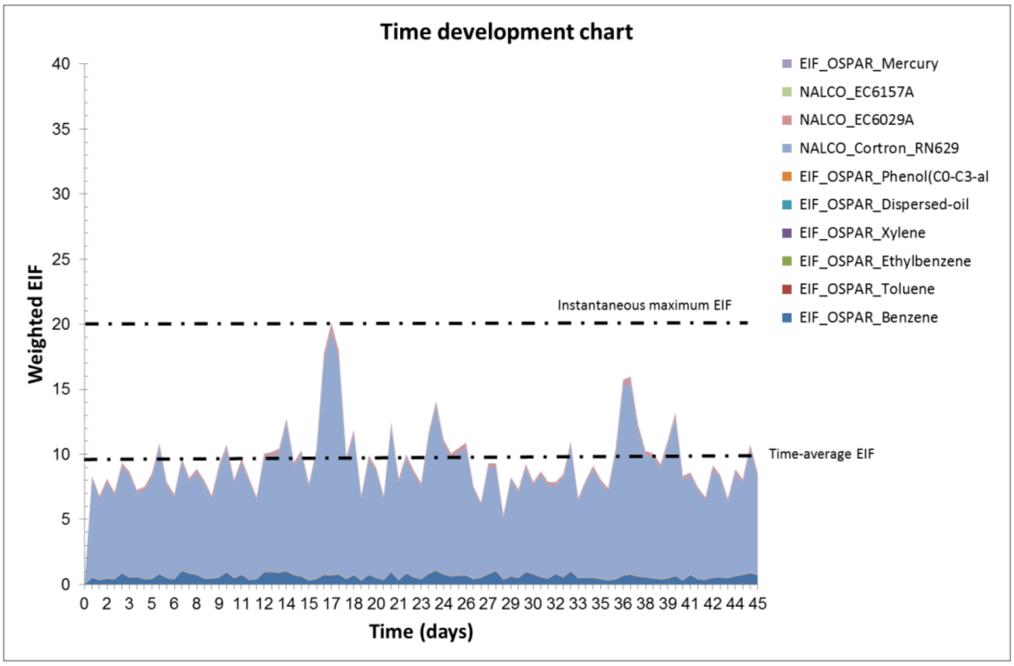


Figure C.38 Scenario 8 - Time series of maximum risk and EIF_{WC} (risk ≥ 5%) in the water column for the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.

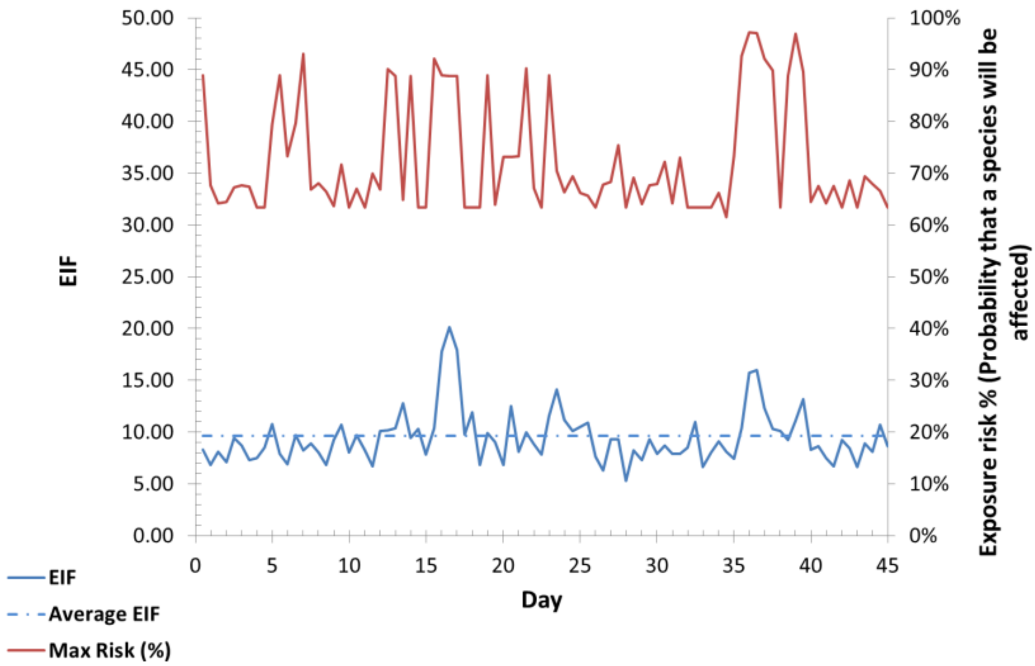


Figure C.39 **Scenario 8 - Map showing the spatial extent of the maximum environmental exposure risk at any location in the water column (≥ 5% [EIF_{WC} >0]) over a 45 day simulation period (all time steps integrated) for naturally occurring substances and production chemicals ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**

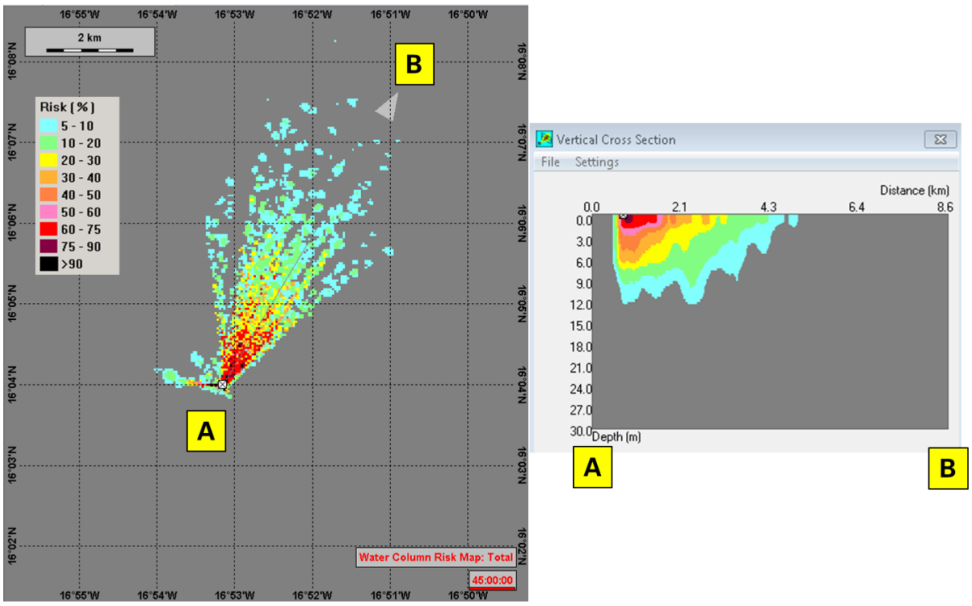
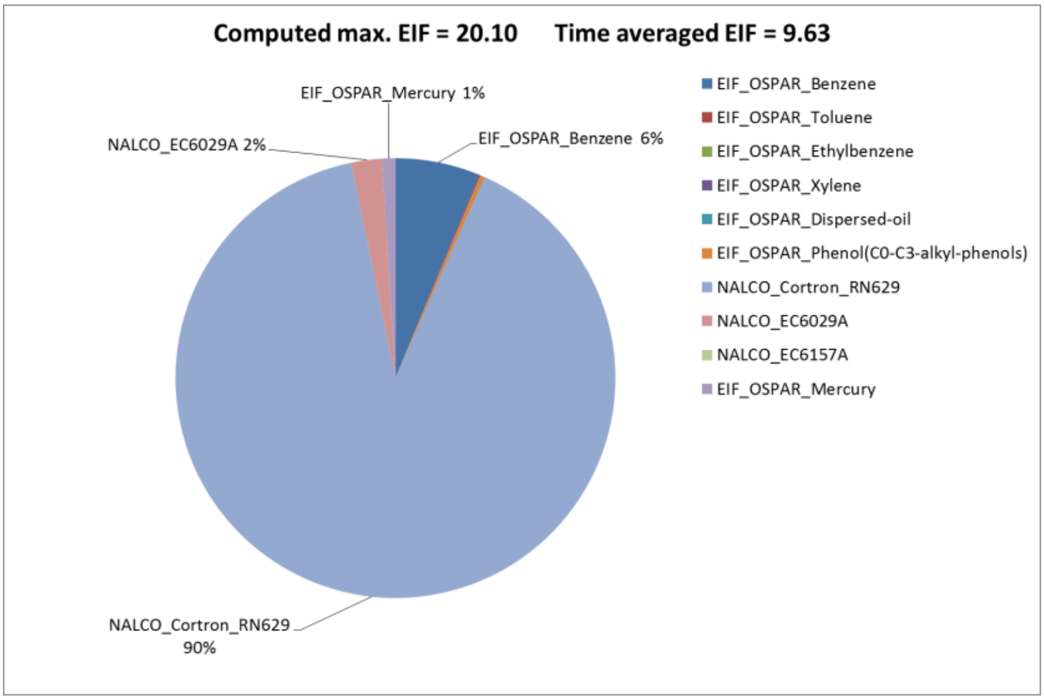
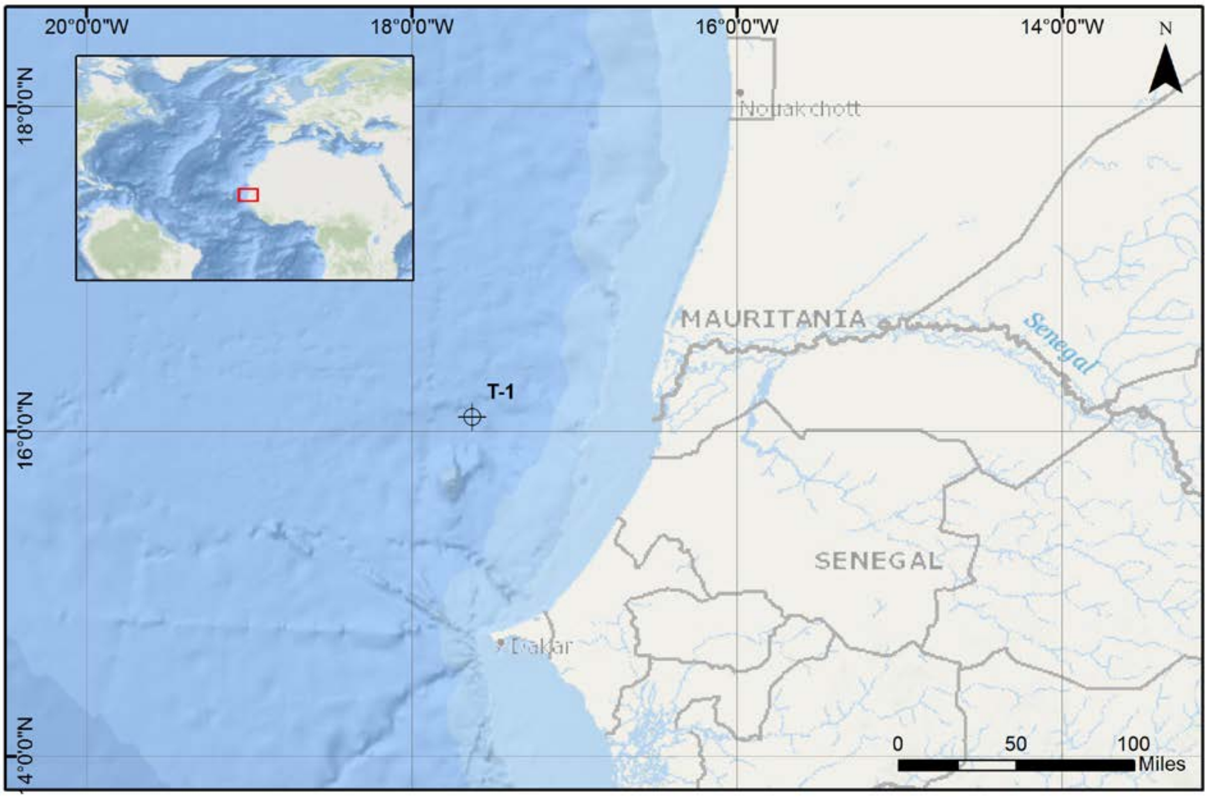


Figure C40 **Scenario 8 - Pie-chart and table showing the contributions to EIF_{WC} of each contaminant in the discharge at the time of maximum EIF_{WC} following the continuous release of PW over the 45 day simulation period for naturally occurring substances and production chemicals ("High" BTEX concentration Case, PW discharge rate of 625 bpd), under the worst case, highest ambient current velocity conditions.**



APPENDIX L : MUDS AND CUTTINGS DISPERSION MODELING REPORT

RPS asa	Draft Report
Applied Science Associates *A member of the RPS Group plc* 55 Village Square Drive South Kingstown, RI 02879 USA **Tel:** +1 (401) 789-6224 **Fax:** +1 (401) 789-1932 **www:** www.rpsgroup.com **www:** www.asascience.com	**Dispersion Modeling of Drilling Discharges: A/G Field, Offshore Mauritania/Senegal** **AUTHOR(S):** Dan Torre, Nathan Vinhateiro, Alicia Morandi, Stephanie Berkman, Sitara Baboolal, Tayebeh Bakhsh, Eric Comerma **Project Manager:** Nathan Vinhateiro **PROJECT NUMBER:** 17-000701 **VERSION:** V3 **DATE:** 18 Dec 2017 **CLIENT:** Brian Balcom **CSA Ocean Sciences Inc.**, Salinas, CA



Document Control Form

Title:

"Dispersion Modeling of Drilling Discharges: A/G Field, Offshore Mauritania/Senegal."

Location & Operator:

A/G Field, BP.

ASA Project Number:

17-000701 CSA (BP) Mauritania/Senegal

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Release	File Name	Date Submitted	Notes
V1	17-000701_CSA_Mauritania/Senegal_Results_8Nov2017		Draft report
V2	17-000701_CSA_Mauritania/Senegal_Report_22Nov2017	Nov. 22, 2017	Draft report with Task 2
V3	17-000701_CSA_Mauritania/Senegal_Report_18Dec2017	Dec. 18, 2017	Report updated to address comments from BP

Disclaimer:

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1. Project Background and Geographic Location

CSA Ocean Sciences Inc. (CSA) contracted Applied Science Associates, Inc. (dba RPS ASA) to evaluate seabed deposition from operational discharges at a deep-water drilling site, offshore Mauritania and Senegal. BP is planning to drill multiple wells (up to 12) at two different drill centers (DC1 and DC3) within the Ahmeyim/Guembeul (A/G) field – part of the Greater Tortue Complex which straddles the maritime boundary between Mauritania and Senegal. The A/G field is located in relatively deep water (~2,500 to 3,000 m), approximately 145 km from the coastline. Dispersion modeling was conducted to assess seabed and water column impacts of discharges from a representative site (T-1), which is one of the southern-most of the 6 development wells planned at DC1 (Figure 1). Water depth at the T-1 drill site is 2,750 m (Table 1).

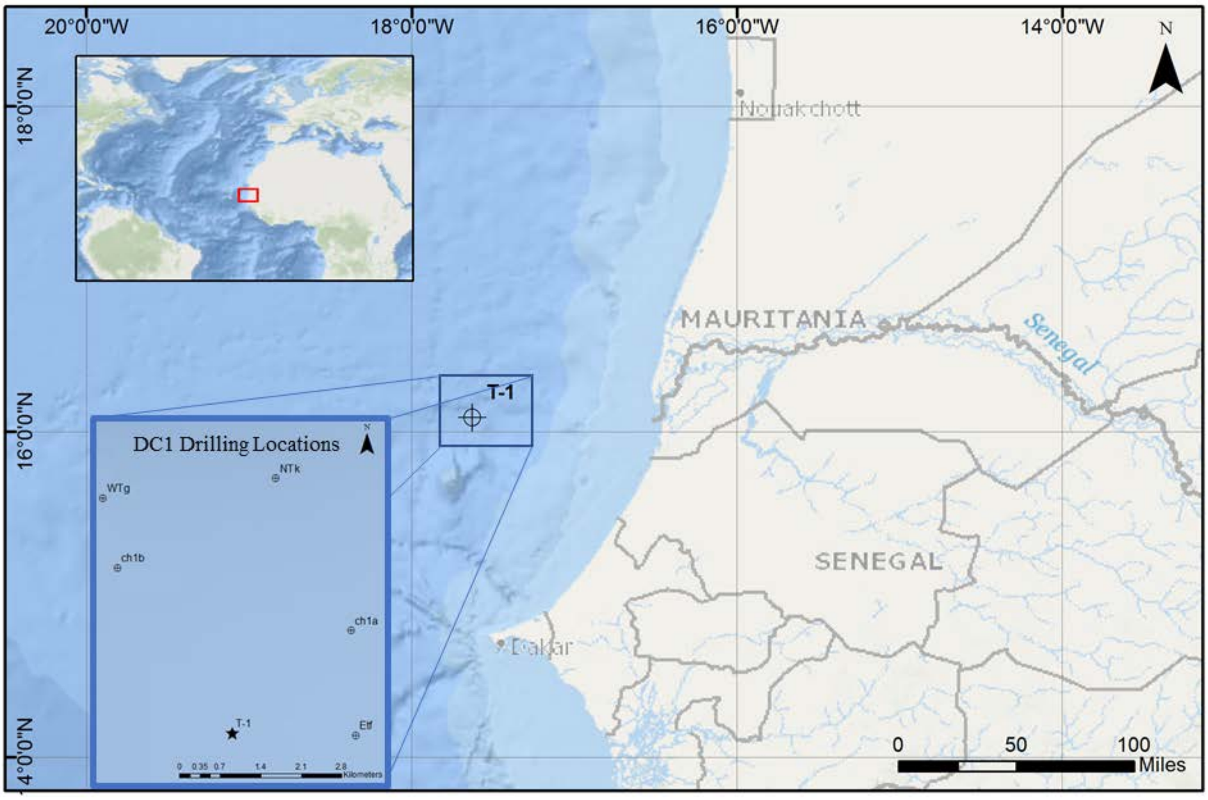


Figure 1. Proposed study area, offshore Mauritania and Senegal. The inset shows the T-1 drilling site relative to all drilling locations at DC-1.

Table 1. Location of the T-1 drilling site, offshore Mauritania and Senegal.

Site Name	Field Name	Latitude (N)	Longitude (W)	Water Depth (m)
T-1	Ahmeyim/Guembeul	16.08700	17.62575	2,750

Simulations of drilling discharges were completed using ASA's MUDMAP modeling system (Spaulding et al., 1994). MUDMAP predicts the transport of solid releases in the marine environment and the resulting seabed deposition. The model requires inputs describing (i) the physical and chemical characteristics of the discharged effluent, (ii) the discharge schedule (timing and release location), and (iii) information describing the receiving waters (bathymetry, density structure, ocean currents). Model output includes estimates of environmental loadings to the seabed (deposition) and water column (increased turbidity) from discharges associated with offshore drilling. A technical description of the MUDMAP model is included in Appendix A.

Information provided by CSA/BP indicates that the DC1 sites will target Cenomanian hydrocarbon deposits, and discharges are expected to be similar to the recent drilling campaign offshore Senegal (RPS ASA report 15-095). Approximately 641 m^3 of drill cuttings are expected to be discharged from 5 intervals ranging from 36" to 8.5" (inches) in diameter. In addition, BP has requested that modeling consider the potential for 25% (by volume) of adhered mud on cuttings for sections drilled with non-aqueous drilling fluids (NADF; sections 3-5).

Model scenarios were developed to account for potential differences in the offshore environmental regime. The climate in southern Mauritania/northern Senegal is driven mainly by the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) which oscillates between a southern position (dry/cool season; January to June) and a northern position (rainy/warm season; July to December). The West African monsoon interconnected with the changing position of the ITCZ. Monsoon winds blow southwesterly during warmer months (June-November) and northeasterly during cooler months (December-May). In addition, the drilling site lies near the confluence of several major ocean current systems including the Canary Current, and the North Equatorial Current, which fluctuate in response to the trade winds and in general alignment with the region's marked wet and dry seasons. For this reason, two (2) MUDMAP simulations were performed in order to evaluate the influence of variability in ocean currents in the region on the pattern of deposition. Simulation periods were selected based on a review of recent literature and an analysis of ocean circulation models within the drilling project region. At the site T-1, operational releases were simulated during the dry season (boreal winter/spring) when surface currents are more weak and variable, and during the wet season (boreal summer/fall) when surface currents intensify and become focused toward the northwest as a result of weakening trade winds. Each simulation covered a period of approximately 35 days (13 days of active drilling/discharge).

2. Model Inputs

2.1. MetOcean Data

Hydrodynamic data from the HYCOM (HYbrid Coordinate Ocean Model) was used as the primary forcing for the cuttings dispersion simulations. The specific version of the model used was the HYCOM + NCODA (Navy Coupled Ocean Data Assimilation) Global 1/12° Reanalysis, which includes native hycom .[ab] data converted to NetCDF on native Mercator-curvilinear HYCOM horizontal grid. Details of the data assimilation procedure are described in Cummings and Smedstad (2013) and Cummings (2005). Fox et al. (2002) describe the technique for projecting surface information (collected for assimilation) downward. The horizontal dimensions of the global grid are 4500 x 3298 grid points resulting in ~7 km spacing on average.

The HYCOM system is run daily at the US Navy DoD Supercomputing Resource Center to provide a 5-day operational forecast (+ 5 day of hindcast as best estimate) composed of 3-D daily mean temperature, salinity, sea surface height, zonal velocity and meridional velocity fields. Ocean dynamics including geostrophic and wind driven currents are reproduced by the model. Data are provided as daily snapshots at 00Z. The most recent reanalysis experiment (GLBa0.08/expt_19.1) includes data between August 1, 1995 and December 31, 2012.

RPS ASA utilizes a series of processing steps to prepare HYCOM output for ingestion by the MUDMAP cuttings dispersion model. The current field at the location of each well is developed using a distance weighted interpolation routine from the nearest 4 (surrounding) HYCOM nodes. At the model cell closest to the T-1 site the water column is represented in 37 vertical layers to a depth of 2,500 m. As shown in the figures below, the HYCOM model reproduces fluctuations in surface flows that are coincident with observations of seasonal variations offshore Mauritania and Senegal (i.e., the intensification and northward focusing of surface currents along the continental slope during the rainy season months). Vertically and time varied currents for a representative period (yr. 2010) were subset from the dataset to use as forcing for the MUDMAP model. The following figures are presented to summarize the hydrodynamic dataset:

- Stick plot showing HYCOM current speeds and directions with depth.
- Vertical current profiles (by month) and current roses comparing the distribution of flow at various depths from the HYCOM cell closest to the drilling site.
- Current roses illustrating differences in the distribution of speed and direction of HYCOM currents by month (season).
- Monthly current speeds derived from the HYCOM model at the sea surface and averaged throughout the full water column.
- Surface current patterns for the offshore region for two modelled release periods.

All figures display current data in the oceanographic convention (stick vectors/roses indicate the direction *toward* which currents are flowing)

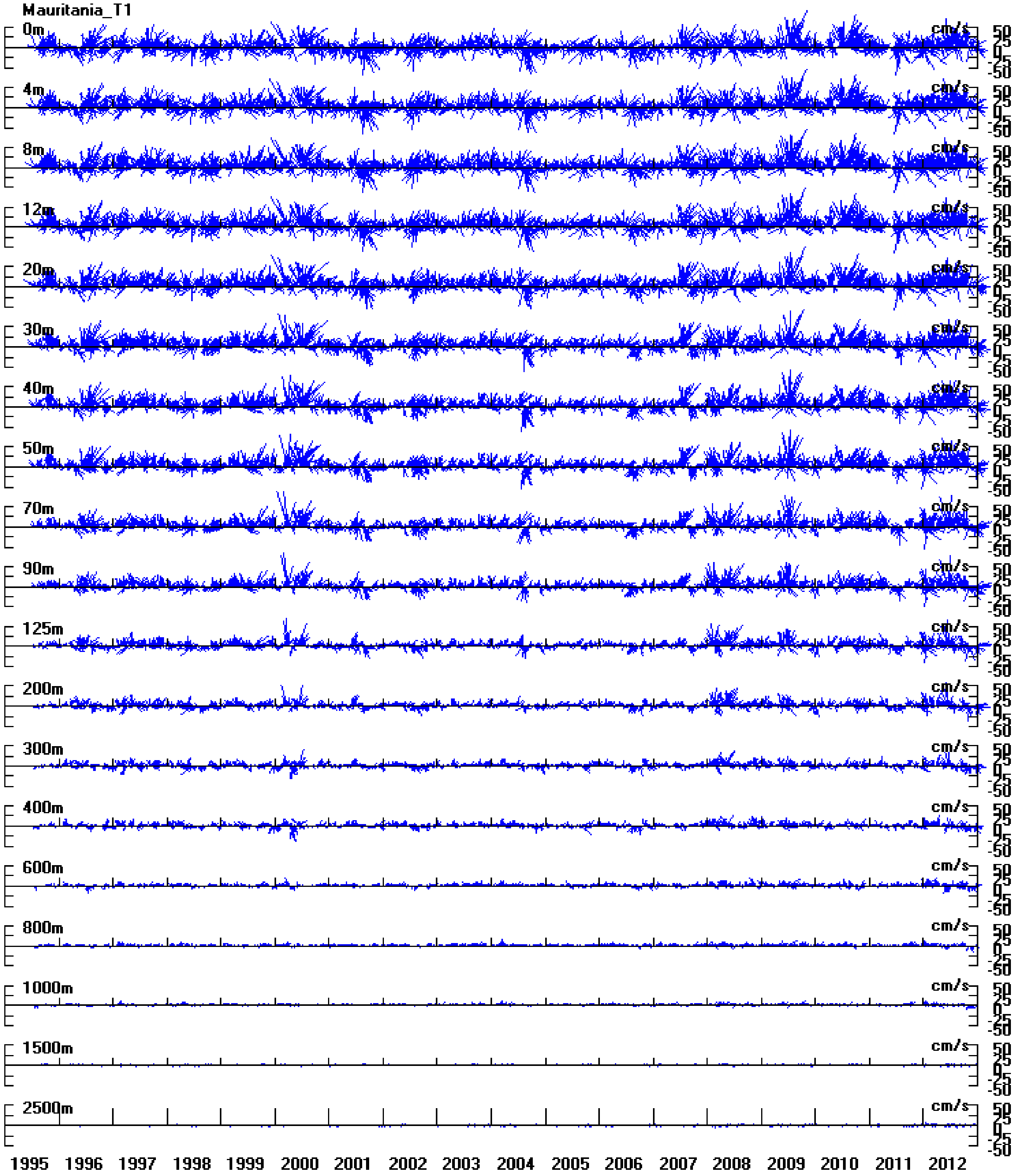


Figure 2. Time series of HYCOM model currents with depth at the T-1 drilling site. Reanalysis period: Aug. 1, 1995 – Dec. 31, 2012.

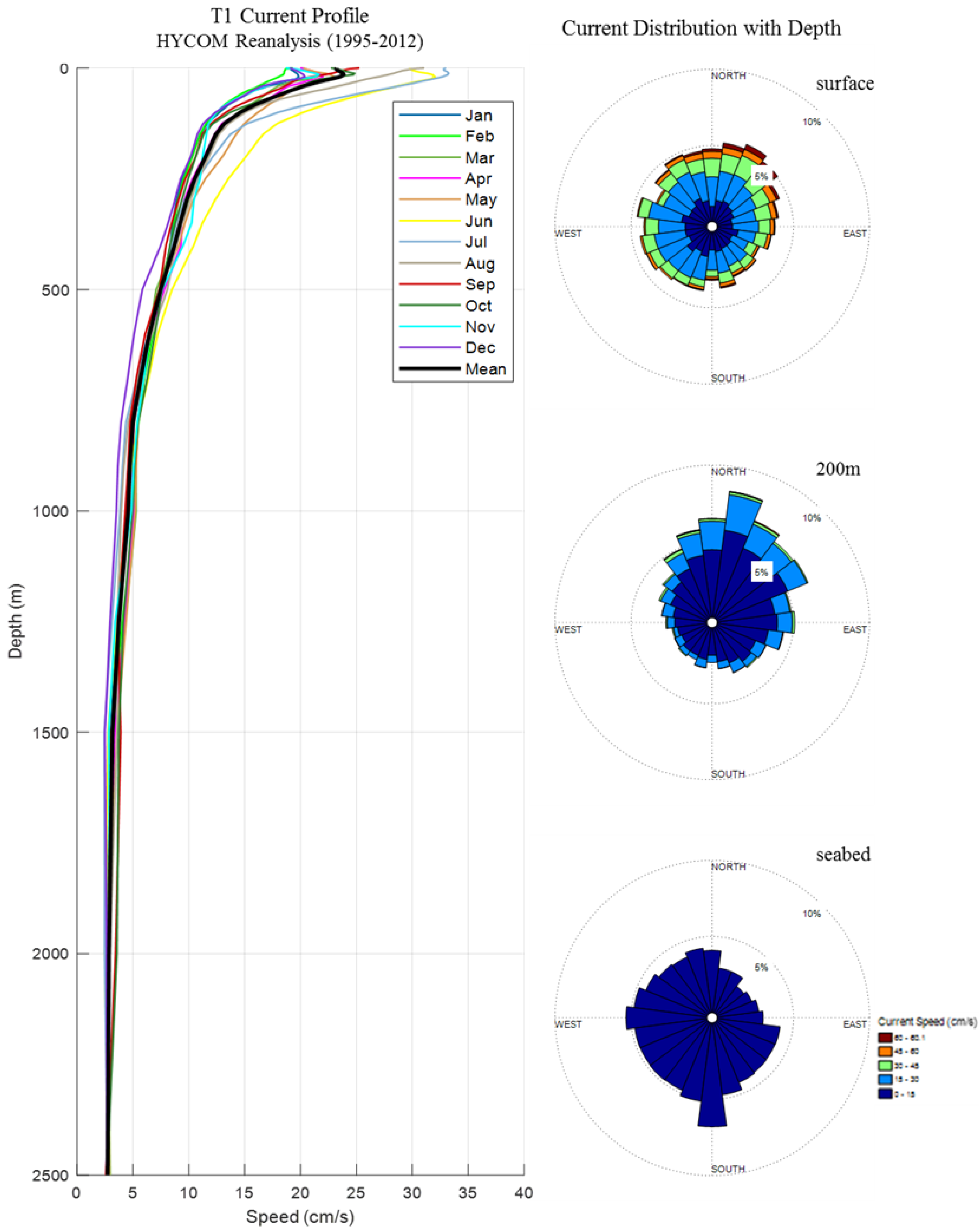


Figure 3. Vertical profiles (left) and current roses showing the distribution of current speeds (right) at T-1, derived from HYCOM model currents between 1995 and 2012.

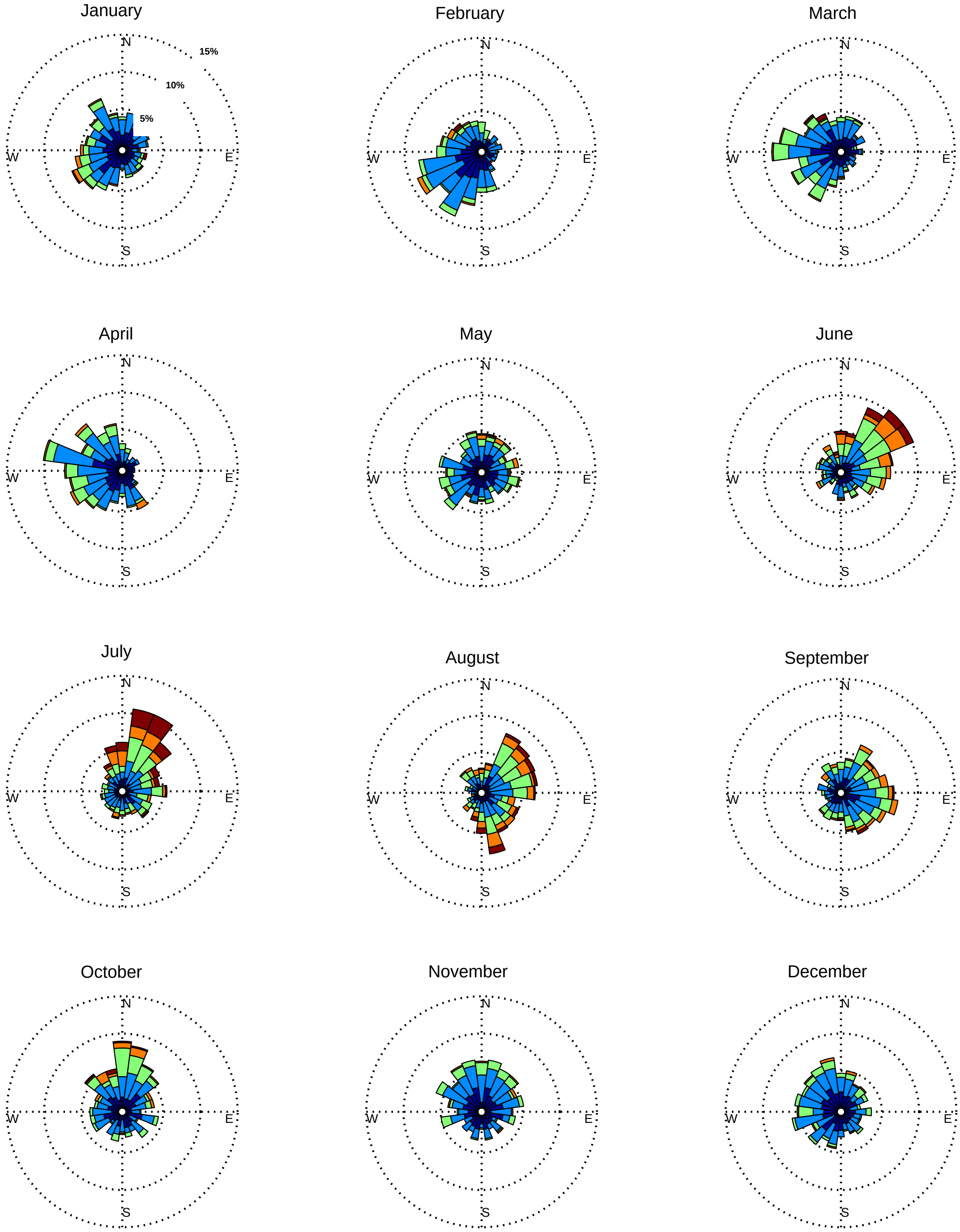


Figure 4. Current roses showing the distribution of HYCOM surface currents (speed and direction) by month at the T-1 drill site (model period: 1995 to 2012).

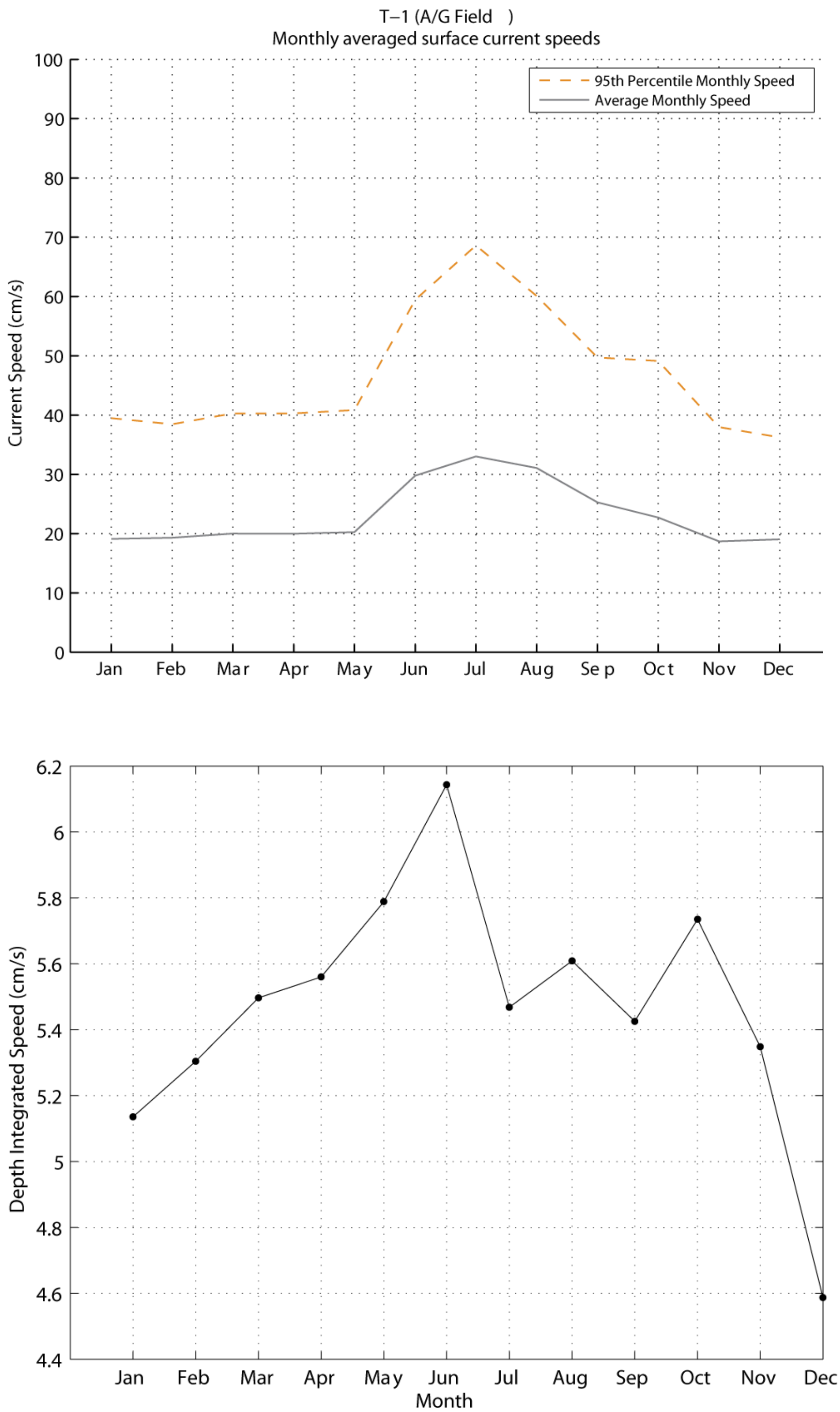


Figure 5. Monthly averaged current speeds at the T-1 drilling location. Top - surface layer currents; bottom - currents averaged through the full water column.

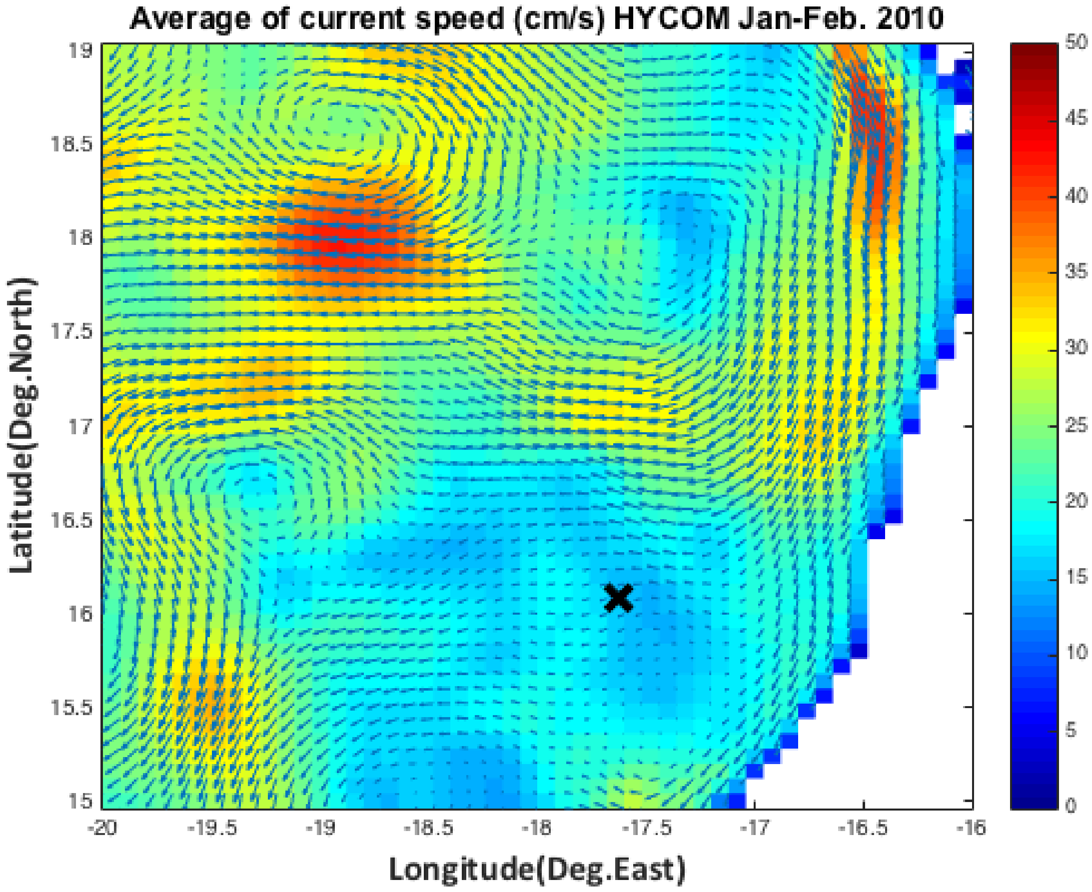


Figure 6. HYCOM surface current speed averaged for the period Jan. - Feb. 2010 (representative dry season). Black cross represents the T-1 drilling location.

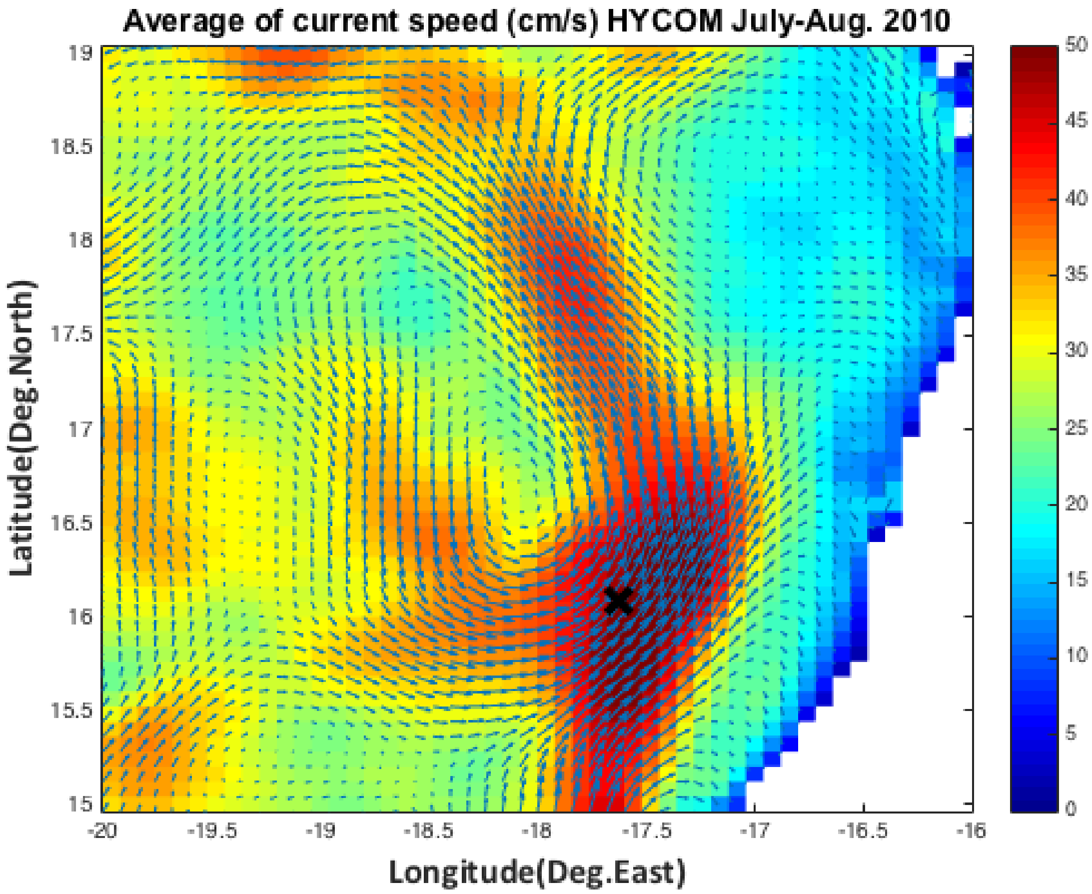


Figure 7. HYCOM surface current speed averaged for the period Jul. - Aug. 2010 (representative wet season). Black cross represents the T-1 drilling location.

2.2. Drilling Schedule

The schedule of discharges provided to RPS ASA indicates that drilling at T-1 will include 5 well sections ranging from 36" to 8.5" (inches) in diameter. As described above, BP has requested that the modeling reflect a "worst case" discharge estimate, which includes an additional 25% by volume of cuttings for sections drilled with NADF to account for potential adherence of residual drilling fluid on the cuttings (Table 2). The drilling rig is expected to be on site at each location for approximately 35 days with 13 days of active drilling. Representative dry/wet season drilling periods are shown below.

Table 2. Drilling discharges program used for model simulations at the T-1 drilling site.

Section	Diameter	Start Date (Season)		Duration (Days)	Cuttings Volume (m^3)[1]	Mud Volume (m3)	Mud Type	Release Depth[2]
		Dry	**Wet**					
Move on Location				3.00				
1	36"	4-Jan	4-Jul	0.50	49	80.0	WBM	Seabed
Between drilling				0.50				
2	26"	5-Jan	5-Jul	2.00	373	873.0	WBM	Seabed
Between drilling				10.00				
3	17.5"	17-Jan	17-Jul	3.00	112 (140)	Cuttings Adjusted for 25% V:V adhered mud	NADF	Sea Surface
Between drilling				5.00				
4	12.25"	25-Jan	25-Jul	4.00	91 (114)	Cuttings Adjusted for 25% V:V adhered mud	NADF	Sea Surface
Between drilling				7.00				
5	8.5"	5-Feb	5-Aug	3.00	16 (20)	Cuttings Adjusted for 25% V:V adhered mud	NADF	Sea Surface

Notes: 1. Volumes within parenthesis include the addition of 25% residual NADF on cuttings for sections 3-5.
2. Releases were simulated at 5 m above seabed and 10 m below sea surface.

As indicated in the drilling program, all cuttings and water based mud (WBM) from riserless drilling (top hole sections 1 and 2) is expected to be released directly at the seabed (i.e., 5 m above the wellhead). Riserless drilling will utilize approximately 6000 bbl (954 m^3) of 9-12 ppg WBM (80 m^3 and 873 m^3, respectively). Subsequent sections will be drilled with a NADF and returned to the surface for treatment. The direct release of bulk NADF is not expected to occur during any stage of drilling although for modeling it was presumed that a fraction of the drilling fluid would remain adhered to cuttings drilled with NADF (approximately 25% of the discharged cuttings by volume). The release of these combined surface returns (cutting and adhered NADF) was simulated at a continuous discharge rate during active drilling intervals from a depth of 10 meters below the sea surface.

The T-1 drilling schedule is currently unknown and the time of year may change as a result of rig availability and regulatory approvals. Because of the large seasonal variations in the oceanography offshore southern Mauritania/northern Senegal, model simulations were performed for different seasonal regimes in order to evaluate the influence of potential variability in regional ocean currents. Specifically, operational releases were simulated to compare the impacts of drilling during southern Mauritania/northern Senegal's dry season (Jan-Feb; Scenario 1), and wet season (Jul-Aug; Scenario 2), for the year 2010. Surface currents in the vicinity of the discharge site are weaker and more variable during the dry season as compared to the wet season when surface currents intensify and become focused northward as a result of weakening trade winds.

2.3. Discharged Solids Characteristics

The characteristics of muds and cuttings used for modelling are presented in Table 3 through Table 6. Particle settling characteristics are presented in Figure 8.

Table 3. Composition of drilling discharges used for modeling (mud data provided by CSA/BP).

Discharged Material	Bulk Density (ppg)	Bulk Density (kg/m^3)	Percent Solid by Weight	Average SG of Solid Fraction
WBM cuttings (section 1-2)	22.1	2,650	100	2.65
SBM cuttings (section 3-8)	16.9	2,030	65	2.65
WBM (sec 1)	9	1,078	22	3.9
WBM (sec 2)	9-12	1,258 (avg)	22	3.9

Table 4. Drill cuttings settling velocities used for WBM simulations (Brandsma and Smith, 1999).

Size Class	Percent Volume	Settling Velocity	
		(cm/s)	(m/day)
1	8.00	1.350E-04	0.12
2	6.00	1.686E-03	1.46
3	7.00	2.182E-02	18.86
4	3.00	2.328E-01	201.14
5	2.00	1.447E+00	1250.37
6	18.00	4.011E+00	3465.65
7	16.00	9.796E+00	8463.98
8	15.00	1.352E+01	11679.45
9	25.00	2.598E+01	22442.45

Table 5. Drilling mud (WBM) settling velocities (Brandsma and Smith, 1999; Dames and Moore, 1978).

Size Class	Percent Volume	Settling Velocity	
		(cm/s)	(m/day)
1	7.01	2.74E-03	2.37
2	7.99	6.10E-03	5.27
3	5.00	1.48E-02	12.77
4	10.00	3.00E-02	25.94
5	13.26	4.36E-02	37.66
6	13.26	5.12E-02	44.24
7	19.24	6.40E-02	55.30
8	19.24	8.23E-02	71.10
9	4.00	4.27E-01	368.69
10	1.00	1.12E+00	969.12

Table 6. Drill cuttings settling velocities used for NADF simulations (SWRI, 2003).

Size Class	Percent Volume	Settling Velocity	
		(cm/s)	(m/day)
1	0.88	0.03	25.92
2	0.75	0.23	198.72
3	1.54	0.65	561.6
4	1.20	2.01	1736.64
5	0.52	4.03	3481.92
6	1.17	7.57	6540.48
7	5.39	13.07	11292.48
8	14.47	18.34	15845.76
9	27.04	23.04	19906.56
10	37.99	28.17	24338.88
11	8.62	51.24	44271.36
12	0.43	106.29	91834.56

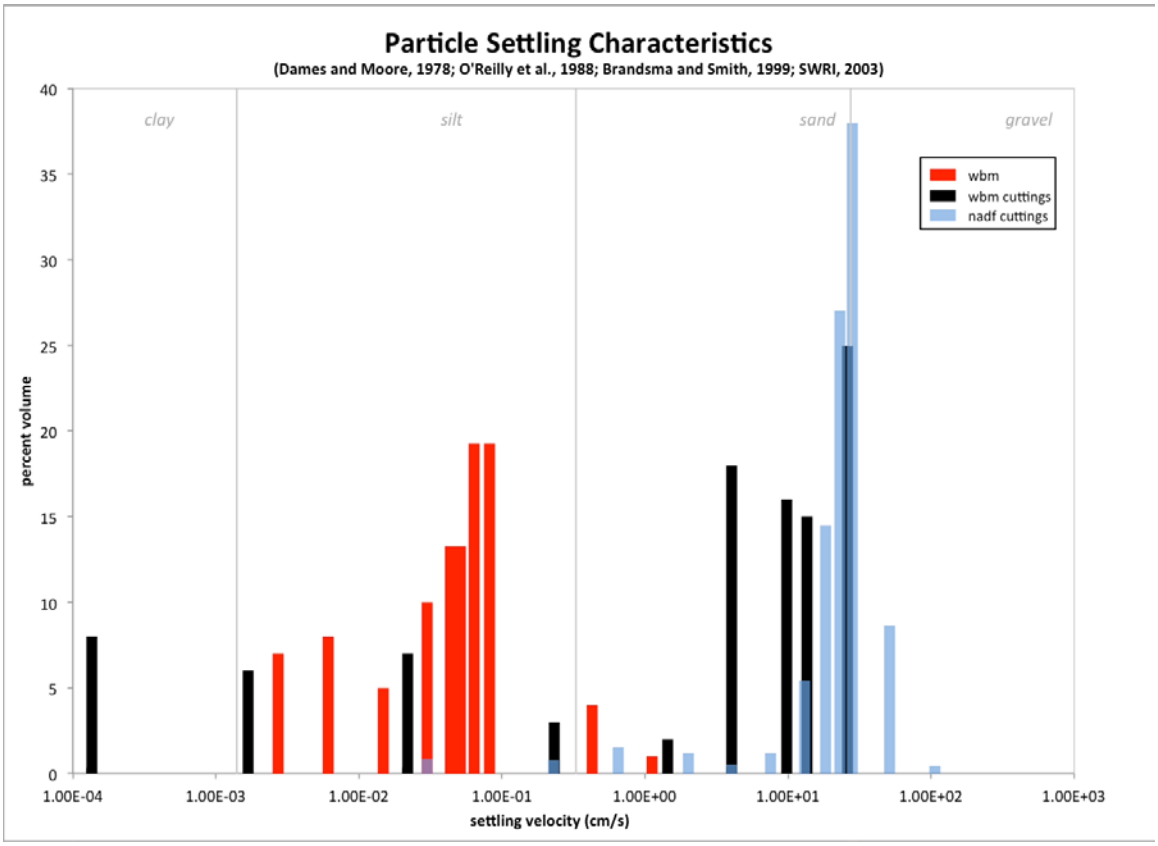


Figure 8. Comparison of the distribution of settling velocities used in the modeling study. Size class divisions are from Gibbs et al. (1971).

3. Model Results

The fate of mud and cuttings released from operational drilling activities at T-1 were assessed through two deterministic scenarios corresponding to the drilling period and discharge volumes shown in Table 7. MUDMAP was used to model the trajectory of cuttings particles from individual drilling sections and to track the far field dispersion for a minimum of 72 hours after the release, accounting for the prolonged settling of very fine sediments (e.g. mud particles) from the water column. The output of each MUDMAP simulation is a concentration grid that describes loading to the seabed associated with each drill section. These grids were aggregated outside of the model to produce maps of cumulative deposition from (i) top hole (riserless) sections and (ii) all drilling sections for each season. Figure 9 and Figure 10 show plan view extents of the model-predicted seabed deposition at each site during the dry season (Scenario 1) and wet season (Scenario 2). Table 8 through Table 9 summarize the extent of deposition for each scenario. Deposit thicknesses were calculated based on mass accumulation on the seabed, sediment bulk density and the assumption of no voids (zero porosity).

Table 7. Summary of model parameters used for each scenario.

Model Scenario	Site	Discharge Period	Description	Discharged Cuttings (m^3)[1]	Discharged Mud (m^3)	Drilling Days (d)
Scenario 1	T-1	Jan-Feb 2010 (Dry Season)	WBM cuttings and WBM from sections 1-2; NADF cuttings and adhered mud from sections 3-5	641 (696)	953	13
Scenario 2	T-1	Jul-Aug 2010 (Wet Season)	WBM cuttings and WBM from sections 1-2; NADF cuttings and adhered mud from sections 3-5	641 (696)	953	13

Notes: 1. Volumes within parenthesis include the addition of 25% residual NADF on cuttings for sections 3-5.

As shown in the bottom panels of the figures below, measurable seabed thicknesses remain confined to a near-field zone within ~1.3 km of the drilling site. The simulation results show a tightly confined cuttings pile (at or above 5 mm) that surrounds the wellhead and a blanket of fine sediment that extends up to 1,220 m to the northeast (furthest extent occurs during the wet season).

Similarities and differences are observed when comparing the dry/wet simulations, for example, the overall footprint (to 0.1 mm) is larger by ~20% during the wet season, and extends north and east from the drilling location. In contrast, deposition areas in the range of 0.5 – 2 mm, are 20-30% more expansive during the dry season. As shown in Figure 11, the expansion in deposition areas < 5mm is largely the result of cuttings discharged from the drillship. The elongation of these thin blankets of fine sediments during the wet season is likely attributed to intensified surface currents during the boreal summer months. In contrast, the larger areas of thicker deposition localized closer to the drilling site can be attributed to the less intense currents associated with the dry season.

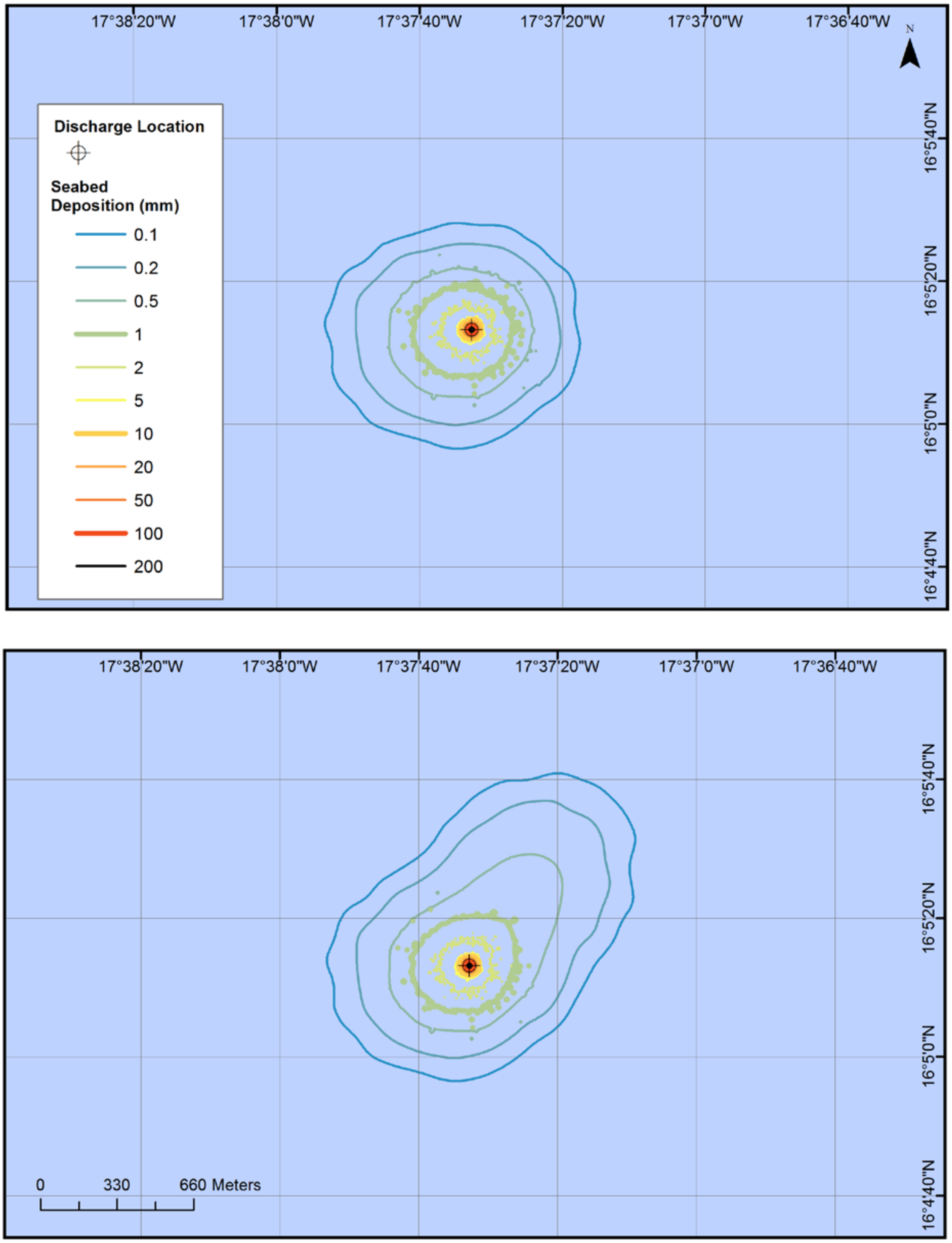


Figure 9. Predicted thickness of drilling discharges at T-1 (dry season). Top: deposition resulting from the riserless drilling intervals (sections 1 and 2). Bottom: deposition resulting from all drilling intervals.

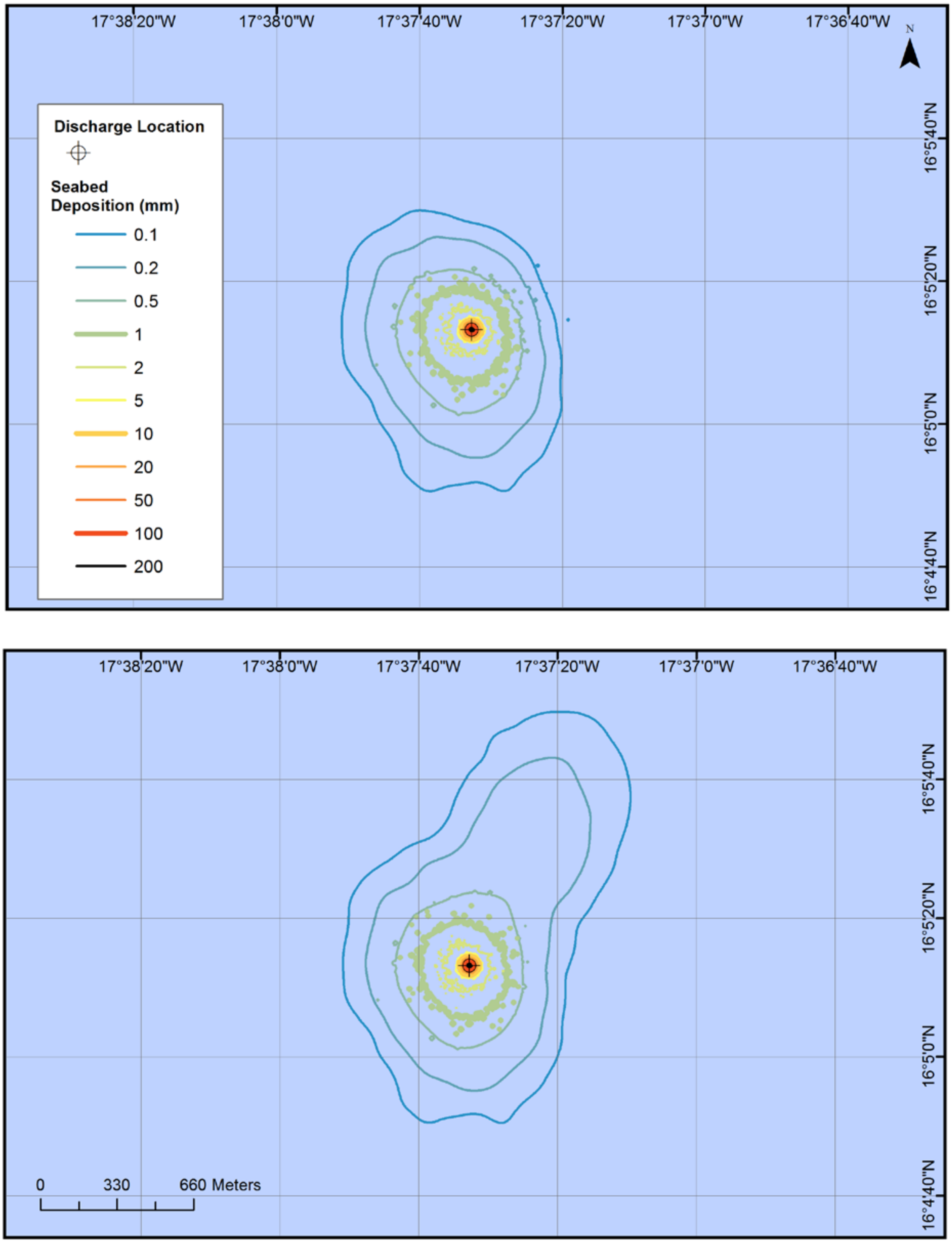


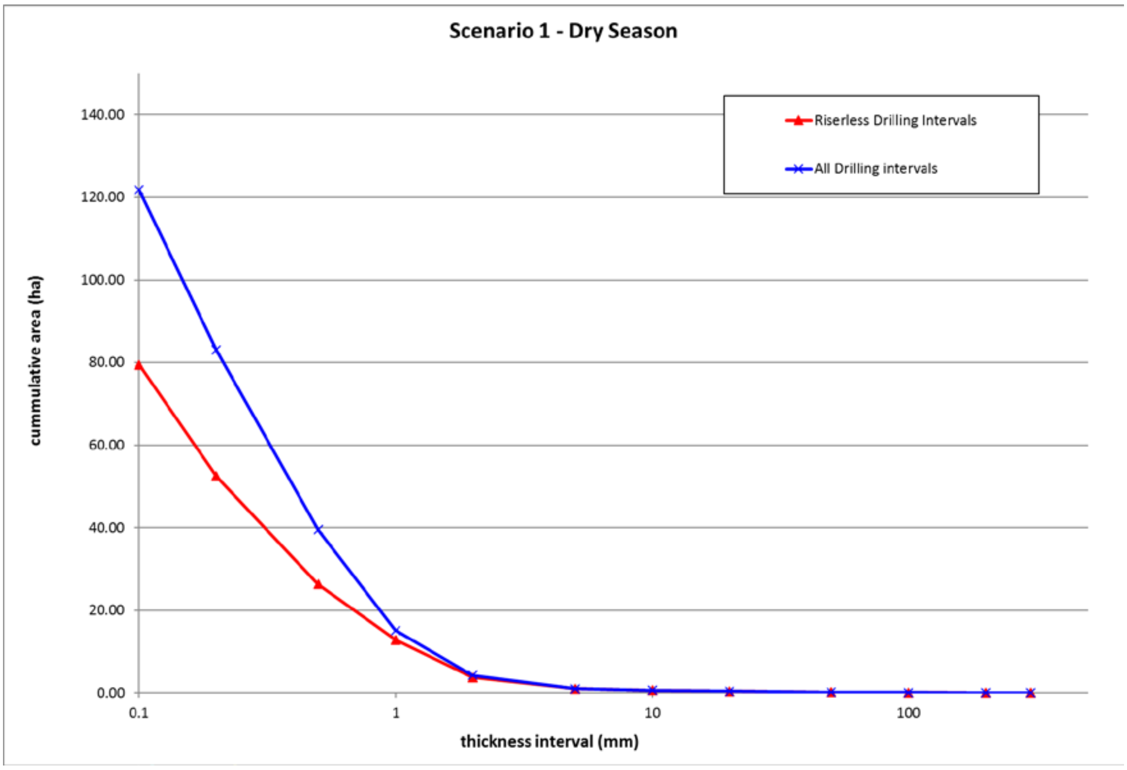
Figure 10. Predicted thickness of drilling discharges at T-1 (wet season). Top: deposition resulting from the riserless drilling intervals (sections 1 and 2). Bottom: deposition resulting from all drilling intervals.

Table 8. Areal extent of seabed deposition (by thickness interval) for each model scenario

Deposition Thickness Interval (mm)	Cumulative Area Exceeding Thickness Interval (km2)			
	Riserless Sections		All Sections	
	Scenario 1 (dry)	Scenario 2 (wet)	Scenario 1 (dry)	Scenario 2 (wet)
0.1	79.4370	85.9520	121.7770	142.9110
0.2	52.4650	53.9020	83.0270	86.6560
0.5	26.3310	25.2590	39.5110	29.4310
1	12.8390	11.0540	15.1090	12.4130
2	3.7700	2.8890	4.2740	3.2010
5	0.9730	0.9410	0.9900	0.9760
10	0.5860	0.5690	0.5860	0.5710
20	0.3640	0.3690	0.3640	0.3690
50	0.1950	0.1920	0.1950	0.1920
100	0.0970	0.1020	0.1000	0.1020
200	0.0250	0.0170	0.0250	0.0200
300	0.0000	0.0000	0.0000	0.0000

Table 9. Maximum extent of thickness contours (distance from release site) for each model scenario.

Deposition Thickness (mm)	Maximum extent from discharge point (m)			
	Riserless Sections		All Sections	
	Scenario 1 (dry)	Scenario 2 (wet)	Scenario 1 (dry)	Scenario 2 (wet)
0.1	610	720	960	1220
1	250	240	250	240
10	50	40	50	50
100	18	18	19	19



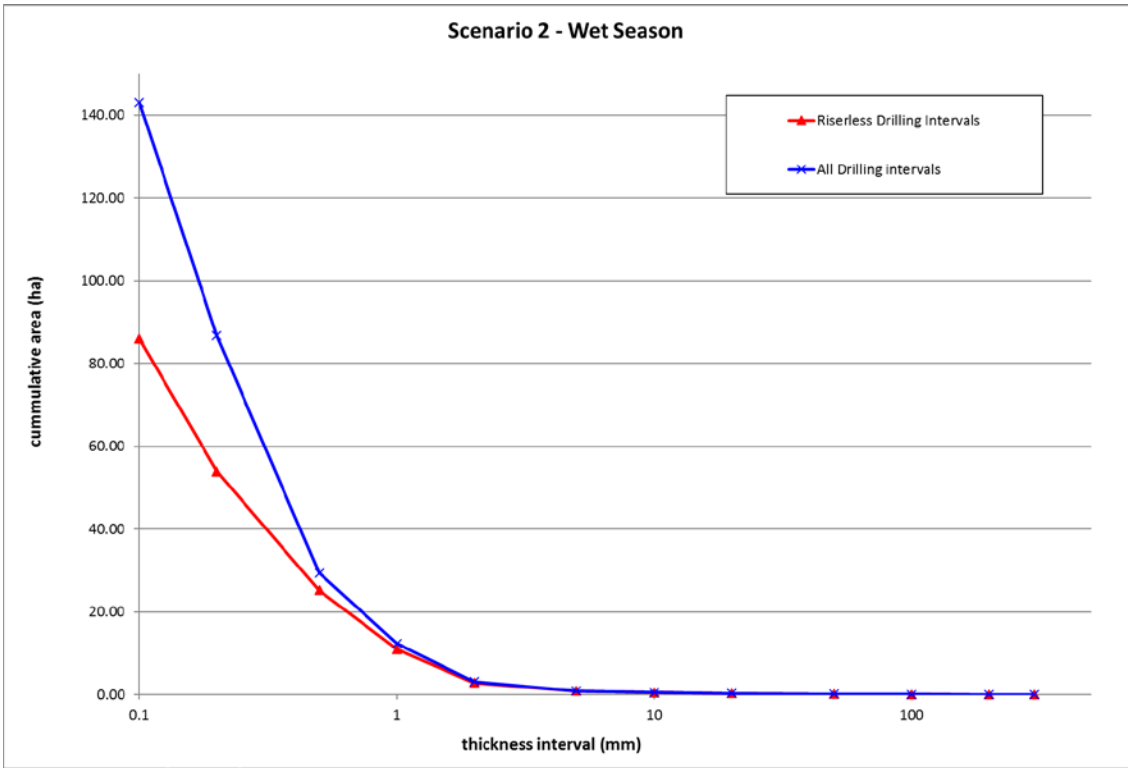


Figure 11. Comparison of seabed deposition areas at T-1 for each season resulting from of top hole drilling (red) and all discharges (blue).

For the top-hole drilling (sections 1-2), there is little noticeable difference in the footprint shape and extent following the discharge. These sediments deposit rapidly during the first few days of operations and surround the drill site forming the more substantial cuttings pile. Table 8 and Figure 11, which compare the extent of deposition between riserless sections and all sections, indicate that deposition at or above 5 mm is almost exclusively the result of top hole drilling. Because currents near the seabed are relatively weak (< 5 cm/s) there is limited opportunity for sediment transport during the top hole phase. Both scenarios result in a fairly concentric depositional footprint that remains close to the well head, which indicates that dispersion processes are nearly as influential as advection from currents due to the settling characteristics of material being released and the release depths.

For Scenario 1 (dry season), the maximum predicted cumulative deposition is 260 mm in the area immediately adjacent to the wellhead. Deposition of 100 mm extends up to 18 m from the well and covers a maximum aerial extent of 0.100 ha; deposition at 10 mm extends to 50 m and covers a maximum area of 0.586 ha; and deposition at a thickness of 1 mm extends a maximum of 240 m and covers 15.109 ha of the seabed. For Scenario 2 (wet season), the maximum predicted cumulative deposition is 240 mm. Deposition of 100 mm extends up to 27 m from the well and covers a maximum aerial extent of 0.102 ha; deposition at 10 mm extends to 40 m and covers a maximum area of 0.5710 ha; and deposition at a thickness of 1 mm extends a maximum of 250 m and covers 12.4130 ha of the seabed.

4. Cumulative Seabed Deposition

4.1. Introduction

Studies describing the biological effects of sedimentation were reviewed and thresholds for deposition were compiled for benthic taxa where available in the literature (Section 4.2). The potential cumulative seabed deposition from the proposed drilling program was evaluated in a geospatial analysis using ArcGIS tools (Section 4.3). Results of the geospatial analysis are presented as maps depicting overlap between areas of potential deposition around the twelve well sites and as areas above deposition thresholds (Section 4.4). Potential impacts are discussed relating the possible cumulative deposition calculated and the biological effects thresholds reviewed (Section 4.5).

4.2. Biological Background

4.2.1. Sedimentation Effects

Although sediment deposition is a natural process, rate of sedimentation varies based on oceanographic characteristics of the area. Deep sea habitats, like those in the current study, are generally characterized by low-energy currents and slow sediment accumulation rates of 1 – 100 mm per thousand years (Gage and Tyler, 1991; Glover and Smith, 2003). Benthic organisms associated with these environments are generally adapted to tolerate a range of conditions and sedimentation rates. Rapid increases in sedimentation associated with mud and cuttings discharges can have direct and indirect effects on benthic infauna communities in deep sea habitats. Direct effects can include smothering, toxicity exposure, and physical abrasion; indirect effects include habitat alterations and changes to community assemblages (DOER, 2005). The severity of sedimentation effects on organisms depends on factors including burial depth, burial rate, burial time, species-specific tolerances, the grain size of the deposited sediments, and seasonal timing (Kjeilen-Eilertsen et al., 2004). For example, higher mortality can occur in the summer than in the winter (Smit et al., 2008). Higher mortality has been shown to occur at higher temperatures in mesocosm and lab studies of mussel and gastropod burial, possibly due to greater oxygen demand at higher temperatures (Chandrasekara and Frid, 1998; Hutchison et al., 2016).

Taxonomic groups react differently and have varying levels of tolerance for sedimentation, with sessile and attached organisms having the lowest tolerance and highest mortality rate during sedimentation events (DOER, 2005; Gates and Jones, 2012). Benthic suspension feeders are also particularly sensitive to mud and cuttings discharges because suspended particles, such as those that compose silt and clay substrates, can remain suspended in the water column for weeks to months and interfere with feeding and growth (DOER, 2005; Smit et al., 2008). For example, crustaceans in the project region (*Leptognathiella, Pseudotanais,* and Paratanaoidae) will likely be the most sensitive to burial, as these taxa are filter feeders with extremely limited motility (CSA, 2017; Jumars et al., 2014). Meanwhile, polychaetes and mollusk species that burrow or feed in subsurface sediments will likely be less sensitive to burial.

Grab samples collected by CSA during the Environmental Baseline Survey (EBS) indicated that sediment at the five offshore project sites (>2,500 m deep) consisted primarily of silt or silt/clay. Therefore, fine particles discharged from drilling are not expected to cause drastic changes in the median sediment grain size or habitat type present in the project region. If the range in grain size of the discharged particles were to differ greatly from the current conditions, it could cause changes in benthic diversity as the new minimum or maximum grain sizes could support preferences of different species even if the median grain size was the same (Smit et al., 2008). Areas with the thickest deposition will incur the most severe impacts and lead to highest mortality rates.

Benthic grab samples indicated that within the project region, species diversity was high, abundance of each species was low, and there was a relatively equal distribution of individuals among taxa (CSA, 2017). Polychaetes, malacostracans, and bivalves represented the highest percent abundance in the offshore samples. Previous research conducted on sedimentation and recovery of benthic infauna in Newfoundland, Canada, observed increased abundance and biomass in some polychaete species and declines in others in the area around the drill site. Reduced abundance in those species negatively affected (e.g., Paraonidae, a taxon also present in the project region) extended approximately 1 - 2 km from the drill site (Paine et al., 2014). This aligns with findings from an extensive literature review that documented biological effects (such as changes in benthic community structure) at distances of 200 – 2,000 m from platforms using water-based drilling fluids (Ellis et al., 2012). The range of effects from synthetic-based drilling fluids was found to be somewhat smaller, detecting biological effects from 50 – 1,000 m from the drill site (Ellis et al., 2012). Ellis et al. (2012) stated that there were virtually always changes to community structure observed within 300 m of a drill site using water-based fluids, which included a reduction in species diversity, increases in opportunistic species abundance, loss of suspension-feeding species, and increase in deposit-feeding species. However, biological effects would generally be stronger for seagrass and hard-bottom epibenthic communities than for the types of soft-sediment communities that dominate the project region.

4.2.2. Deposition Thresholds and Recovery

Specific sedimentation thresholds tested and reported by Smit et al. (2008) indicate that epibenthic, sessile, filter-feeding species cannot survive sediment burial depths over 10 mm. Meanwhile, infauna taxa that are adapted to habitat covered in sediment may escape from burial under 100 mm of sediment or more (Kjeilen-Eilertsen et al., 2004). In a mesocosm and field study, Trannum et al. (2011) observed that 24 mm of water-based drill cuttings lowered oxygen availability and reduced abundance for macrofauna in the sediment. Overall, Smit et al. (2008) estimated that mortality of 5% of benthic organisms (including mollusks, polychaetes, and crustaceans) would occur at burial depths of 6.3 mm (3.1 – 10.6 mm) and mortality of 50% would occur at burial depths of 54 mm (37 – 79 mm).

Studies on the recovery of benthic infaunal communities post-sedimentation present varying results. The ability of a benthic community to recover after sediment deposition depends on larval settlement, the rate of bioturbation, and sediment mixing by currents (Smit et al. 2008; Trannum et al., 2011). Because many benthic species have drifting pelagic larvae, resettlement can occur within months post-disturbance. Trannum et al. (2011) observed reestablishment of species-rich communities within 6 months of sedimentation and noted that the most successful colonizers were species in the Spionidae family of polychaete worms, which are present in the project region. In studies from the North Sea, recolonization of cuttings piles from the edges of the pile occurs in 1 – 5 years (Kjeilen-Eilertsen et al., 2004). There is little information available on recovery timescales for benthic habitats after drilling multiple wells in a region (Ellis et al., 2012). Areas with the thickest deposition will likely rely on larval transport and resettlement for recolonization, as survival of buried organisms is unlikely. In areas with lower levels of deposition, reestablishment by surviving organisms that burrow or sift through sediment to feed is possible, as they mix mud and cuttings with native sediments and slowly return habitats to pre-drilling conditions (Smit et al., 2008; Gates and Jones, 2012). In the project region, 6 of the 10 most abundant infaunal species were either tube-building or burrowing and may aide in the redistribution of sediment and recovery of benthic habitat in the project region (CSA, 2017).

Time is an important factor in determining the impact of drilling discharges on the benthic environment; unfortunately, it is also the factor that is least understood. Developing thresholds of deposition rate may be the best method for determining levels of effect on benthic organisms, but the data to support such thresholds are rare in the literature and difficult to discern (Kjeilen-Eilertsen et al., 2004). For instance, a particular high deposition rate might be tolerated if there is no further deposition for a few months following burial, or a lower rate of continuous deposition might be better tolerated.

At present, reliable thresholds regarding the timing of deposition or chronic and sublethal impacts of long-term deposition on the ecosystem have not yet been developed (Ellis et al. 2012). Additionally, many studies of biological effects of drilling discharge were conducted on the continental shelf, and information on impacts in the deep-sea environment is limited. Another data gap is the cumulative impact of multiple wells in a region. One study (Hernández Arana et al., 2005) assessed the impact of 200 wells in shallow shelf waters of the Gulf of Mexico and found that stations located in areas of high platform densities had lower abundance and biomass and different assemblages than sample stations with fewer drill sites nearby. Research into cumulative effects is limited and needs to account for recovery times at regional scales (Ellis et al., 2012).

4.3. Geospatial Analysis Methods

The UTM coordinates of 12 well sites from DC1 and DC3 were plotted and buffered to the maximum extent of each of 7 deposition thickness thresholds. The maximum distances from the well site were derived from the modeling output for the dry and wet scenarios (Table 10).

Table 10. Maximum extent of thickness contours (distance from release sites) for each model scenario used to evaluate cumulative sediment deposition.

Deposition Thickness (mm)	Maximum extent from wells (m)	
	All Sections	
	Scenario 1 (dry)	Scenario 2 (wet)
0.1	960	1220
0.5	580	370
1	250	240
5	70	65
10	50	50
50	26	26
100	19	19

The concentric buffered regions around each well point are a conservative representation of the potential areas of concern for sediment deposition from all drilling sections at each well. For this analysis, the directionality of sediment deposition modelled at the T-1 well site was removed from consideration to capture the potential for differences in currents, bathymetry, and resulting deposition patterns at the other well sites. Thus, the thickness areas discussed in this section should be considered generalized estimates of the maximum areas of concern (AOCs) for potential deposition around the well sites, rather than predicted areas of likely impact based on direct modeling at each point. Figure 12 illustrates the spatial difference in the thickness contours from the modeling output and the AOCs of potential deposition thickness around each well site. The AOCs represent the maximum distance of deposition for each model scenario, extending in any direction from the discharge point.

Each buffer polygon was assigned a deposition thickness threshold and converted to raster files with a cell size of 20 x 20 meters. The Cell Statistics tool within the Spatial Analyst extension was used to detect the maximum value of each cell in the AOC around each well site. This step removed the overlap of buffered regions that corresponded to the same well site. Lastly, the Cell Statistics tool was used again to sum the raster files of deposition thickness together in several configurations:

- All wells, dry season scenario;
- All wells, wet season scenario;
- Sequential wells (2020 – 2021), dry season scenario;
- Sequential wells (2020 – 2021), wet season scenario;
- 2025 wells, dry season scenario;
- 2025 wells, wet season scenario;
- 2028 wells, dry season scenario;
- 2028 wells, wet season scenario;
- 2032 wells, dry season scenario; and
- 2032 wells, wet season scenario.

Finally, the number of cells of each summed raster file that fell within specific thickness ranges were recorded to calculate the area above thickness thresholds and evaluate the percent of deposition AOC overlap between wells in each configuration.

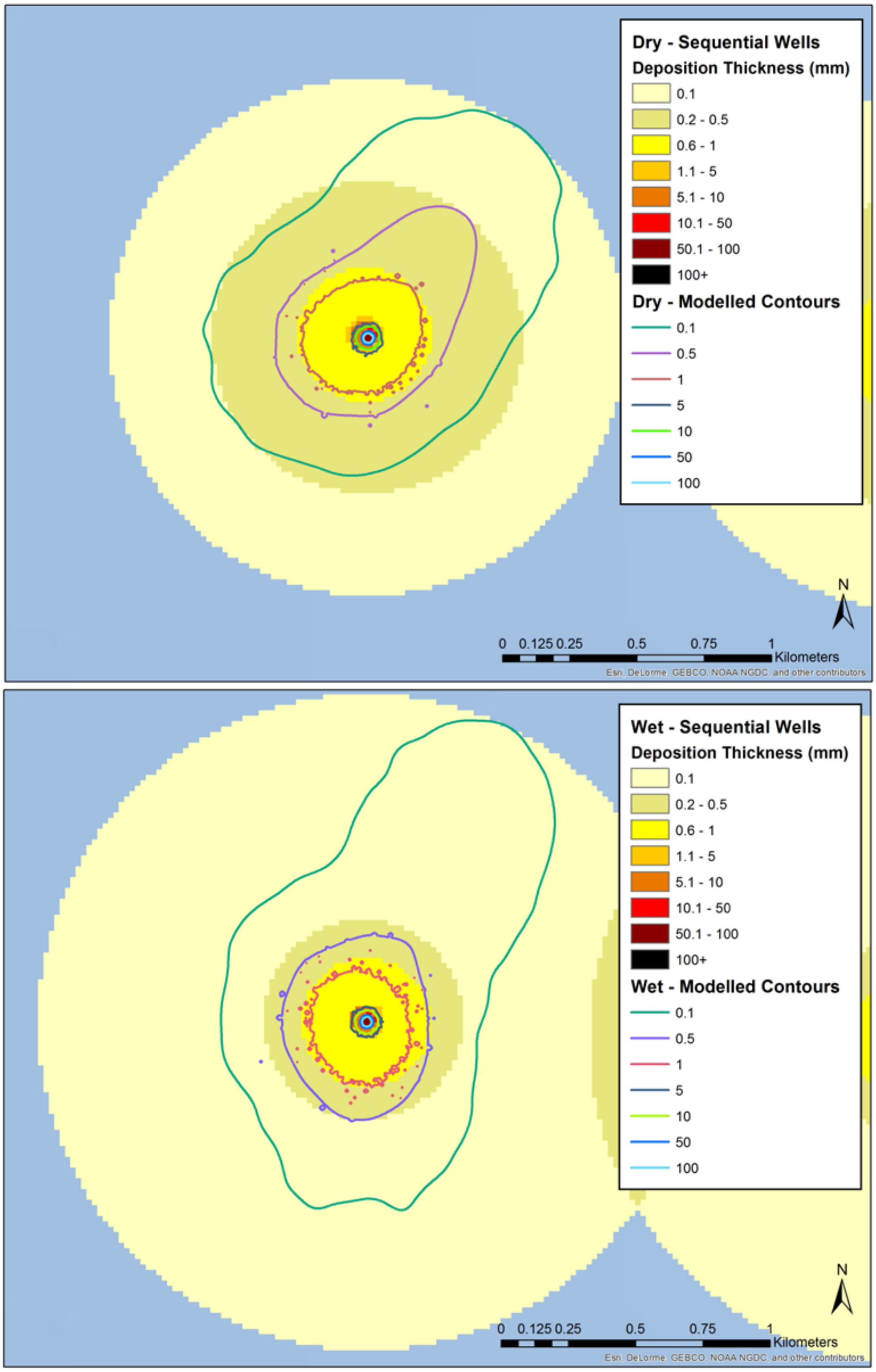


Figure 12. Comparison of modelled contours of seabed deposition at well site T-1 during the dry (top) and wet (bottom) season scenarios to the potential areas of cumulative deposition developed in the geospatial analysis (see legend).

4.4. Cumulative Deposition Results

Results of the geospatial analysis of cumulative deposition are presented as follows:

- Cumulative deposition maps for both seasons, which summed all well deposition AOCs together assuming no time elapsed between drilling episodes (Figure 13);
- Temporal maps for both seasons depicting all well sites with their deposition AOCs summed together based on the drill schedule: 4 sequential wells in 2020-2021, 3 wells in 2025, 2 wells in 2028, and 3 wells in 2032. These maps illustrate the spatial overlap of the wells drilled at different times but do not sum together the thickness AOCs of wells scheduled to drill at different times, even if they overlap in space (Figure 14); and
- Cumulative deposition maps for both seasons, displaying just the wells that were summed together based on drill schedule (Figures 15, 16, 17, and 18).

Each pair of wet season / dry season maps within a figure are presented at the same spatial scale; however, the map scale may vary between figures.

In addition to the map figures, the percent of the area within each thickness AOC and the percent overlap between AOCs of different well sites are presented in Tables 11 and 12 below.

Table 11. Percent of the maximum area of concern for each thickness threshold range in the dry season scenario.

Deposition Thickness Range (mm)	Cumulative (All Wells)	Sequential Wells	2025 Wells	2028 Wells	2032 Wells
0.1	56.7	63.5	50.7	63.5	63.5
0.2 – 0.5	30.3	29.8	23.4	29.8	29.7
0.6 – 1.0	11.3	6.3	20.0	6.2	6.2
1.1 – 5.0	1.3	0.3	5.3	0.2	0.3
5.1 – 10	0.2	0.2	0.3	0.2	0.2
10.1 – 50	0.1	0.0	0.2	0.0	0.0
50.1 - 100	0.1	0.0	0.1	0.1	0.0
100+	0.0	0.0	0.0	0.0	0.0
% Overlap Between Well AOCs - Dry	10.5	0.0	28.7	0.0	0.0

Table 12. Percent of the maximum area of concern for each thickness threshold range in the wet season scenario.

Deposition Thickness Range (mm)	Cumulative (All Wells)	Sequential Wells	2025 Wells	2028 Wells	2032 Wells
0.1	74.3	88.7	59.5	90.8	90.8
0.2 – 0.5	19.6	7.3	31.9	5.3	5.4
0.6 – 1.0	4.7	3.7	5.2	3.6	3.6
1.1 – 5.0	1.2	0.1	3.1	0.1	0.1
5.1 – 10	0.1	0.1	0.2	0.1	0.1
10.1 – 50	0.1	0.0	0.1	0.0	0.0
50.1 - 100	0.0	0.0	0.0	0.0	0.0
100+	0.0	0.0	0.0	0.0	0.0
% Overlap Between Well AOCs - Wet	18.0	1.9	35.9	0.0	0.0

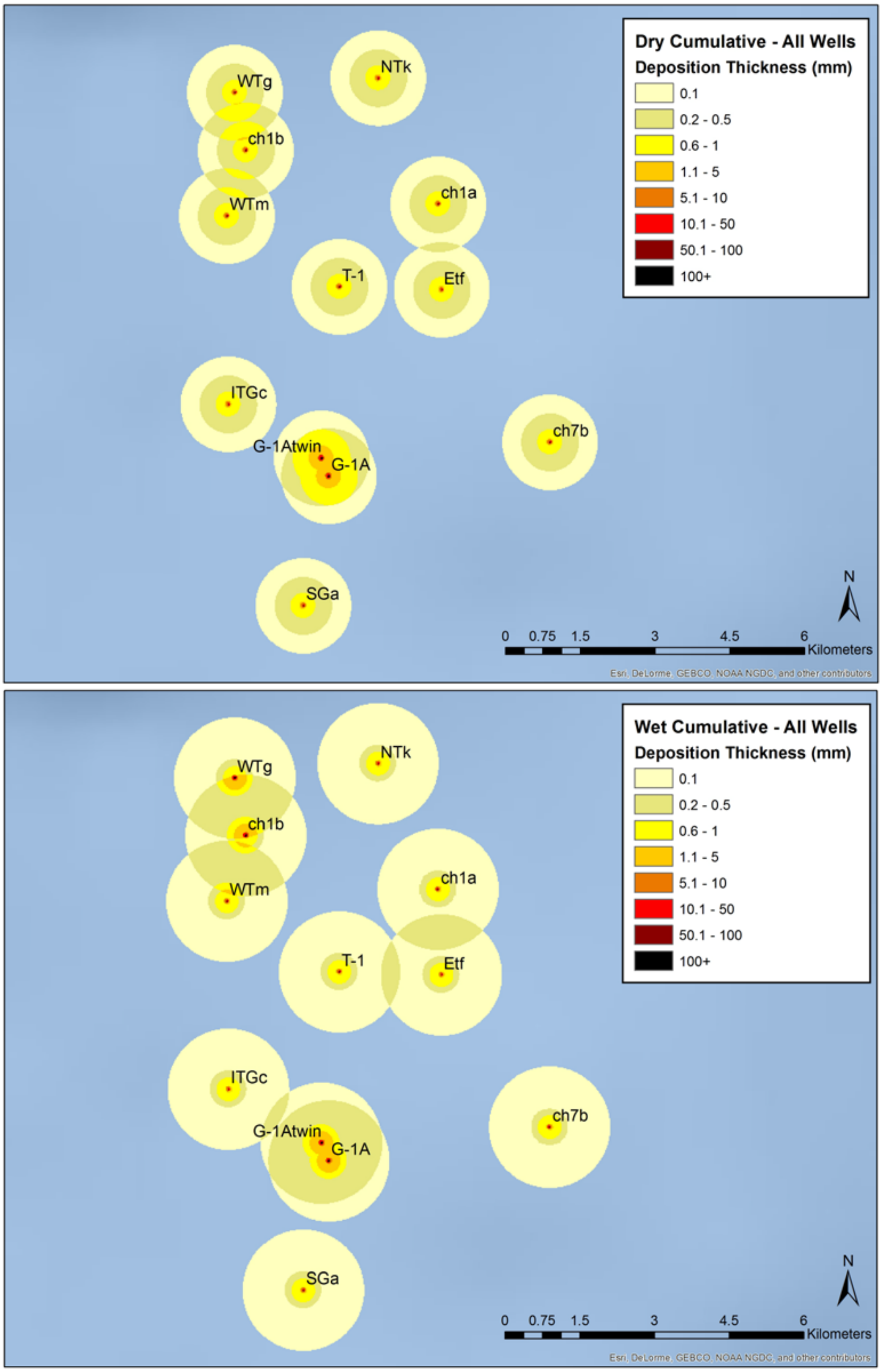


Figure 13. Cumulative deposition from all 12 wells based on the dry (top) and wet (bottom) season scenarios.

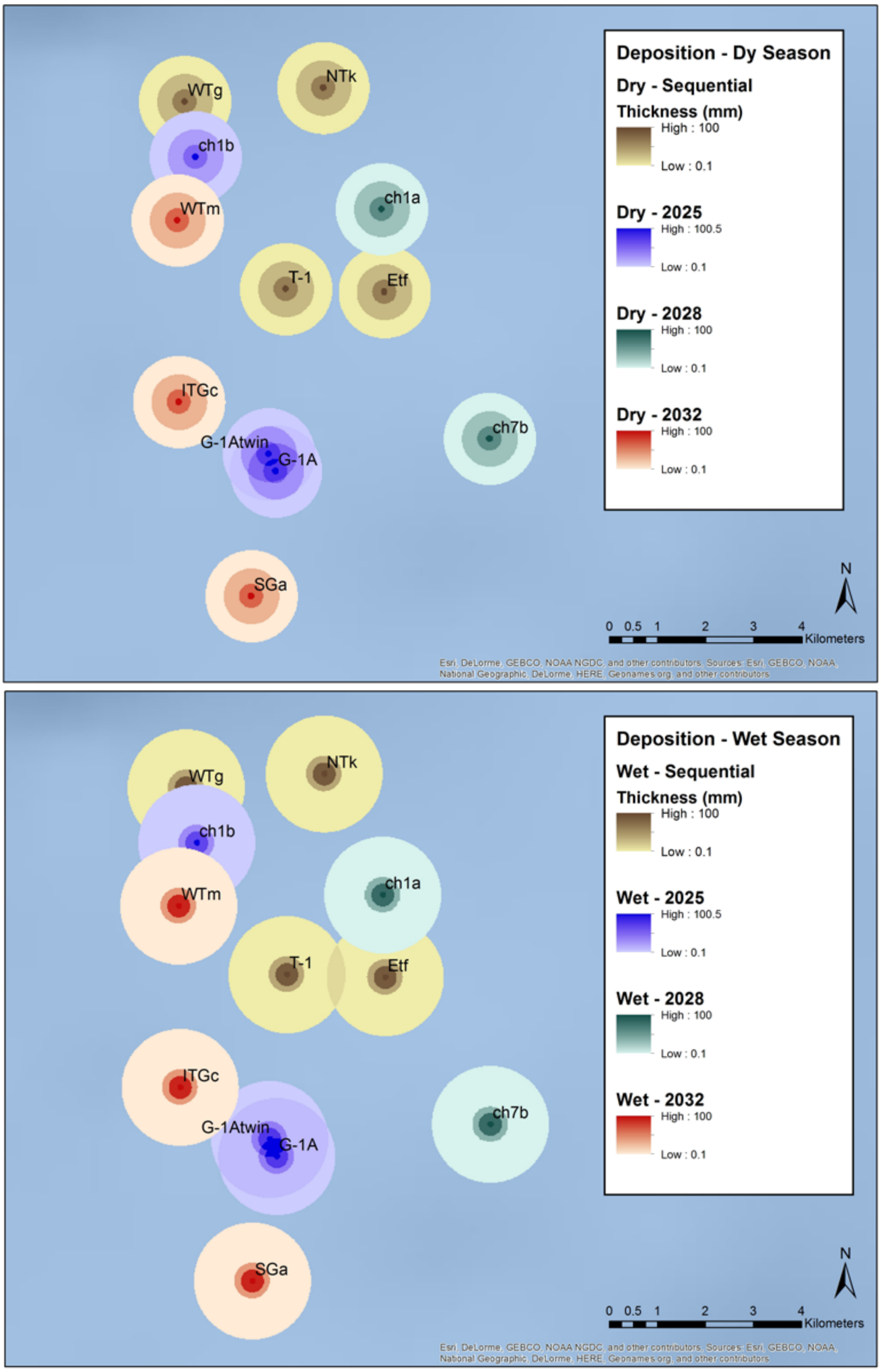


Figure 14. Temporal depiction of cumulative deposition based on the drill schedule for the dry (top) and wet (bottom) scenarios. Spatial overlap is only depicted for wells scheduled for drilling within the same timeframe: sequential (2020-2021), 2025, 2028, or 2032.

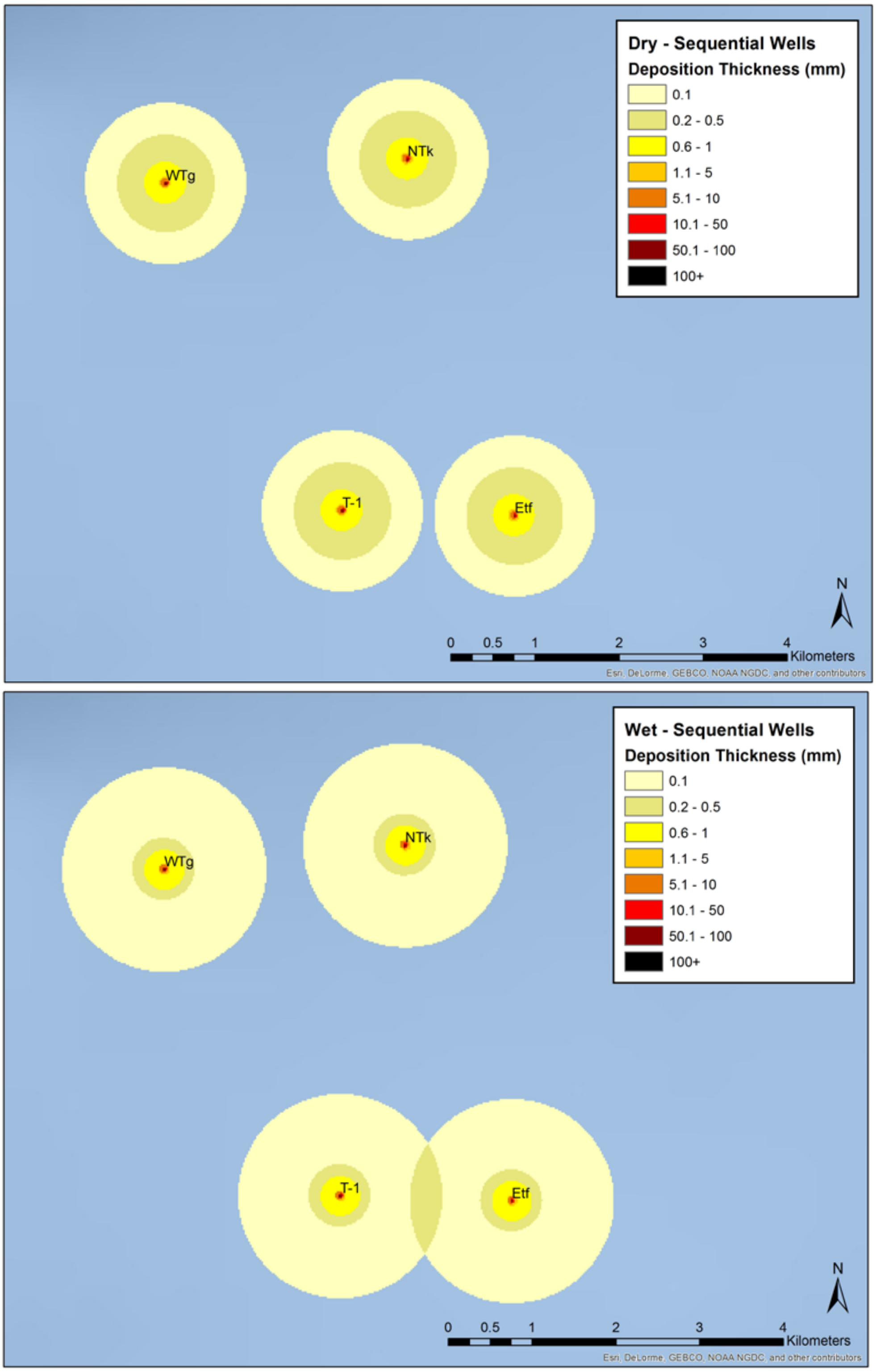


Figure 15. Cumulative deposition from the four wells scheduled to be drilled sequentially from 2020-2021 based on the dry (top) and wet (bottom) scenarios.

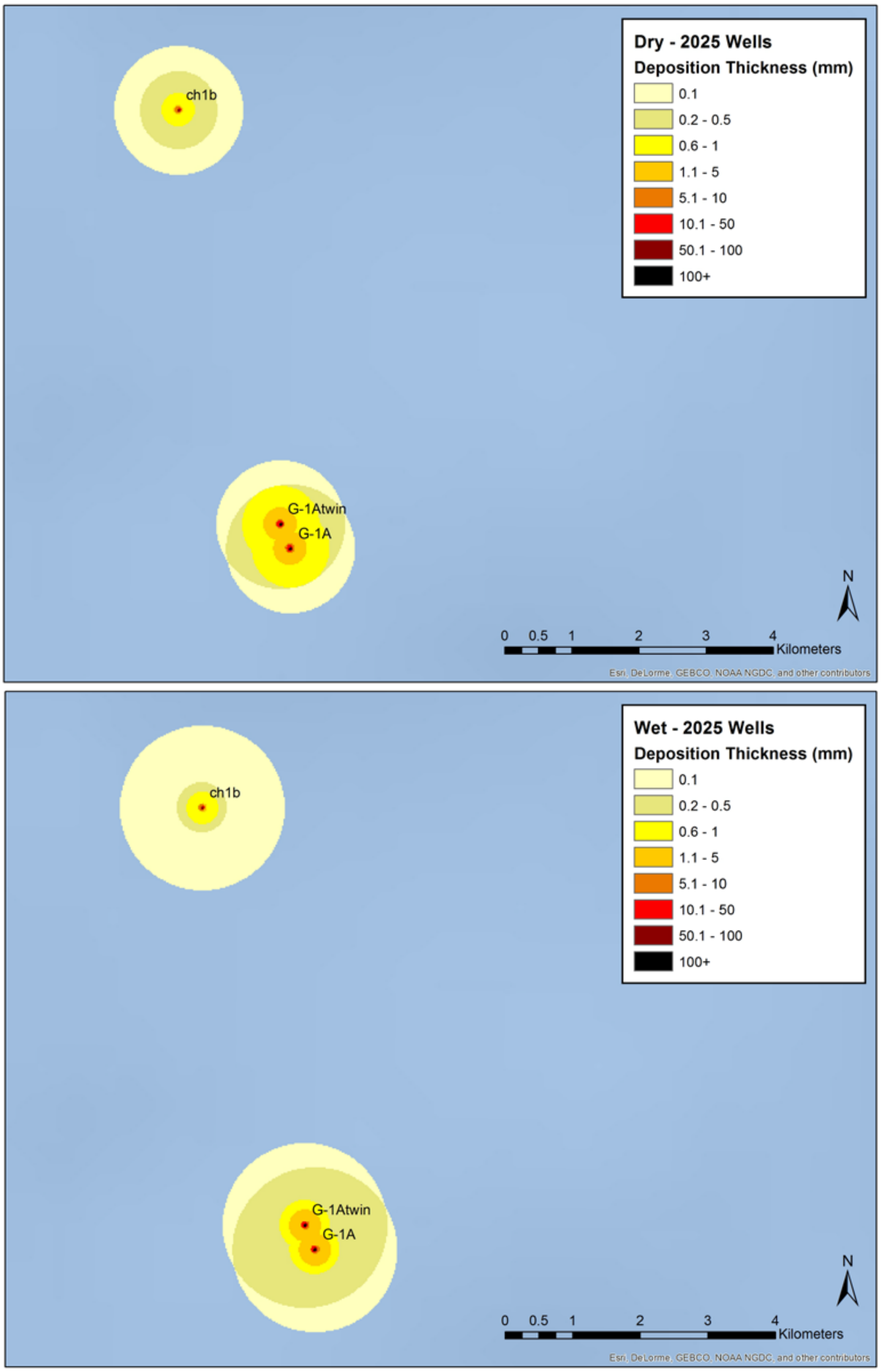


Figure 16. Cumulative deposition from the three wells scheduled to be drilled during 2025 based on the dry (top) and wet (bottom) scenarios.

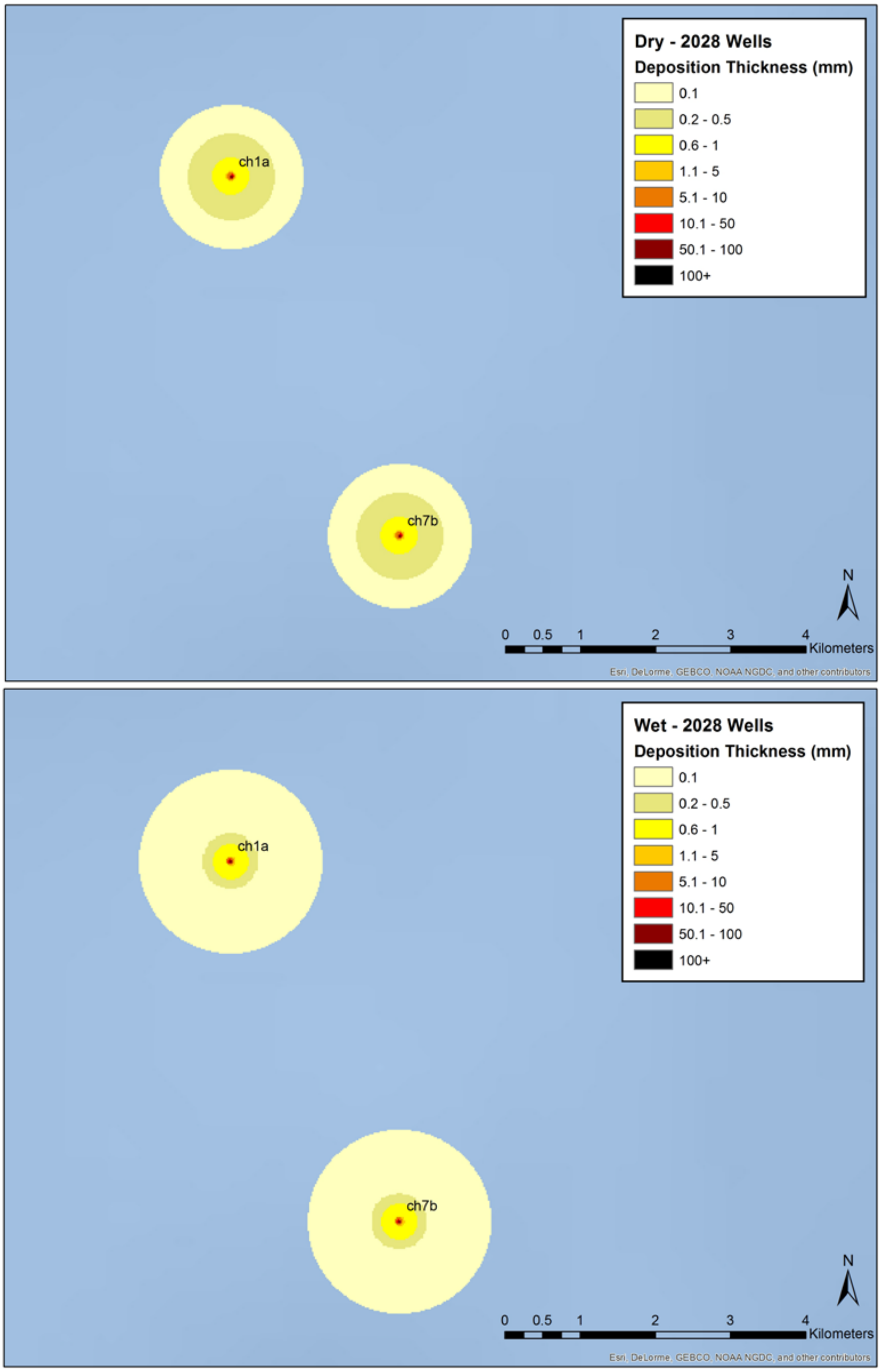


Figure 17. Cumulative deposition from the two wells scheduled to be drilled during 2028 based on the dry (top) and wet (bottom) scenarios.

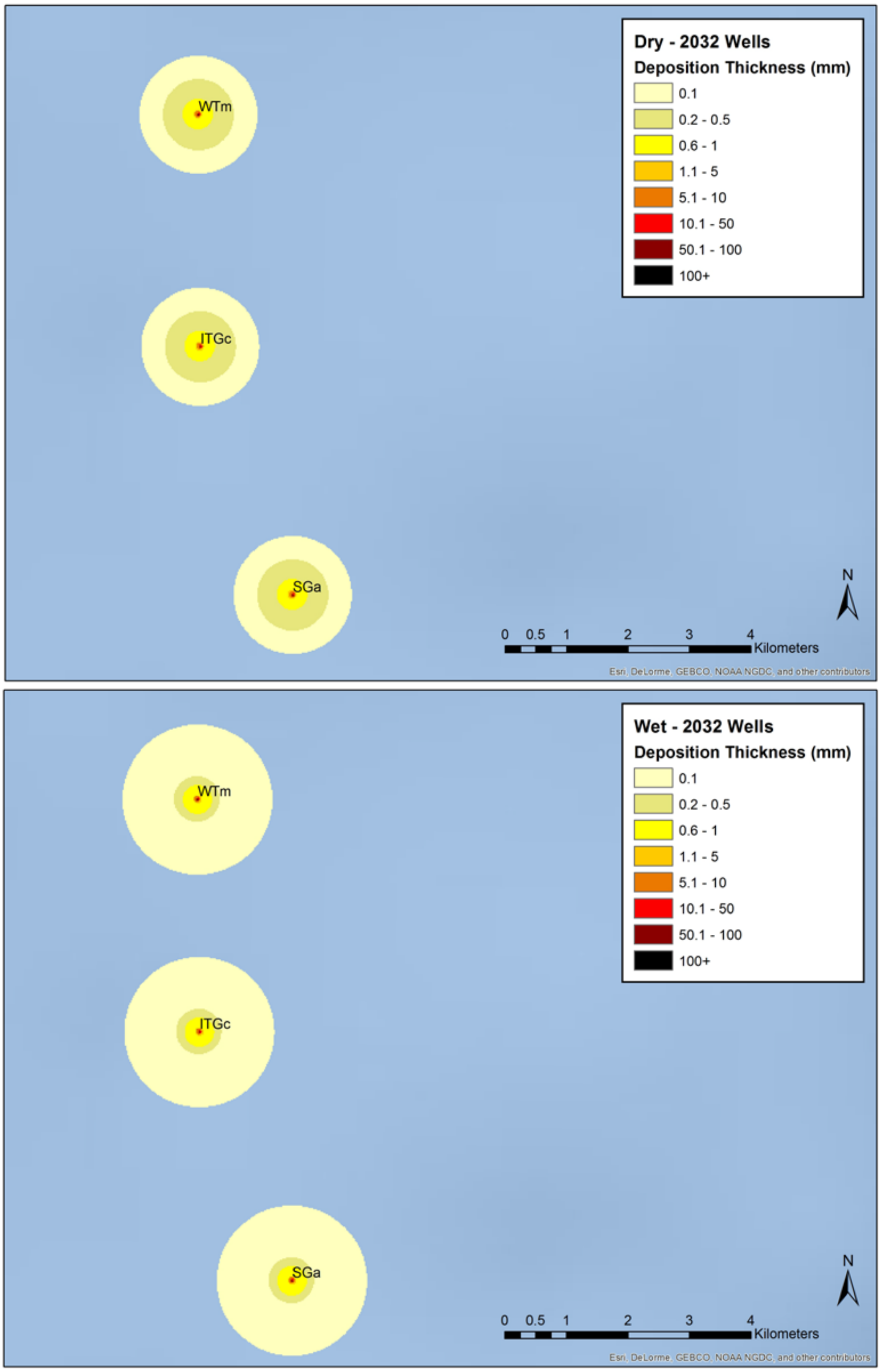


Figure 18. Cumulative deposition from the three wells scheduled to be drilled during 2032 based on the dry (top) and wet (bottom) scenarios.

4.5. Discussion of Results

As can be seen from the figures in Section 4.4, the AOCs of maximum potential deposition varied somewhat between the dry and wet season scenarios. In the dry season, the maximum extent of the 0.1 mm deposition thickness threshold was smaller than during the wet season, suggesting a reduction in current transport of suspended sediment during the dry season. Thus, the maximum extent for all other thickness thresholds were larger during the dry season than during the wet season since the drilling discharges didn't spread out as far. The maximum extent for the largest thickness thresholds (10 mm, 50 mm, and 100 mm) were identical for both dry and wet season scenarios (Table 10).

In the cumulative maps depicting the spatiotemporal overlap of AOCs from all wells at once for each season (Figure 13), there is potential overlap between AOCs of 7 wells in the dry scenario and 9 wells in the wet scenario (Figure 13). This overlap between AOCs of different wells represents approximately 10% of the total AOC area in the dry scenario and 18% in the wet scenario. The vast majority of the AOC area is for deposition thicknesses < 1.0 mm in both seasonal scenarios (98.3% dry, 98.5% wet; Tables 11 and 12). Deposition thicknesses that may cause 5% mortality to benthic organisms (> 6.4 mm, or 5.1 – 50 mm in this analysis) comprised 0.3% of the cumulative AOC area for the dry scenario and 0.2% of the cumulative AOC area for the wet scenario, or approximately 0.09 km^2 for both. Deposition thicknesses that may cause 50% mortality to benthic organisms (> 54 mm, or 50.1 – 100+ mm in this analysis) comprised < 0.01% of the cumulative AOC area or approximately 0.02 km^2 for both season scenarios.

In the temporal maps depicting different well configurations based on the drilling schedule, there is the potential for less accumulation in the overlapped AOCs assuming that the benthic communities can recover between drilling sessions (Figure 14). Note that this is a large assumption, considering that the drilling sessions are scheduled approximately 3-5 years apart and recovery times in the deep sea can potentially take many years. Of the four scheduled drilling sessions (sequential 2020-2021, 2025, 2028, and 2032), there is no spatiotemporal overlap between the AOCs of the wells scheduled to be drilled in 2028 (Figure 17) or in 2032 (Figure 18) for either seasonal scenario. For the sequential wells (Figure 15), there is 1.9% overlap in AOC area for the wet season only. The largest amount of spatiotemporal overlap occurred for the 2025 wells, with 28.7% overlap in AOC area during the dry season and 35.9% overlap during the wet season. This overlap lead to deposition thicknesses that may cause 5% mortality in 0.5% of the 2025 AOC for the dry scenario and 0.3% for the wet, or approximately 0.03 km^2. Deposition thicknesses that may cause 50% mortality comprised 0.10% of the 2025 AOC for the dry scenario and 0.07% for the wet, or approximately 0.01 km^2

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Appendix A: MUDMAP Model Description

MUDMAP is a personal computer-based model developed by ASA to predict the near and far-field transport, dispersion, and bottom deposition of drill muds and cuttings and produced water (Spaulding et al; 1994). In MUDMAP, the equations governing conservation of mass, momentum, buoyancy, and solid particle flux are formulated using integral plume theory and then solved using a Runge Kutta numerical integration technique. The model includes three stages:

Stage 1: **Convective decent/jet stage** – The first stage determines the initial dilution and spreading of the material in the immediate vicinity of the release location. This is calculated from the discharge velocity, momentum, entrainment and drag forces.

Stage 2: **Dynamic collapse stage** – The second stage determines the spread and dilution of the released material as it either hits the sea surface or sea bottom or becomes trapped by a strong density gradient in the water column. Advection, density differences and density gradients drive the transport of the plume.

Stage 3: **Dispersion stage –** In the final stage the model predicts the transport and dispersion of the discharged material by the local currents. Dispersion of the discharged material will be enhanced with increased current speeds and water depth and with greater variation in current direction over time and depth.

MUDMAP is based on the theoretical approach initially developed by Koh and Chang (1973) and refined and extended by Brandsma and Sauer (1983) and Khondaker (2000) for the convective descent/ascent and dynamic collapse stages. The far-field, passive diffusion stage is based on a particle based random walk model. This is the same random walk model used in ASA's OILMAP spill modeling system (ASA, 1999).

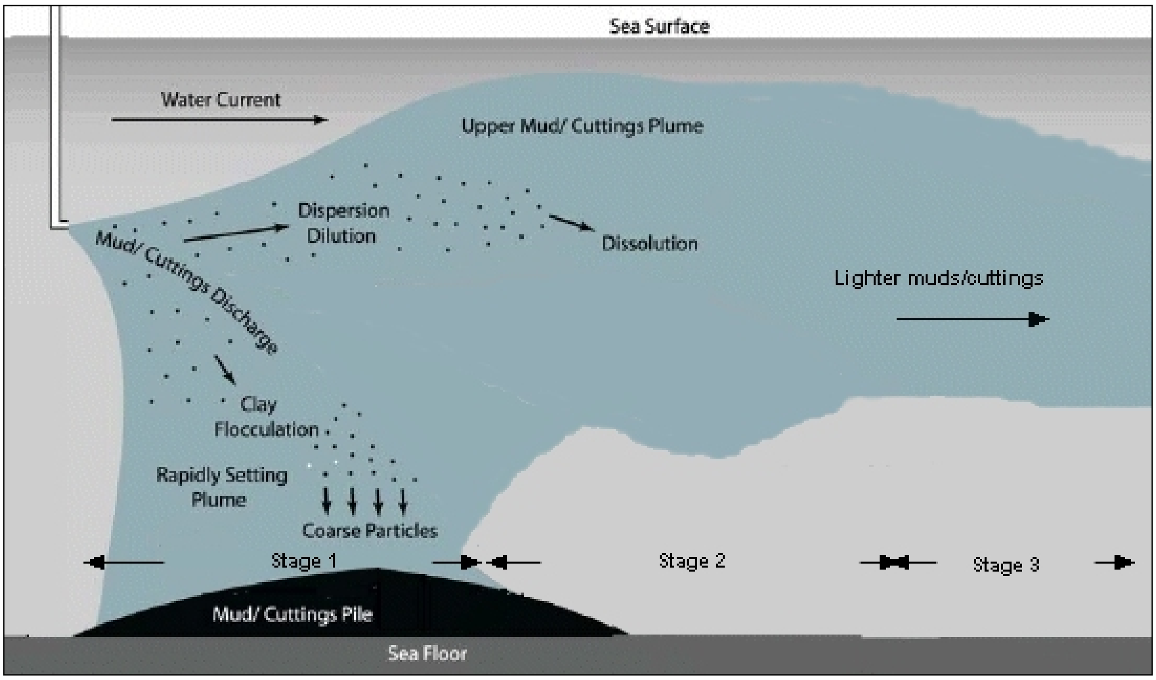

Figure A1. Conceptual diagram showing the general behavior of cuttings and muds following discharge to the ocean and the three distinct discharge phases (after Neff, 2005).

The model's output consists of calculations of the movement and shape of the discharge plume, the concentrations of soluble (i.e. oil in produced water) and insoluble (i.e. cuttings and muds) discharge components in the water column, and the accumulation of discharged solids on the seabed. The model predicts the initial fate of discharged solids, from the time of discharge to initial settling on the seabed As MUDMAP does not account for resuspension and transport of previously discharged solids, it provides a conservative estimate of the potential seafloor concentrations (Neff, 2005).

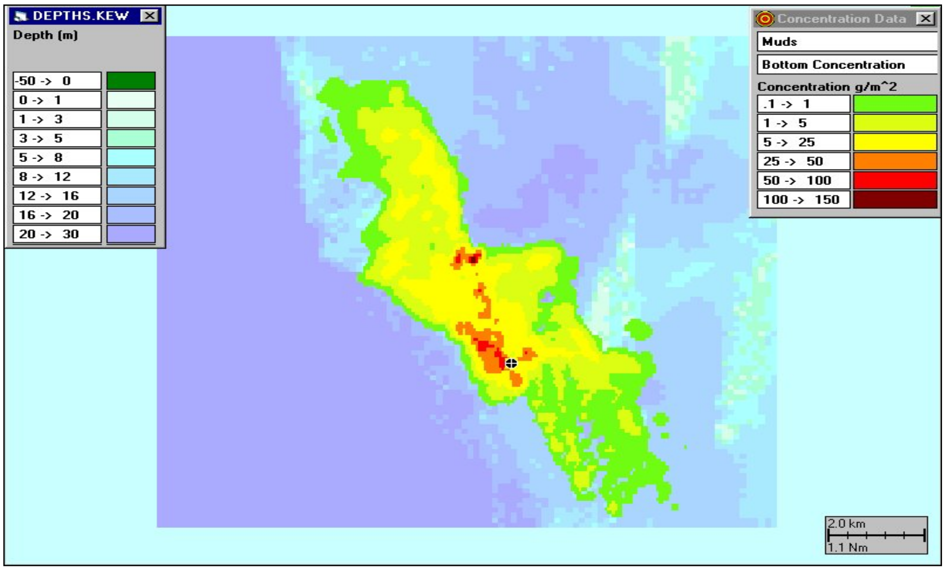

Figure A2 Example MUDMAP bottom concentration output for drilling fluid discharge.

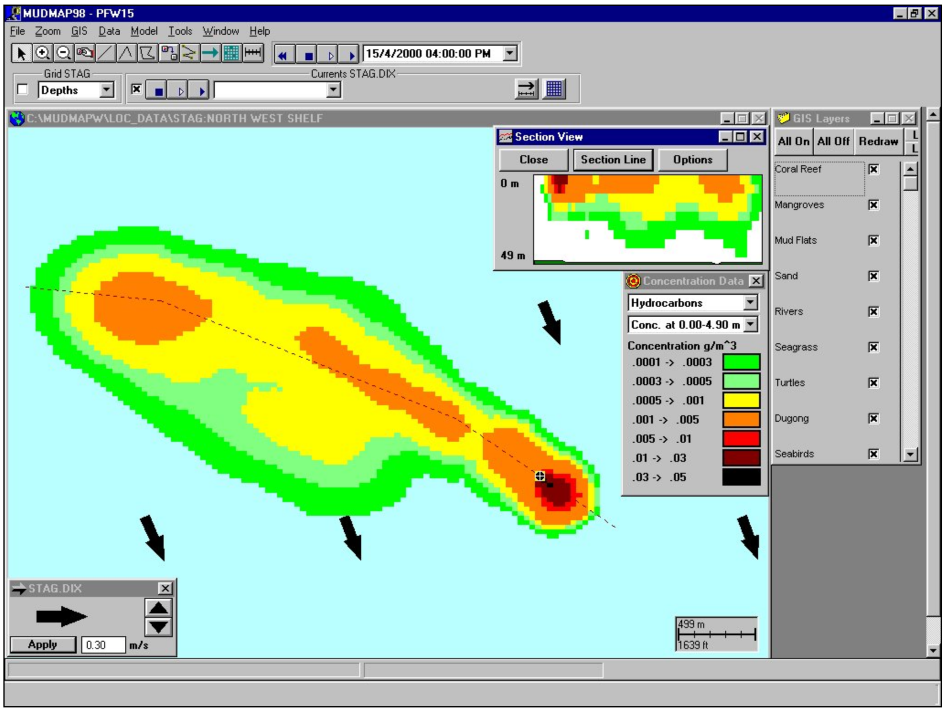

Figure A3. Example MUDMAP water column concentration output for drilling fluid discharge.

MUDMAP uses a color graphics-based user interface and provides an embedded geographic information system, environmental data management tools, and procedures to input data and to animate model output. The system can be readily applied to any location in the world. Application of MUDMAP to predict the transport and deposition of heavy and light drill fluids off Pt. Conception, California and the near-field plume dynamics of a laboratory experiment for a multi-component mud discharged into a uniform flowing, stratified water column are presented in Spaulding et al. (1994).

King and McAllister (1997, 1998) present the application and extensive verification of the model for a produced water discharge on Australia's northwest shelf. GEMS (1998) applied the model to assess the dispersion and deposition of drilling cuttings released off the northwest coast of Australia.

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APPENDIX M : PLANKTON ENTRAINMENT MODELING REPORT

Plankton Entrainment Modeling Report

DOCUMENT NO. CSA-GOLDER-KOSMOS-FL-18-80098-3086-01-REP-03

VERSION	DATE	DESCRIPTION	PREPARED BY:	REVIEWED BY:	APPROVED BY:
03	02/06/18	Revised	D. Snyder	B. Balcom	B. Balcom
04	03/28/18	Revised	D. Snyder B. Douglas	B. Balcom	B. Balcom
05	05/18/18	Revised	D. Snyder	B. Balcom	D. Snyder B. Balcom

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1.0 Introduction

The proposed Ahmeyim/Guembeul (A/G) LNG project, as detailed in **ESIA Section 2**, seeks to transport natural gas extracted from wells located approximately 125 km offshore via pipeline to a floating, production, storage and offloading (FPSO) vessel for processing. Processed gas will be transported by pipeline to a Nearshore Hub/Terminal facility located offshore along the Mauritania-Senegal maritime border. At the Nearshore Hub/Terminal, the natural gas will be liquefied by a specialized liquefied natural gas processing vessel (FLNG) for storage and periodic transfer to LNG carriers destined for transport to foreign markets. The liquefaction of gas will require a considerable volume of seawater to be withdrawn from the area surrounding the Nearshore Hub/Terminal facility. This report provides a preliminary assessment of the potential environmental impact of seawater extraction on planktonic organisms contained within that volume of water that are unable to escape or avoid being entrained.

The proposed project is expected to liquefy about 16,000 m^3 of gas per day (Golar LNG, 2017). The overall process will require up to 54,000 m^3 of seawater per hour including 38,000 m^3 for liquefaction; 12,500 m^3 to cool condensers; and about 3,000 m^3 to cool engine rooms. Thus, the total daily volume of seawater intake is 1.296 million m^3. This water will be drawn in through sea chests (large tanks) within the hull of the FLNG.

Such large volumes of water will contain an abundance of plankton that may be entrained (drawn into) the system with the water. Assuming that all of the entrained planktonic organisms die, there is concern regarding the long-term, population level effects of removing large numbers of plankton (including egg and larval stages of fishes and invertebrates) from multiple fish and invertebrate species residing in local waters.

Zooplankton may be broadly divided into holoplankters and meroplankters. Holoplankters are organisms that spend their entire lives in the pelagic realm, whereas meroplankters are the early life stages of invertebrates that only spend a short portion of their lives in the plankton. Impact analyses of water intakes generally focus on fish eggs and larvae (ichthyoplankton) but also consider effects on larvae of invertebrates such as crabs, shrimps, and mollusks. Several of these taxa are economically important to artisanal or industrial fisheries.

2.0 Objectives

A common approach used to assess impacts of entrainment is to estimate densities of planktonic organisms (fish eggs and larvae) from samples collected near or within the intake stream to ascertain entrainment losses. These site-specific entrainment values are compared with overall and species-specific abundance estimated for a larger parcel of water potentially subject to entrainment. This parcel is known as the source water. From the ratio of entrainment losses to source, population impacts can be translated into a proportional mortality (or survival) of the local populations. This approach, generally referred to as the empirical transport model (ETM), was originally developed to assess impacts of water intakes by riverine power plants on early life stages of fishes (Boreman et al., 1978, 1981). This original formulation requires extensive data on life history and size classes of focal species not usually available for coastal marine assemblages.

Recognizing this, MacCall et al. (1983) developed a simplified version of the ETM that has been used extensively (e.g., off California) to assess entrainment impacts on larval fishes and invertebrates by coastal power plants and desalination operations (e.g., Raimondi, 2016; Steinbeck et al., 2007). However, even the simplified approach involves sampling water intakes in existing facilities. The ETM has also been used by applicants and approved by regulators to evaluate proposed facilities such as LNG operations that require large volumes of seawater (e.g., Entrix, Inc., 2007). For the A/G LNG project, proposed facility location and intake volume estimates have been developed, and plankton samples have been collected in the project area.

The tasks (objectives) of this exercise are as follows:

- Task 1: Identify the source water body and calculate its total volume;
- Task 2: Gather data on species-specific densities of fish larvae and total densities of fish eggs and major zooplanktonic groups from the project area; and

- Task 3: Use data as input into the model to estimate species-specific proportional entrainment and proportional mortalities.

3.0 Methods

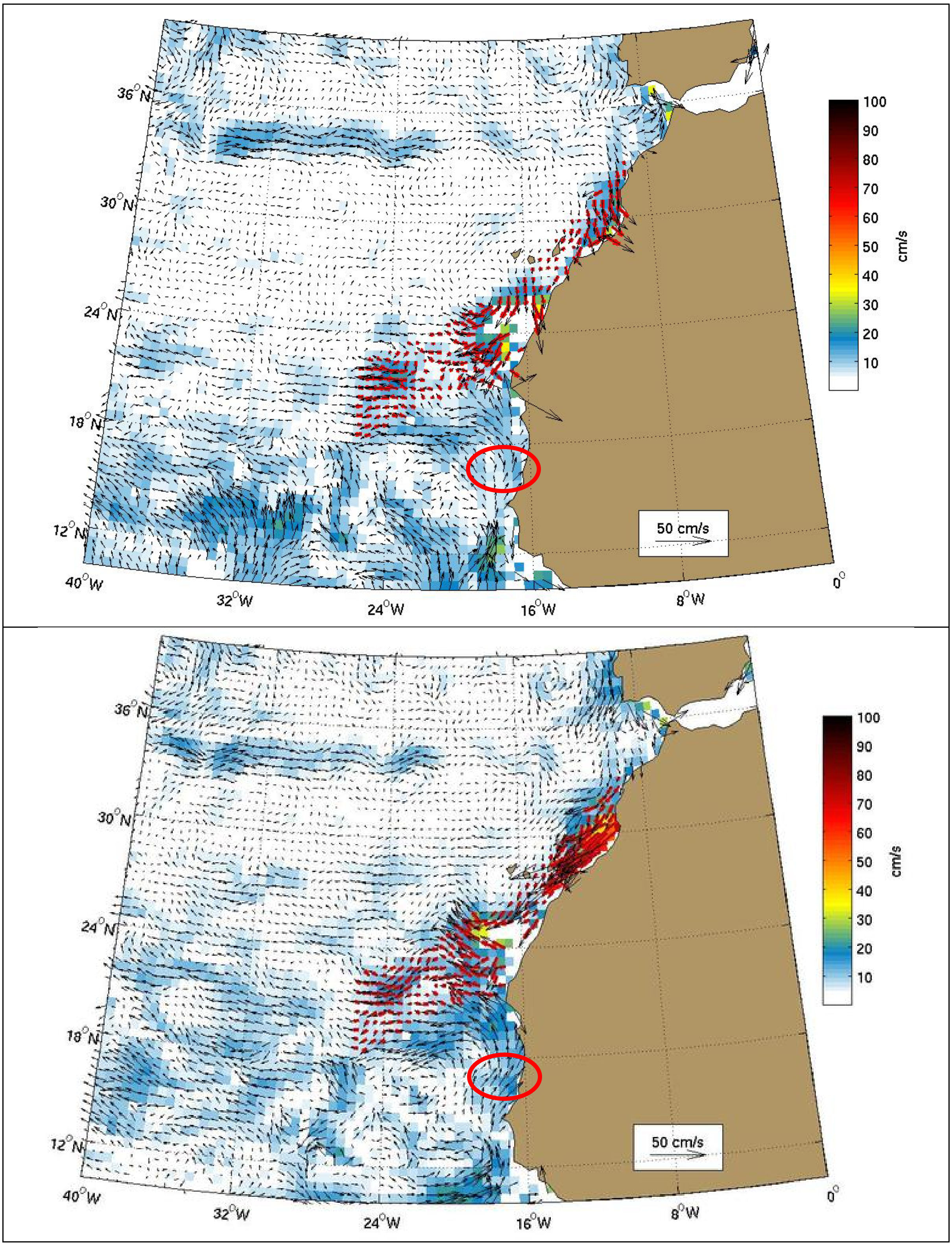
3.1 Task 1 – Source Water Calculations

The source water body was calculated as a cylinder of water centered at the proposed intake (i.e., FLNG berthed at the Nearshore Hub/Terminal). The radius of the cylinder was provided by ambient current flow that could transport a parcel of water from the outer edge of the cylinder to the intake in 1 day (24 h). The volume of this cylinder was defined as all the water on the shelf within the cylinder from surface to seafloor. As there was no direct, site-specific measurement of currents for the proposed project area at the time of the study, the available scientific literature was searched to obtain an estimate of current velocity for the region.

The project area is embedded within the Canary Current Upwelling system (Auger et al., 2016; Menna et al., 2016) which extends from Cape Blanc, Mauritania to Cape Vert, Senegal. Oceanographers have partitioned the region into discrete north-south sub-units when describing circulation, sea surface temperature, and upwelling during a typical year (e.g., Auger et al., 2016; Arkhipov, 2009; John and Zelck, 1997; Hamann et al., 1981). The sub-unit encompassing the project area is bounded on the north and south by 18 N° Latitude and 15 N° Latitude, respectively. The western boundary is located, approximately, along the 2,000 m isobath; the eastern boundary is the southern Mauritania and northern Senegal shoreline. This sub-unit has been called the Mauritanian Bight or Senegalo-Mauritania section (Auger et al., 2016).

Circulation patterns within the Senegalo-Mauritania area vary between winter (December to May) and summer (June to October); circulation is largely wind driven and not directly influenced by upwelling that occurs offshore and to the north (Menna et al., 2016). In winter, water temperatures drop below 24℃, with predominant current flows to the south or southwest (but see below). In summer, water temperatures increase to >24°C, and currents tend to flow northward along the coast. The current speeds are not well known but have been estimated to range from 10 to 40 cm sec^{-1} based on a prediction of average surface currents for the region available from the Global Drifter Program (GDP; University of Miami, 2017).

Methods used for the extrapolation of drifter data to larger regions is described in detail by Lumpkin and Johnson (2013) and Laurindo et al. (2017). For the periods coinciding with the plankton sampling periods (Winter 2016 and Summer 2017), the GDP showed that currents in the project area were northerly during both Winter and Summer at about 20 cm sec^{-1} (**Figure 1**).



(Source: University of Miami, 2017)

Figure 1. Canary Current regional surface current velocities estimated from the Global Drifter Program. The project area is located offshore along 16° N Latitude, denoted by a red oval. Upper panel = winter; lower panel = summer.

Assuming the current could vary its direction, a passively transported plankter (i.e., an individual plankton specimen) could come from as far as away as 17.3 km south, west, or north of the intake on any given day. To the east, the distance from the proposed intake would be interrupted by the shoreline.

The source water parcel was delineated with those dimensions and the shoreline (**Figure 2**). The area was rasterized in ArcGiS as a layer representing the sea surface. Next, bathymetry data were input from the Marine Geoscience Data System (Marine Geoscience Data System, 2017; Ryan et al., 2009) and a second raster layer under the polygon was formed, representing the seabed. Volume was derived by comparing the two raster surfaces and calculating the volume between them. The calculated volume of this semi-circular area depicted in **Figure 2** was 33.632×10^9 m^3.

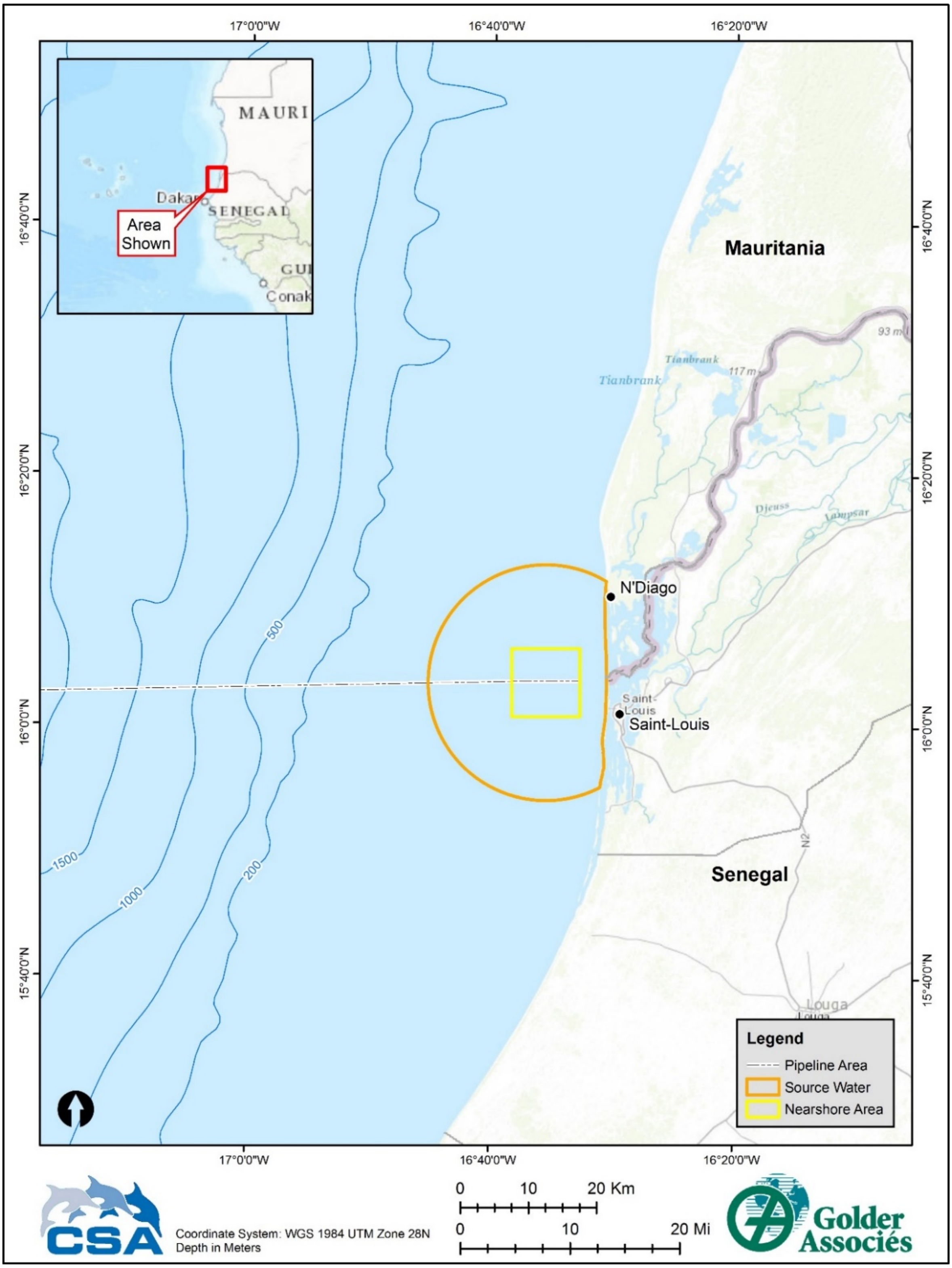


Figure 2. **Source water area identified for the proposed nearshore LNG facility.**

3.2 Task 2 – Plankton Sampling

Samples were collected from stations randomly located within a rectangular area (~12 km^2) within the proposed Nearshore Hub/Terminal area. Plankton samples were collected using a 1-m ring net with

500-micrometer (µm) mesh. A flow meter was fixed inside the mouth of the net to quantify the volume of water filtered during the tows. A double trip system was used to collect discrete samples in the upper (0 to 10 m) and lower (10 to 20 m) portions of the water column at each station. To collect depth-discrete samples, the net was folded up on deck to prevent it from opening, then lowered at a constant payout speed (~10 m/min) from the surface to near bottom (~20 m). At depth (~20 m), a messenger weight was released down the tow wire to open the net. After towing for 5 minutes a second messenger was released to close the net. To collect a surface sample, the same procedure was followed except the net was lowered to the 10 m depth before tripping the open net. This sampling approach resulted in the collection of two samples per station, one from the lower water column (10-20 m depth stratum), and one from the upper water column (0-10 m depth stratum). Samples were collected from each station during both day and night to capture any diurnal vertical migration which is often exhibited by plankters (e.g., Hanel et al., 2010). Samples were collected during two surveys, the first during Winter (November and December) 2016 and the second in Summer (July and August) 2017. Although the entrainment analyses focus on the Nearshore Hub/Terminal Area, samples were also collected at an Offshore Area, and a Mid-Depth Area (Summer only). These additional areas are potential locations of other project facilities that may use ambient cooling water but in quantities much lower than those described above for the Nearshore Hub/Terminal. Information on the Offshore and Mid-Depth samples may be found in **Appendix G.** All samples were fixed in 5% formalin in the field, labelled, and transported to the plankton taxonomist for identification and enumeration.

In the laboratory, fish eggs and larvae were sorted and identified to the lowest practical taxonomic level. The smallest and largest larval fish taxa in each sample were measured as total lengths (mm). Zooplankton were sorted into major groups and counted. Zooplankton numbers were very high necessitating splitting the samples into smaller aliquots for counting. Data were adjusted to include splits and converted to numbers per m^3.

Bias in plankton sampling results from organisms avoiding the net, patchiness of plankton distribution, and extrusion of organisms through the mesh. Studies have shown that extrusion can occur but severity depends on several factors such as towing speed and duration (Johnson and Morse, 1994). Mesh sizes of 500 µm are used when focusing on larval fishes as fewer smaller organisms are collected making sample sorting easier and more efficient. Additionally, the coarser mesh reduces the chance of the net becoming clogged. Conventional plankton samples are often taken using 333 µm mesh nets because the finer mesh retains smaller zooplankters. It is acknowledged that some individual larval fishes and many small zooplankters could be extruded (forced through the mesh during a tow) through 500 µm mesh; however, the relatively slow speeds (< 1 knot) and short durations (5 minutes) of the tows reduced the likelihood of extensive extrusion biasing the samples.

3.3 Task 3 – Estimate Species-Specific Proportional Entrainment and Proportional Mortality

Densities of entrained taxa were estimated for ichthyoplankton and invertebrate zooplankters using data described under Task 2. These estimates are considered to be preliminary and only relevant for the time and place of the field survey.

Mean density of larval fishes (expressed as numbers of individuals per 100 cubic meters [100 m^{-3}]) collected during the field survey were multiplied by the projected daily intake requirements for the facility (1,296,000 m^3 day^{-1}) to determine the number of organisms entrained per day for each taxon. This may be expressed as the following equation:

$$N_{\text{entrained}} = \text{Intake volume } (m^3\ day^{-1}) \times \text{number of individuals } 100\ m^{-3}$$

Entrainment rates were calculated separately for upper (0-10 m) and lower (10-20 m) water column to examine the potential differences between the two depth strata assuming the same intake volume.

Proportional entrainment (PE) is the probability of entrainment for an individual in one day.

This is calculated as:

$$PE = N_{entrained.} / N_{source}$$

Where

$N_{entrained}$ = estimated number of larvae entrained during one day, calculated as estimated density in the water entrained that day multiplied by cooling water intake volume, and
N_{source} = estimated number of larvae in the source water that day.

If the densities of eggs and larvae at the intake site are similar to those in the source water, the densities will cancel leaving only the volumetric ratio as a factor. Here the densities were one in the same, so PE was reduced to the volumetric ratio as follows:

$$PE = 1{,}296{,}000\ m^3 / 33{,}632{,}241{,}641\ m^3 = 0.0000385 \text{ or } 0.004\%$$

Proportional mortality (PM) described by MacCall et al. (1983) is an estimate of the probability of entrainment over the period of risk. This value is also referred to as conditional or fractional mortality. The estimation of PM requires an estimate of PE as an input. PM is calculated as follows:

$$PM = 1-(1-PE)^d$$

Where d is the period of risk in days.

The period of risk is based on species-specific planktonic larval duration obtained from scientific literature on daily growth of larvae.

Limited information are available on the planktonic larval duration of the taxa collected so three taxa of small pelagic species were assessed for PM using larval durations estimated from the literature as input into the PM equation. These three taxa, jack mackerel (*Trachurus* sp.), round sardine (*Sardinella aurita*), and European anchovy (*Engraulis encrasicolus*) are small pelagic species targeted by regional artisanal fisheries in the area.

4.0 Results

4.1 Ichthyoplankton Composition and Densities

Samples collected from the Nearshore Hub/Terminal Area in Winter yielded 110 individuals from 33 fish taxa in 21 families and nine orders (**Table 1**). The most species-rich orders were the perch-like fishes (Perciformes) and the flatfishes (Pleuronectiformes) represented by eleven and nine taxa, respectively. Individual taxa contributing most to the total larval density at the nearshore location included croakers and drums (Sciaenidae) (29.1 %), sardines (*Sardinella* spp.) (7.5%), horse mackerels (*Trachurus* spp.) (7.2%), sea basses (Serranidae) (4.6%), and codlets (*Bregmaceros* sp.) (4.6%).

Samples taken in summer months produced 46 larval fish taxa from 22 families and 9 orders (**Table 1**). The most species-rich orders were the perch-like fishes (Perciformes) and the flatfishes (Pleuronectiformes) represented by 28 and 13 taxa, respectively. Individual taxa contributing most to the total larval density were Atlantic bumper (*Chloroscombrus chrysurus*) contributing 37.7%, grunts (Haemulidae; 11.7%), jacks/leerfish (*Caranx*/*Lichia amia*; 11.3%), (Sciaenidae; 10.6 %), horse mackerels (*Trachurus* spp.; 8.4%), and tonguefishes (*Symphurus* sp.; 4.1%).

Table 1. **Phylogenetic listing of fish larvae collected in plankton samples during Winter 2016 (n=12) and Summer 2017 (n=10) at the Nearshore Hub/Terminal Area.**

Order	Family	Taxon	Winter (Mean n 100 m^{-3})	Summer (Mean n 100 m^{-3})
Elopiformes	Elopidae (Tenpounders)	*Elops*	1.1	-
Anguilliformes		Anguilliformes	-	1.1
	Muraenidae (Moray Eels)	Muraenidae	0.8	7.3
	Ophichthidae (Snake Eels)	Ophichthidae	-	20.0
	Nettastomatidae (Sawtooth Eels)	Nettastomatidae	-	4.8
Clupeiformes		Clupeiformes	4.4	6.4
	Clupeidae (Sardines)	Clupeidae	2.6	9.9
		Sardinella	5.7	-
		Sardinella aurita	3.0	56.6
		Sardinella sp.	-	34.6
	Engraulidae (Anchovies)	Engraulidae	-	6.9
		Engraulis encrasicolus	1.6	-
Myctophiformes	Myctophidae (Lanternfishes)	*Diaphus*	0.9	-
Aulopiformes	Paralepididae (Barracudinas)	Paralepididae	-	1.3
	Synodontidae (Lizardfishes)	*Saurida*	0.7	-
Lampridiformes	Lophotidae (Crestfishes)	Lophotidae	0.8	-
Gadiformes	Bregmacerotidae (Codlets)	*Bregmaceros* sp.	4.0	-
Mugiliformes	Mugilidae (Mullets)	*Mugil* sp.	-	1.8
		Mugilidae	-	1.5
Beryciformes		Beryciformes	-	1.2
	Holocentridae (Squirrelfishes)	Holocentridae	-	1.7
Scorpaeniformes	Scorpaenidae (Scorpionfishes)	Scorpaenidae	-	0.7
Perciformes		Perciformes	3.3	6.9
	Acanthuridae (Surgeonfishes)	*Acanthurus* sp.	-	1.7
	Carangidae (Jacks)	Carangidae	-	0.6
		Caranx sp.	-	10.6
		Caranx/Lichia amia	-	70.8
		Chloroscombrus chrysurus	-	236.5

Table 1. (Continued).

Order	Family	Taxon	Winter (Mean n 100 m^{-3})	Summer (Mean n 100 m^{-3})
		Decapterus sp.	-	3.8
		Naucrates sp.	-	0.9
		Seriola sp.	-	0.7
		Trachurus	6.4	-
		Trachurus sp.	-	67.4
	Ephippidae (Spadefishes)	Ephippidae	0.7	1.8
Perciformes (Cont'd)	Gerreidae (Mojarras)	Gerreidae	-	0.7
	Gobiidae (Gobies)	Gobiidae	2.8	8.2
	Haemulidae (Grunts)	Haemulidae	2.4	94.6
	Labridae (Wrasses)	Labridae	2.2	-
	Sciaenidae (Drums and Croakers)	*Leiostomus xanthurus*	4.0	12.6
		Sciaenidae	24.6	66.7
		Stellifer sp.	-	14.5
		Umbrina	0.9	-
	Serranidae (Sea Basses)	Serranidae	4.1	11.7
	Sparidae (Porgies)	Sparidae	0.6	0.9
	Sphyraenidae (Barracudas)	*Sphyraena* sp.	-	10.4
		Sphyraena sphyraena	-	2.8
		Sphyraenidae	-	5.1
	Trachinidae (Weaverfishes)	Trachinidae	1.1	-
	Trichiuridae (Cutlassfishes)	*Trichiurus* sp.	-	18.4
Pleuronectiformes		Pleuronectiformes	0.9	2.7
	Bothidae (Lefteye Flounders)	*Monolene*	0.6	-
		Symphurus sp.	-	5.0
	Cynoglossidae (Tonguefishes)	Cynoglossidae	1.5	-
		Cynoglossus monodi	0.8	-
		Symphurus	1.9	-
		Symphurus sp.	-	28.0
	Paralichthyidae (Sand Flounders)	*Citharichthys*	0.8	-
		Paralichthyidae	2.1	-

Table 1. (Continued).

Order	Family	Taxon	Winter (Mean n 100 m^{-3})	Summer (Mean n 100 m^{-3})
		Syacium papillosum	1.2	-
		Syacium sp.	-	0.9
	Pleuronectidae (Righteye Flounders)	Pleuronectidae	2.0	-
Tetraodontiformes	Tetraodontidae (Smooth Puffers)	*Sphoeroides* sp.	-	2.3
	Total Taxa		32	43

During winter months, numbers of larvae per 100 m^3 of water ranged from 1.7 to 113.5 and averaged 35.7. The highest numbers of larvae were collected at night from both 0 to 10 and 10 to 20 m depth strata (**Table 2**). Mean numbers of larvae per 100 m^3 were higher in the 0-10 m stratum during both day and night sample periods. However, day/night and depth stratum, or their interaction, were not significantly different based on a two-way analysis of variance (**Table 3**). The number of fish eggs in the samples from the nearshore area ranged from 0 to 100.0 eggs 100 m^{-3} and averaged 22.3 eggs 100 m^{-3} (**Table 2**). Egg densities were significantly higher in the 0 to 10 m depth stratum (**Table 3**).

During summer months, numbers of larvae in the samples ranged from 2.4 to 957.6 individuals 100 m^{-3} and averaged 564.5 individuals 100 m^{-3}. A breakdown of sample means for day/night and depth stratum are given in **Table 2**. Mean numbers of larvae per 100 m^{-3} did not differ significantly between depth strata and day/night or their interaction were not significantly different (two-way analysis of variance, **Table 3**). The number of fish eggs in the samples collected in summer ranged from 2.2 to 7715 eggs 100 m^{-3} and averaged 394 eggs 100 m^{-3}. Egg densities did not differ significantly between depth strata or time period (**Table 3**).

Table 2. Means and standard deviations (SD) for total fish larvae and egg densities (n 100 m-3) collected at the Nearshore Hub/Terminal Area during Winter 2016 and Summer 2017 surveys. Samples (n=3) were collected in each combination of day/night and upper and lower strata in the water column.

Survey	Time	Depth	Larvae		Eggs	
			Mean	SD	Mean	SD
Winter	Day	Lower	20.7	17.2	2.6	3.3
		Upper	28.4	19.0	68.1	49.5
	Night	Lower	37.9	19.9	2.2	3.1
		Upper	54.7	52.7	16.1	15.5
Summer	Day	Lower	667.9	601.3	331.6	310.9
		Upper	471.7	245.2	841.2	1,022.1
	Night	Lower	466.5	656.3	165.4	223.6
		Upper	646.8	439.6	505.5	160.6

Table 3. Results of two-way analysis of variance for the effects of time (day/night) and depth (water column strata) on density of fish larvae and eggs collected at the Nearshore Hub/Terminal Area in Winter (2016) and Summer (2017). Df=degrees of freedom, MS=Mean Square, F=Fisher's ratio (MS/Residual). Significant results (p<0.05) are in bold.

Survey	Source	Df	Larvae			Eggs		
			MS	F	p-value	MS	F	p-value
Winter	Time	1	1,489.5	1.6	0.25	2,061.9	3	0.12
	Depth	1	412.3	0.4	0.53	4,732.2	**6.9**	**0.03**
	Time × Depth	1	47.24	0.05	0.83	1,999.5	2.9	0.12
	Residuals	8	948.99			677.5		
Summer	Time	1	414	0.002	0.969	15	0.381	0.56
	Depth	1	5,204	0.021	0.889	48.8	1.239	0.308
	Time × Depth	1	85,022	0.348	0.577	1.7	0.044	0.841
	Residuals	6	244,572			39.4		

The taxonomic composition and abundance of larval fishes taken from the Nearshore Area in Winter were dominated numerically by the larvae of soft bottom species which collectively contributed about 50% of the numbers of larvae in the samples. Soft bottom species were represented by Sciaenidae (drums, croakers, and seatrouts), Paralichthyidae (sand flounders), Sparidae (porgies), and Aulopiformes (lizardfishes). The coastal pelagic species (sardines, anchovies, jack mackerels) contributed an additional 16% to the larvae collected.

The range of total lengths recorded for taxa collected (except eels) during Winter 2016 are presented by depth stratum in **Figure 3**. Larger individuals of the sciaenids and gobiids were collected in the lower water column.

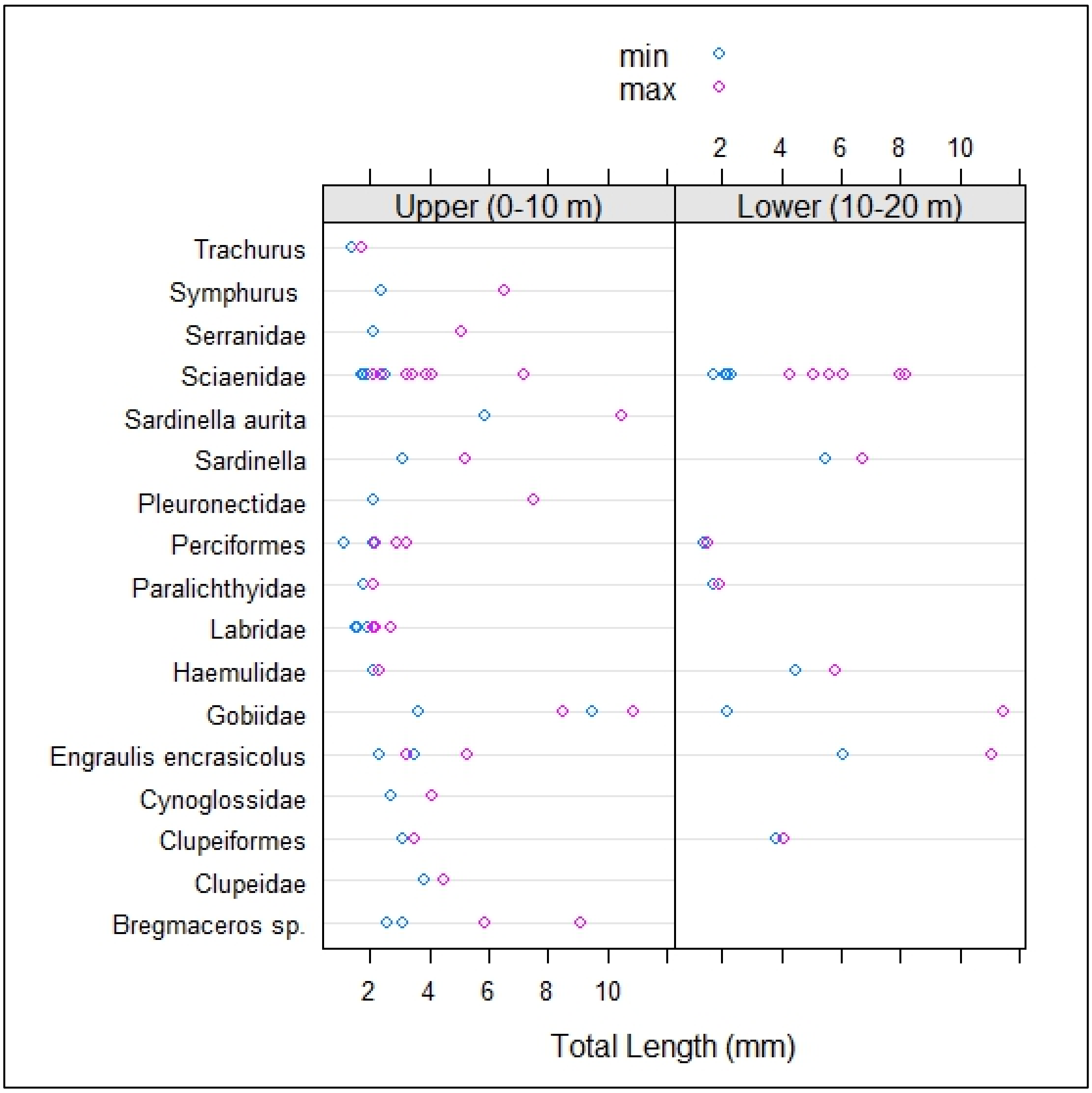


Figure 3. **Total length measurements for fish larvae (exclusive of eels) collected from the Nearshore Area during Winter 2016, by depth stratum.**

The taxonomic composition and abundance of larval fishes taken from the Nearshore Area in Summer were dominated by Atlantic bumper (*Chloroscombrus chrysurus*), grunts (Haemulidae), jacks/Leerfish (*Caranx*/*Lichia amia*), Sciaenidae, horse mackerels (*Trachurus* spp.), and tonguefishes (*Symphurus* sp.). The range of lengths recorded for abundant taxa in summer samples are presented in **Figure 4**.

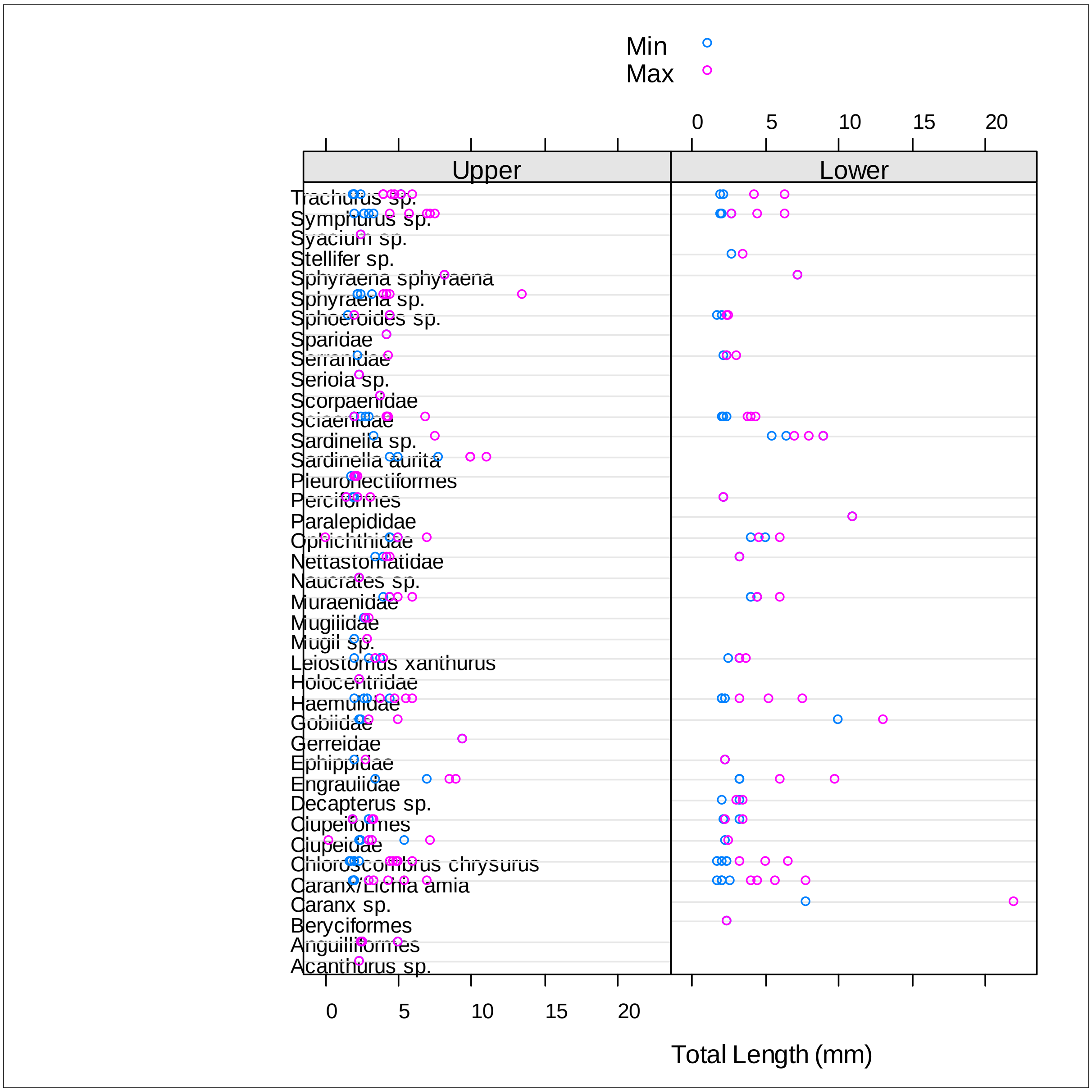


Figure 4. Total length measurements for fish larvae collected from the Nearshore Area during Summer 2017, by depth stratum.

4.2 Zooplankton Composition and Densities

The winter samples produced 24 zooplankton groups from several phyla including arthropods, mollusks, cnidarians, and chaetognaths (**Table 4**). Groups accounting for the highest densities were copepods. Individual groups contributing most to the total density at the nearshore location were copepods (64.0%), *Lucifer* (12.7%), chaetognaths (8.3%), shrimps (2.5%), and ostracods (2.3%).

The summer samples collected in the area of the Nearshore Hub/Terminal produced 19 major planktonic groups (**Table 4**). The greatest contributors to overall abundance were *Lucifer* sp. (57.2%), copepods (16.9%), caridean shrimps (7.6%), doliolids (4.5%), cladocerans (3.2%), chaetognaths (3.0%), and crab larvae (2.9%).

Table 4. **Mean densities (individuals m^{-3}) of major zooplankton groups in samples collected at the Nearshore Hub/Terminal during Winter 2016 and Summer 2017 surveys, listed in alphabetical order.**

Group	Nearshore Hub/Terminal	
	Winter	Summer
Amphipods	8.6	7.1
Annelids	1.7	-
Anomurids	-	34.1
Bivalves	1.1	-
Caridean shrimps	-	79.4
Chaetognaths	31.7	39.1
Cladocerans	30.8	33.0
Cnidarians	-	-
Copepod eggs	-	-
Copepods	276.1	177.5
Crab larvae	25.3	34.3
Crustaceans (unidentified)	-	-
Ctenophores	3.1	-
Dolioloids	-	67.3
Echinoderms	1.6	-
Formaminiferans	-	-
Gastropods	4.1	2.2
Heteropods	-	-
Hydrozoans	1.4	28.0
Isopods	3.1	-
Larvaceans	1.0	6.3
Lobster larvae	-	13.5
Lucifer spp.	116.8	599.9
Macrurans	-	8.5
Malacostraca	-	6.1
Mysids	17.4	15.2
Octopus larvae	-	-
Ostracods	37.3	-
Penaeid shrimps	-	5.4
Polychaetes	1.5	2.2
Pteropods	5.8	-
Radiolarians	1.3	-
Scyphozans	3.9	-
Shrimps	15.2	-
Siphonophores	7.6	24.7
Squid larvae	0.4	-
Squillids	-	-
Tunicates	3.3	-
Total Groups	**24**	**19**

Zooplankton densities in Winter and Summer accounted for over 99% of all organisms collected in the plankton samples with fish eggs and larvae contributing <0.1%. In Winter, total zooplankton densities ranged from 179.6 to 1,345.3 individuals m^{-3}, averaging 522.5 individuals m^{-3}. In Summer, total zooplankton densities ranged from 51.9 to 2,363.1 individuals m^{-3}, and averaged 1,047.0 individuals m^{-3}. Both seasonal zooplankton determinations are orders of magnitude higher than the typical fish densities observed. Summary statistics for total zooplankton densities in the Nearshore Hub/Terminal Area during Winter and Summer are provided in **Table 5**.

Table 5. **Means and standard deviations (SD) for total zooplankton densities (individuals m^{-3}) collected at the Nearshore Hub/Terminal, Mid-Depth, and Offshore Areas during Winter 2016 and Summer 2017 surveys.**

Time	Stratum (m)	Winter Mean	SD	Summer Mean	SD
Nearshore					
Day	0-10	444.13	136.40	1,435.92	735.37
	10-20	395.36	167.63	1,085.24	1,165.43
Night	0-10	598.65	124.52	772.56	912.81
	10-20	652.01	613.44	680.84	889.44

Two-way analysis of variance did not reveal any significant differences in zooplankton density with day/night or depth stratum during either Winter or Summer (**Table 6**).

Table 6. **Results of two-way analysis of variance for density of zooplankton (individuals m^{-3}) collected at the Nearshore Hub/Terminal during the Summer 2017 survey. Df=Degrees of Freedom, MS=Mean Square, F=F (Fisher's) ratio (MS/Residual). Significant results are in bold.**

Source	Df	Winter			Summer		
		MS	F	p-value	MS	F	p-value
Nearshore							
Time	1	16	0.001	0.991	684,059	0.757	0.418
Depth	1	12,697	1.156	0.314	152,644	0.169	0.695
Time × Depth	1	7,821	0.071	0.796	40,238	0.045	0.84
Residual	8	109,629			903,722		

4.3 Entrainment Rates

4.3.1 Ichthyoplankton

Daily entrainment rates calculated for the ten most abundant ichthyoplankton taxa from the upper water column (0-10 m) in Winter are shown in **Table 7**. The highest daily rates are for the sciaenid taxon (drums and croakers) with an estimated 267,952 individuals. Following the sciaenids were sardine larvae (*Sardinella* sp.) with a daily average entrainment of nearly 44,962 individuals. The related round sardine (*S. aurita*) exhibited a daily entrainment rate of nearly 16,935 individuals. Overall daily entrainment for all taxa collected has been estimated at 538,540 individuals. Daily entrainment rate for fish eggs in the upper water column averaged of approximately 340,416 individuals (**Table 7**).

Entrainment rates for the top ten most abundant taxa from the upper water column of the Summer samples are also presented in **Table 7**. The larval fish numbers collected in summer samples were considerably higher than in the Winter samples. The top ten ranked taxa ranged from 2.7 to 0.1 × 10^6 individuals per day (**Table 7**). The most abundant taxa were Atlantic bumper, unidentified grunts, unidentified jacks/leerfish, and drums and croakers. The estimate for drums and croakers entrainment in Summer (301,662) was relatively similar to that for Winter (267,952). However, estimates for sardines, collectively represented by *Sardinella* sp. and *Sardinella aurita*, were considerably higher than winter estimates for the same taxa (**Table 7**). These estimates all exceeded the highest values reported for the Winter samples by as much as tenfold. Estimates reflect the relative increase in regional spawning activity during the Summer months. The estimated total larvae entrained in one day for the upper water column in Summer was 7,020,753 individuals. Total fish eggs entrained per day was 3,122,903 (**Table 7**).

Table 7. Estimated ichthyoplankton entrainment for the 10 most abundant taxa collected in the upper 0 to 10 m of the water column from the Nearshore Hub/Terminal Area during Winter 2016 and Summer 2017 surveys. R=Rank order of abundance.

Taxon	Winter				Summer			
	Mean (n 100 m^{-3})	%	R	Entrainment (n day^{-1})	Mean (n 100 m^{-3})	%	R	Entrainment (n day^{-1})
Chloroscombrus chrysurus	-	-	-	-	209.2	38.6	**1**	2,710,790
Haemulidae	0.3	0.7	-	-	80.8	14.9	**2**	1,047,358
Caranx/Lichia amia	-	-	-	-	59.8	11.0	**3**	774,602
Sciaenidae	20.7	49.8	**1**	267,952	23.3	4.3	**6**	301,662
Sardinella aurita	1.3	3.1	**7**	16,935	34.0	6.3	**4**	440,010
Trachurus sp.	-	-	-	-	30.7	5.7	**5**	397,734
Sardinella sp.	-	-	-	-	14.8	2.7	**7**	191,677
Symphurus sp.	-	-	-	-	12.3	2.3	**8**	159,989
Ophichthidae	-	-	-	-	10.9	2.0	**9**	141,787
Perciformes	2.0	4.8	**3**	25,674	7.5	1.4	-	-
Sphyraena sp.	-	-	-	-	8.4	1.5	**10**	108,260
Leiostomus xanthurus	1.3	3.1	**8**	16,804	6.8	1.3	-	-
Serranidae	0.7	1.7	-	-	6.1	1.1	-	-
Clupeidae	1.0	2.3	-	-	5.5	1.0	-	-
Muraenidae	0.1	0.3	-	-	5.1	0.9	-	-
Sardinella	3.5	8.3	**2**	44,962	0.0	0.0	-	-
Gobiidae	1.5	3.5	**5**	19,047	2.4	0.4	-	-
Clupeiformes	0.7	1.7	-	-	3.3	0.6	-	-
Labridae	1.7	4.1	**4**	22,011	0.0	0.0	-	-
Pleuronectiformes	0.3	0.6	-	-	1.6	0.3	-	-
Bregmaceros sp.	1.3	3.2	**6**	17,430	0.0	0.0	-	-
Engraulis encrasicolus	1.2	2.9	**9**	15,810	0.0	0.0	-	-
Trachurus	1.1	2.6	**10**	13,824	0.0	0.0	-	-
Total Larvae	41.6			538,539	541.7			7,020,753
Total Eggs	26.3			340,416	241.0			3,122,903

In the lower water column (10-20 m), samples from Winter entrainment of larval fishes were dominated by sciaenids with an estimated daily average of over 263,047 individuals (**Table 8**). The next most abundant taxa were gobiids (gobies) at over 22,000 individuals per day and an unidentified sciaenid (Sciaenidae species 1) with over 18,000 individuals per day. Total daily entrainment was 379,465 larvae. Total fish eggs entrained were 23,220.

Lower water column samples from Summer were numerically dominated by Atlantic bumper followed by drums and croakers (**Table 8**). Entrainment for these two taxa were 2.6 and 1.3 × 10^6 individuals per day, respectively. These values exceeded the Atlantic bumper and drums and croakers estimates for the upper water column during the same survey. Again, total numbers of eggs and larvae collected greatly exceeded the numbers documented for the same area during Winter. The total larvae entrained per day for the lower water column in Summer was 7,612,072. The estimate of daily fish egg entrainment was 7,112,143.

Table 8. Estimated ichthyoplankton entrainment for the 10 most abundant taxa collected in the lower 10 to 20 m of the water column from the Nearshore Hub/Terminal Area during Winter 2016 and Summer 2017 surveys. R=Rank order of abundance.

Taxon	Winter				Summer			
	Mean (n 100 m^{-3})	%	R	Entrainment (n day^{-1})	Mean (n 100 m^{-3})	%	R	Entrainment (n day^{-1})
Chloroscombrus chrysurus	-	-	-	-	216.6	36.9	**1**	2,807,382
Sciaenidae	20.3	69.3	**1**	263,047	96.8	16.5	**2**	1,255,060
Caranx/Lichia amia	-	-	-	-	67.7	11.5	**3**	877,480
Trachurus sp.	-	-	-	-	63.6	10.8	**4**	824,708
Haemulidae	0.5	1.6	**8**	6,142	51.6	8.8	**5**	668,460
Symphurus sp.	-	-	-	-	33.5	5.7	**6**	433,795
Sardinella sp.	-	-	-	-	12.9	2.2	**7**	166,721
Ophichthidae	-	-	-	-	9.0	1.5	**8**	116,857
Leiostomus xanthurus	1.4	4.7	**3**	18,022	5.8	1.0	**10**	75,103
Clupeidae	0.3	1.2		4,522	6.3	1.1	**9**	81,955
Gobiidae	1.7	6.0	**2**	22,616	2.5	0.4	-	-
Clupeiformes	0.7	2.5	**4**	9,529	3.2	0.5	-	-
Perciformes	0.7	2.5	**5**	9,529	0.8	0.1	-	-
Paralichthyidae	0.5	1.7	**6**	6,353	-	-	-	-
Labridae	0.5	1.7	**7**	6,278	-	-	-	-
Pleuronectidae	0.4	1.5	**9**	5,651	-	-	-	-
Engraulis encrasicolus	0.4	1.3	**10**	4,948	-	-	-	-
Total Larvae	29.3			379,465	587.4			7,612,072
Total Eggs	1.8			23,220	548.8			7,112,143

4.4 Proportional Mortality

MacCall et al. (1983) suggest that PM can be viewed as population level estimates of mortality. Organisms with shorter planktonic durations may be more at risk as they would be coming from more proximate spawning areas, whereas those with long larval durations could be coming from much greater distances and would be less at risk.

Three taxa of small pelagic species (i.e., jack mackerel, *Trachurus* sp.; round sardine, *Sardinella aurita*; European anchovy, *Engraulis encrasicolus*) were assessed for PM using larval durations estimated from the literature as input into the PM determinations (**Table 9**). Calculated PM estimates are very low for all three taxa; these preliminary results indicate that population level impacts from water intake by the proposed FLNG facility will be minimal. PM for shrimp, crab, and mollusk larvae were not estimated because of the lack of species-level information needed to determine planktonic larval duration.

Table 9. Proportional mortality (PM) estimates for larvae of selected fish taxa.

Taxon	Proportional Entrainment (PE)	Larval Duration (days)	Survival (1-PE)[a]	PM (1-(1-PE)[b]
Trachurus sp.	3.85×10^{-5}	30[1]	0.998844	0.001156
Sardinella aurita	3.85×10^{-5}	28[2]	0.998921	0.001079
Engraulis encrasicolus	3.85×10^{-5}	12[3]	0.999538	0.000462

1 - Van Beveren et al., 2016.
2 - Mbaye et al., 2015
3 - Dulcic, 1997.
a - Survival rate per day
b - Proportional mortality rate per day

5.0 Discussion

Site-specific plankton samples from Winter and Summer seasons revealed the range of ichthyoplankton and zooplankton presence and abundance found in this region. Dramatic differences in numbers of individuals collected in the two seasons illustrate the effect of multi-species spawning on the composition and abundance of plankton samples. The shelf area off the Mauritania-Senegal maritime boundary supports a diverse assemblage of demersal and pelagic species that spawn by broadcasting eggs into the water column. Others have documented similar variability among seasons and areas off northwest Africa (Arkhipov, 2015). Although seasonal differences in numbers were great, smaller scale day-night and 10-m depth strata did not differ significantly among one another.

The PE estimate of 0.004% presented is conservative and is typical of open coast areas with complex circulation and relatively uniform habitat (water column and level seafloor). PE estimates for enclosed water bodies with limited circulation are often much higher (e.g., 1 to 30%; Steinbeck et al., 2007). It is important to realize that these project-specific estimated entrainment losses represent a small fraction of the total eggs produced by regional adult spawning populations. For example, females of the west African sciaenid *Pseudotolithus elongatus* can release over 200,000 eggs during a single spawning event (Ekanem et al., 2004). Round sardines can spawn 26,000 to 316,000 eggs during a single event and most individuals spawn multiple times during a season (Tsikliras and Antonopoulou, 2006). In open waters sampling variability can also be very high. Larvae are known to be distributed in discrete clumps or patches over the seascape (McManus and Woodson, 2012). Individuals of some taxa may broadly aggregate whereas others are sparsely distributed. For example, the Atlantic bumper, the most abundant species collected during the Summer survey is known to form aggregations in other regions (Leffler, 1989). The samples used here should accurately reflect the level of variability expected for a single intake point in the geographic area.

In addition, although this analysis indicates a very small percentage of the plankton are at risk, most ichthyoplankton, as well as the phyto- and zooplankton that larval fishes feed upon, are distributed widely, well beyond the calculated source water population from which the cooling water is drawn. Arkhipov (2009), using data from ichthyoplankton samples collected over the shelf waters off Mauritania from 1997 to 2008, estimated standing stocks of eggs and larvae for several pelagic species between latitudes 16° and 21° N. Standing stock is an estimate of the total number of eggs or larvae (stocks) for a given area at a particular moment in time. The estimated standing stock of *Sardinella aurita* eggs averaged 111.1×10^{10} eggs and ranged from 546.1×10^{10} eggs in June-July of 1998 to zero in December-January of 2005-2006. Standing stock of *S. aurita* larvae during the same period averaged 968.7×10^{9} and ranged from 545.4×10^{10} in August 2001 to zero in June-July 1998. Standing stocks for other pelagic species including horse mackerels (*Trachurus* spp.) and flat sardine (*S. maderensis*) were of similar orders of magnitude.

Widely distributed plankton taxa are expected to originate from shelf and, to a lesser extent, oceanic waters. Because the Senegal River mouth is located along the southern portion of the eastern source water boundary, it is possible that ichthyoplankton and zooplankton could be transported from the river into the source water plankton assemblage. Although little is known about plankton inhabiting the Senegal River, Champalbert et al. (2007) documented the presence of shrimp, crab, and fish larvae. Certainly some fraction of these larvae could be advected into the source water plankton population depending on the season and current patterns, but the composition of the samples collected at the Nearshore Hub/Terminal Area do not indicate many taxa of estuarine origin.

Although invertebrate plankton (particularly shrimp, crab and mollusk larvae) would be similarly affected by the cooling water intake, these groups were not evaluated because individuals were not identified to a taxonomic level that would allow a meaningful assessment. Despite their high abundance, holoplanktonic groups such as copepods, chaetognaths, siphonophores, amphipods, and mysids are rarely assessed due to wide geographic distribution and high population turnover rates (Steinbeck et al., 2007). Estimates presented in the current analysis are considered representative of the time period when samples were collected. The numbers and kinds of larvae present will differ for different times of the year as spawning patterns and currents will seasonally change. Samples from a different time period will likely exhibit different taxonomic composition, densities, and mean current speeds, one or more of which would potentially change entrainment estimates and the PE ratio.

It is inherently difficult to reliably extrapolate the effects of entrainment losses to the population level because of numerous confounding factors including water temperature, salinity, and nutrient concentrations (Berraho et al., 2015; Hinde et al., 2017; Arkhipov, 2009); circulation patterns and upwelling (Auger et al., 2016; Olivar et al., 2016); prey availability (Hinde et al., 2017); and variability of adult spawning times and locations (Arkhipov, 2009).

6.0 Summary

Plankton samples were collected at two different depth strata during both day and night during Winter 2016 and Summer 2017. Based on the collection of plankton samples from three randomly selected stations located in the Nearshore Hub/Terminal Area, eggs and larvae densities were higher in the 0 to 10 m depth stratum, with higher values evident at night. Zooplankton densities accounted for over 99% of all organisms collected in the plankton samples with fish eggs and larvae contributing <0.1%. The range of taxa collected represents the assemblage expected for the water depth and latitude. Most taxa collected were coastal or shelf forms such as carangids (jacks, leerfishes, and jack mackerels), gobiids (gobies), sciaenids (drums and croakers), cynoglossids (tonguefishes), paralichthids (sand flounders), and bothids (lefteye flounders) that reside along the soft bottom environment of the inner shelf (water depths <60 m). Based on sizes of larvae collected, many could have been spawned within the source water (i.e., within a 17.3 km radius of the proposed FLNG site). A few oceanic taxa such as lanternfishes (*Diaphus* sp.) were also collected, indicating shoreward movement of some larvae spawned in deeper waters (>300 m) as has been documented for this region (Olivar et al., 2016; John and Zelck, 1997).

Daily entrainment rates calculated for ichthyoplankton taxa from the upper water column in Winter were highest for the sciaenid taxon (drums and croakers), contributing nearly 46% to total entrainment losses. Other ichthyoplankton taxa entrainment losses (e.g., *Sardinella* sp.) were 9% or less. In the lower water column, entrainment of larval fishes was also dominated by sciaenids.

In Summer, the dramatic increase in ichthyoplankton density resulted in entrainment rates that greatly exceed the Winter estimates. Atlantic bumper, a number of jack taxa, grunts, and sardines accounted for most individuals. In spite of these seasonal differences, losses from entrainment represent an extremely minor fraction of the standing stock.

The ratio of entrainment densities to source water densities is 0.004%. This ratio is constant for all taxa evaluated, as identical entrainment densities and source water densities were employed in the calculations. Density differences between the depth strata are not obvious for specific taxa; statistical treatment beyond the summary data is problematic, given the sparse nature of the data.

The PE estimate of 0.004% presented is conservative and is typical of open coast areas with complex circulation and relatively uniform habitat (water column and level seafloor). In addition, although this analysis indicates a very small percentage of the plankton are at risk, most ichthyoplankton, as well as the phyto- and zooplankton that larval fishes feed upon, are distributed widely, well beyond the calculated source water population from which the cooling water is drawn.

Widely distributed plankton taxa are expected to originate from shelf and, to a lesser extent, oceanic waters. Because the Senegal River mouth is located along the southern portion of the eastern source water boundary, it is possible that ichthyoplankton and zooplankton could be transported from the river into the source water plankton assemblage. While little is known about plankton inhabiting the Senegal River, it is possible that some fraction of shrimp, crab, and fish larvae from the Senegal River could be advected into the source water plankton population depending on the season and current patterns.

Invertebrate plankton (e.g., shrimp, crab and mollusk larvae) would be similarly affected by the cooling water intake, although these groups were not evaluated in this analysis. Despite their high abundance, holoplanktonic groups such as copepods, chaetognaths, siphonophores, amphipods, and mysids are rarely assessed due to wide geographic distribution and high population turnover rates. Estimates presented in the current analysis are considered representative of both sampling periods – Winter and Summer – when samples were collected. The numbers and kinds of larvae present will differ for different times of the year as spawning patterns and currents will seasonally change. This was demonstrated by the differences in fish larval composition and abundance collected between Winter and Summer sampling periods.

Finally, it is inherently difficult to reliably extrapolate the effects of entrainment losses to the population level because of numerous confounding factors including water temperature, salinity, and nutrient concentrations (Berraho et al., 2015; Hinde et al., 2017; Arkhipov, 2009); circulation patterns and upwelling (Auger et al., 2016; Olivar et al., 2017); prey availability; and variability of adult spawning times (Arkhipov, 2009). The level of variability was highlighted by the differences in ichthyoplankton densities found between the Winter and Summer samples from the nearshore and offshore areas.

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APPENDIX N : ACCIDENTAL EVENT SCENARIOS MODELING REPORTS

APPENDIX N
Accidental Event Scenarios Modeling Reports

APPENDIX CONTENTS

APPENDIX N-1 : OIL SPILL MODELING REPORTS

APPENDIX N-1a : OIL SPILL MODELING REPORT – WELL HEAD FAILURE

Oil Spill Modelling Report – Well Head Failure
Tortue Phase 1a

BP p.l.c.

Document Number: GEOM0132a R03

Issued: 19 January 2018

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EXECUTIVE SUMMARY

Oil spill modelling was completed by Oil Spill Response Ltd. (OSRL) on behalf of BP for the Tortue Phase- 1a project, offshore Senegal and Mauritania (Figure 1). The results of this analysis will support the Oil Spill Contingency Plan and the Environmental Impact Assessment for the area. The modelled scenarios are summarised in Table 1.

Scenario 1. Well blowout of 227,000 m^3 of condensate over 60 days during summer (April-September)

Scenario 2. Well blowout of 227,000 m^3 of condensate over 60 days during winter (October-March)

A spill at this location, approximately 120 km from the shore, has a 96% probability of making shoreline impact (light oiling or higher) if the spill happens in Summer and a 33 % chance of shoreline impact if it occurs in Winter. Mauritania and Senegal are the only two countries at risk of shoreline impact, but Senegal is most likely to be more severely impacted.

Both Mauritania and Senegal Waters' will be impacted by this spill scenario. Whilst more countries will be impacted in the summer scenario (9 countries in summer vs. 6 countries in winter), a winter spill is far more likely to impact Waters' of Cape Verde (51% in summer vs. 100 % in winter) and The Gambia (42 % in summer vs. 92% in winter).

However, the thickness of the condensate spill is limited to mostly sheen and rainbow sheen that will more readily disperse. A small amount of metallic sheen (>5 µm) may be found in the local area around the well (~25 km). Because of the high turbidity created by the gas at the well site, condensate droplets are very small. Consequentially, they rise more slowly and do not concentrate in the same way as if there was an absence of gas.

DOCUMENT HISTORY

Document Number	Revision	Document Type	Author	Technical Review	Format Review	Date of Issue
GEOM0132a	R01	Draft Modelling Report	JKM	LHM	SJB	24-Nov-2017
GEOM0132	R02	Client Comments Addressed	JKM	LHM	SJB	12-Jan-2018
GEOM0132	R03	Client Comments Addressed	LHM	N/A	N/A	19-Jan-2018

JKM – Jenny Kirsty Mitchell LHM – Liam Harrington-Missin SJB – Simon Blaen

DISCLAIMERS

- Modelling results are to be used for guidance purposes only and response strategies should not be based on these results alone.
- The resolution / quality of wind and current data vary between regions and models. As with any model, the quality and reliability of the results are dependent on the quality of the input data.

Considering the above, all advice, modelling, and other information provided is generic and illustrative only and not intended to be relied upon in any specific instance. The recipient of any advice, modelling or other information from, or on behalf of, OSRL acknowledges and agrees that any number of variables may impact on an oil spill and, as such, should be addressed on an individual basis. OSRL has no liability in relation to such advice, modelling or other information and the recipient of such information hereby fully indemnifies and holds harmless OSRL its officers, employees, shareholders, agents, contractors and sub-contractors against any costs, losses, claims or liabilities arising about such advice, modelling, training or other information.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Background

Oil spill modelling was completed by Oil Spill Response Ltd. (OSRL) on behalf of BP for the Tortue Phase 1a project, offshore Senegal and Mauritania (Figure 1). The results of this analysis will support the Oil Spill Contingency Plan and the Environmental Impact Assessment for the area. The modelled scenarios are summarised in Table 1.

Scenario 1. Well blowout of 227,000 m^3 of condensate over 60 days during summer (April-September)

Scenario 2. Well blowout of 227,000 m^3 of condensate over 60 days during winter (October-March)

The modelling was carried out using SINTEF's Oil Spill Contingency and Response (OSCAR) model. OSCAR is a 3D modelling tool used to predict the movement and fate of oil on the sea surface and throughout the water column (see APPENDIX F for further details).

1.2 Aims

The aim of this report is to present the risk to the sea surface and shoreline by creating spatial maps of:

1. Probability - to estimate how likely an area is to be impacted.
2. Arrival time - to estimate how quickly an area could be impacted.
3. Emulsion thickness - to estimate how severely an area could be impacted.

The data behind these maps allow us to answer the following questions:

1. How quickly could condensate reach nearby shorelines and what mass?
2. Which countries are more likely to be affected by a condensate spill from the Tortue phase 1a Well?
3. Which environmental sensitivities could be affected by a condensate spill from the Tortue phase 1a Well?

Table 1: Scenario setup

Description	Well blowout - Summer	Well blowout - Winter
Season	April-September	October-March
Latitude	16° 05' 14.7516" N	
Longitude	017° 37' 32.718" W	
Total Volume Released	227,000 m^3	
Total Mass Released	189,747.3 MT	
Duration of Release	60 days	
Depth of Release	2,725 m	
Nearest Shoreline	~120 km, St Louis, Senegal	

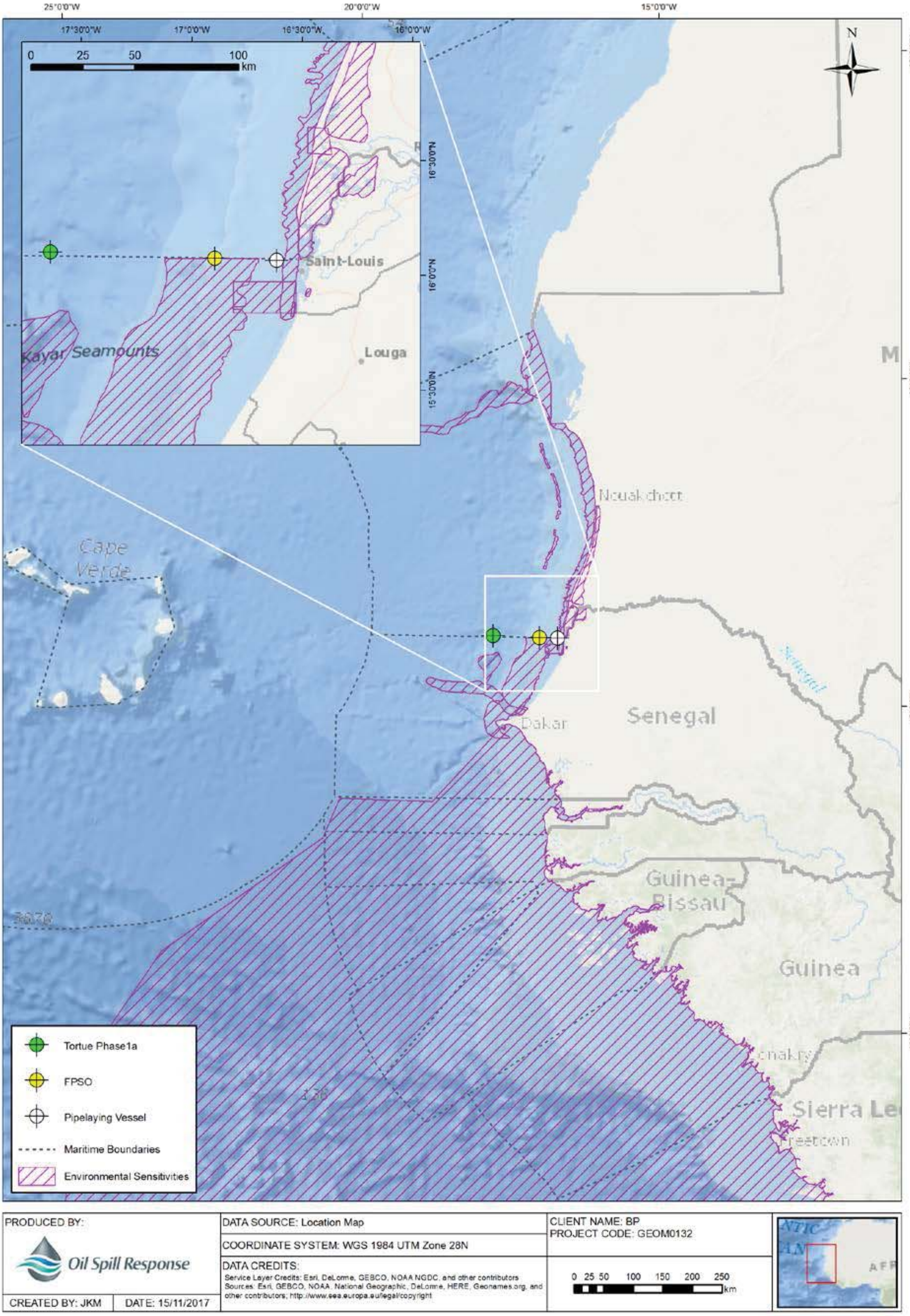


Figure 1: Map showing the release location

1.3 Modelling Setup

Two worst case stochastic simulations were run for the Tortue phase 1a project (Table 2), with a total of 308 individual trajectories post-processed for the scenario to create the stochastic results. Each trajectory began on a different start date, so that each spill was simulated using a range of wind and current conditions.

Three years of hydrodynamic data (sourced from Copernicus and NOAA) were used as model inputs. See APPENDIX A to APPENDIX E for more information on the model setup.

Table 2: Summary of stochastic setup for spill scenarios

Description	Well Blowout in Summer	Well Blowout in Winter
Location	16° 05' 14.7516" N 017° 37' 32.718" W	
Time of Year	April-September	October-March
Release Period	60 days	
Release Rate	3,783.3 m^3/day	
Total Release (Volume)	227,000 m^3	
Total Run Duration	95 days	
Total Number of Trajectories	154	154
Time Between Trajectories	4 days, 14 hours	3 days, 3 hours

1.4 Thresholds

Thresholds define the point below which data are no longer informative. For example, when surface emulsion thickness is less than 0.04 µm, the oil is no longer visible to the naked eye so may be considered negligible to a response. The thresholds applied to this study are given in Table 3.

Table 3: Thresholds used in the post-processing stage of the modelling

Threshold	Value	Description
Surface	0.04 µm	The Bonn Agreement Oil Appearance Code defines five oil layer thicknesses based on their optic effects and true colours. 0.04 µm is the minimum thickness that can be seen with the naked eye.
Water column	6 ppb (Dissolved)	Low level, in-water dissolved HC exposure.
	70 ppb (Total)	Entrained HC exposure level, OSPAR predicted no effect concentration (PNEC).
Shoreline	0.1 litres/m^2	Lower threshold for light oiling from the ITOPF document “Recognition of oil on shorelines”.

The thickness key used in the surface emulsion thickness maps throughout this document is derived from the Bonn Oil Appearance Code (Table 4).

Table 4: Key used for sea surface emulsion thickness outputs

Appearance	Layer Thickness Interval	Colour
Sheen	0.04 µm - 0.3 µm	
Rainbow	0.3 µm -5 µm	
Metallic	5 µm - 50 µm	
Discontinuous True Colour	50 µm - 200 µm	
Continuous True Colour	>200 µm	

The thickness key used in the shoreline maps throughout this document is derived from the ITOPF Technical Information Paper (TIP) No. 6 “Recognition of oil on shorelines” (ITOPF, 2011b; Table 7). Very light oiling is deemed negligible by ITOPF (ITOPF, 2011b); no practical response is required for a very lightly oiled shoreline, apart from monitoring the oil spill.

Table 5: Key used for water column dissolved concentrations

Water Column Classification	Concentration	Colour
Low	< 50 ppb	
Moderate	50 - 400 ppb	
High	> 400 ppb	

Table 6: Key used for water column total concentrations

Concentration	Colour
< 150 ppb	
150 – 500 ppb	
500 – 750 ppb	
750 - 1000 ppb	
> 1000 ppb	

Table 7: Key used for shoreline emulsion thickness outputs

Shoreline Oiling Classification	Concentration	Thickness	Colour
Light Oiling	0.1 – 1 litres/m^2	0.1 mm – 1.0 mm	
Moderate Oiling	1 – 10 litres/m^2	1 mm – 10 mm	
Heavy Oiling	> 10 litres/m^2	> 10 mm	

2 RESULTS

2.1 Stochastic Results

The stochastic results for Scenario 1 were calculated from 154 trajectories. The scenario involves the release of 227,000 m^3 of condensate over 60 days during the summer (April to September) and is tracked for a further 35 days.

The following results are presented:

Sea Surface

Shoreline

Water Column (Dissolved Hydrocarbon)

Water Column (Total Hydrocarbon)

Well Blowout
Surface

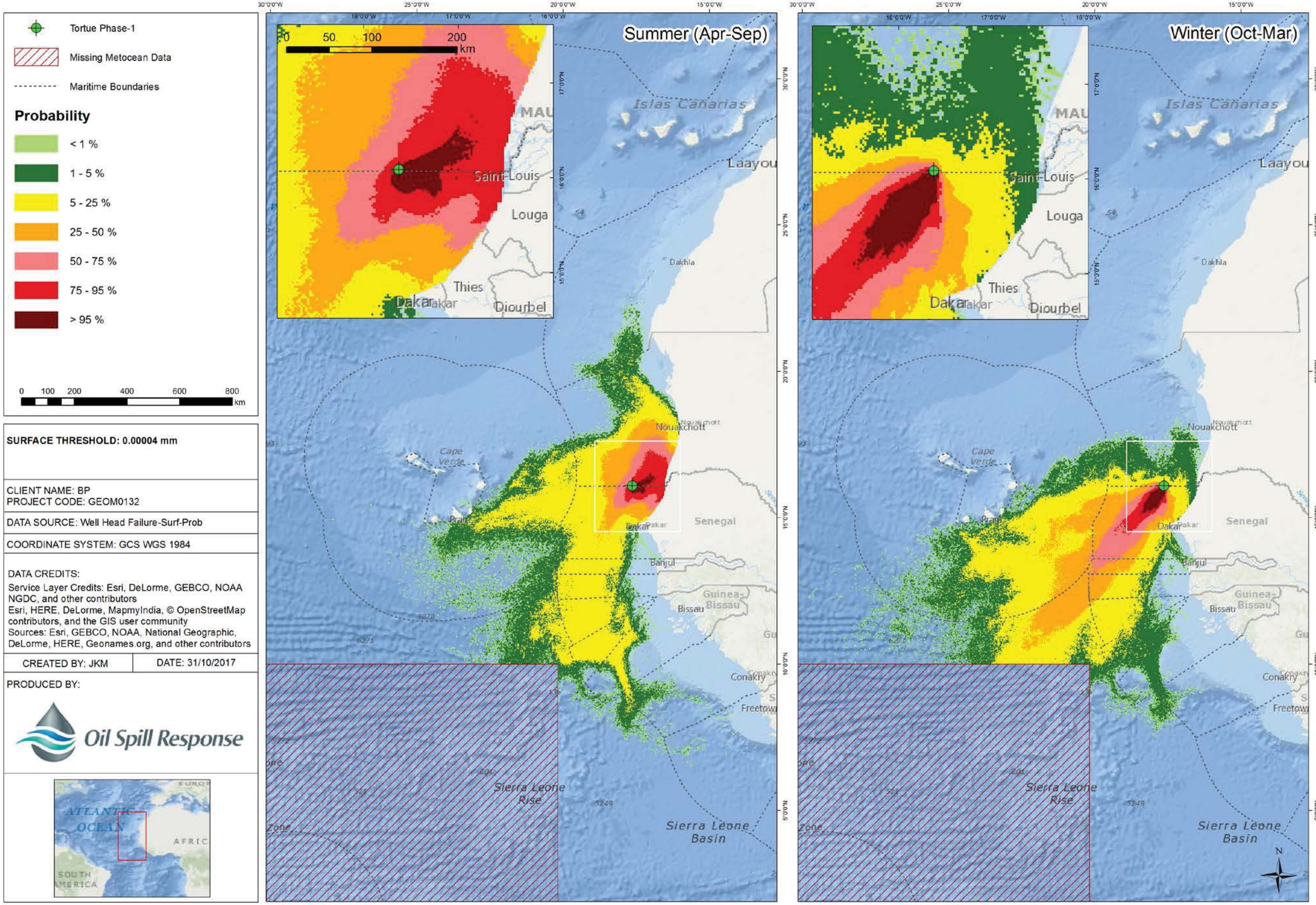


Figure 2: Well Blowout – Surface Probability of Cell Impact– Summer (left) & Winter (right)

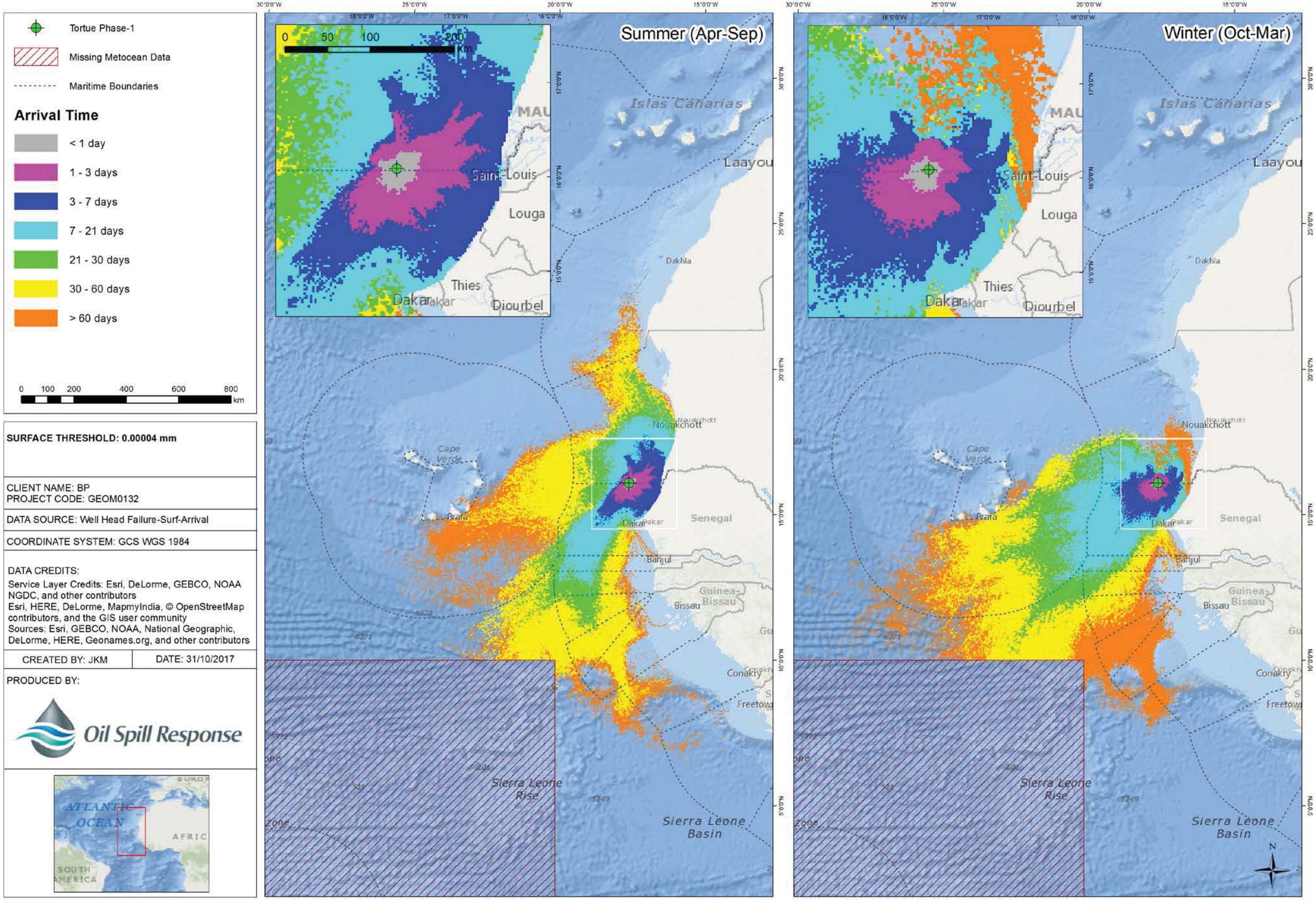


Figure 3: Well Blowout – Surface Minimum Arrival Time – Summer (left) & Winter (right)

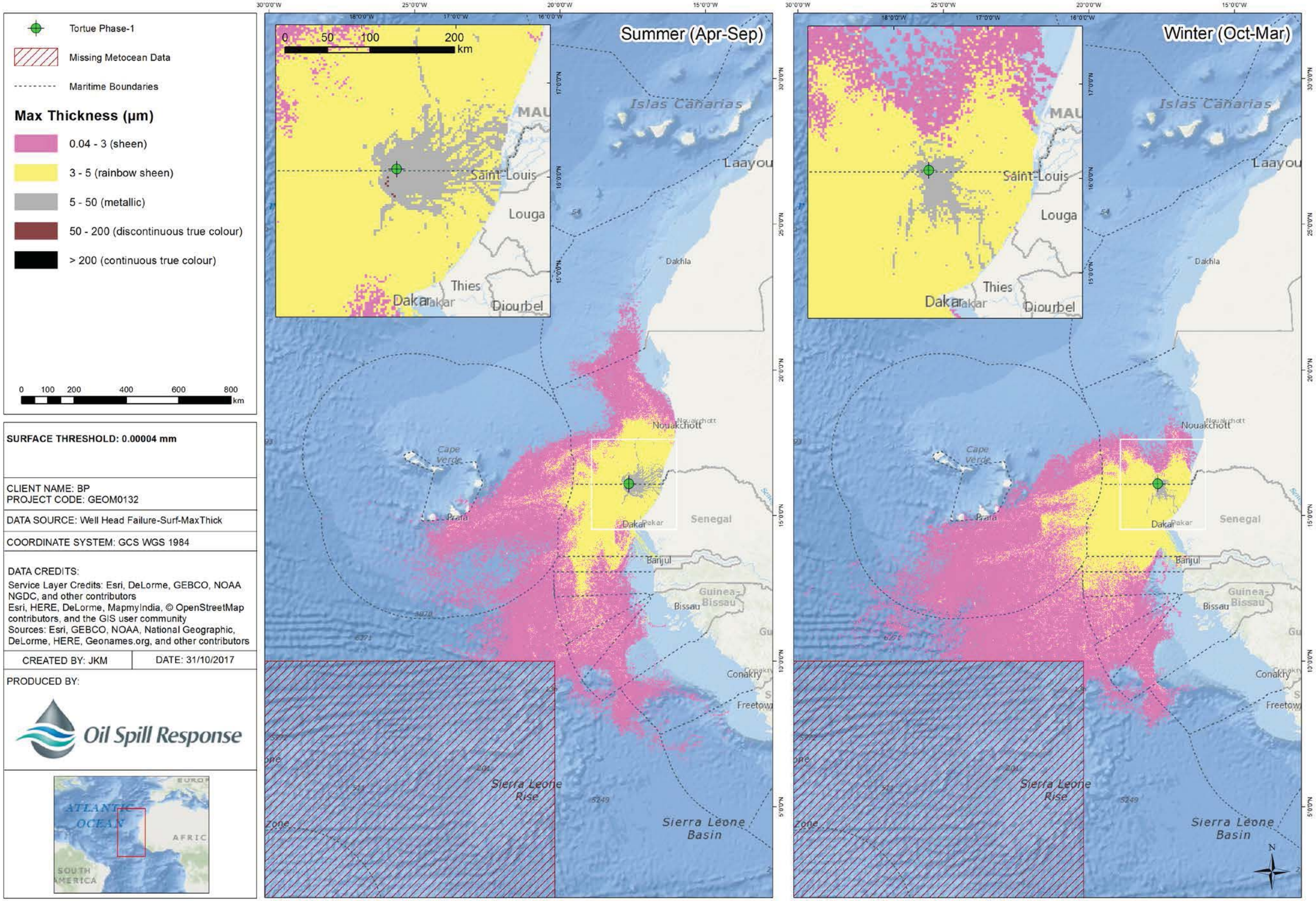


Figure 4: Well Blowout – Surface Maximum Emulsion Thickness – Summer (left) & Winter (right)

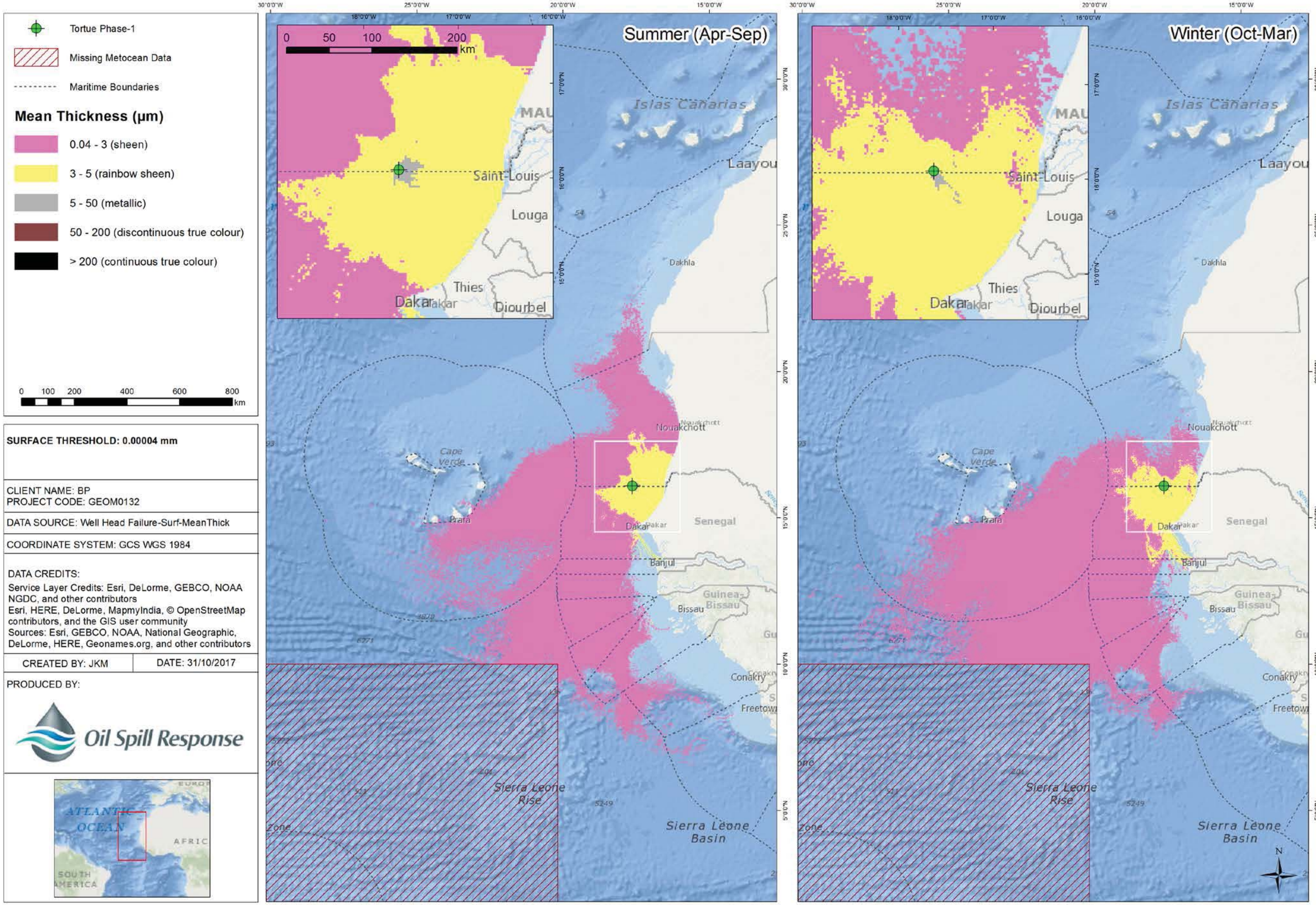


Figure 5: Well Blowout – Surface Average Emulsion Thickness – Summer (left) & Winter (right)

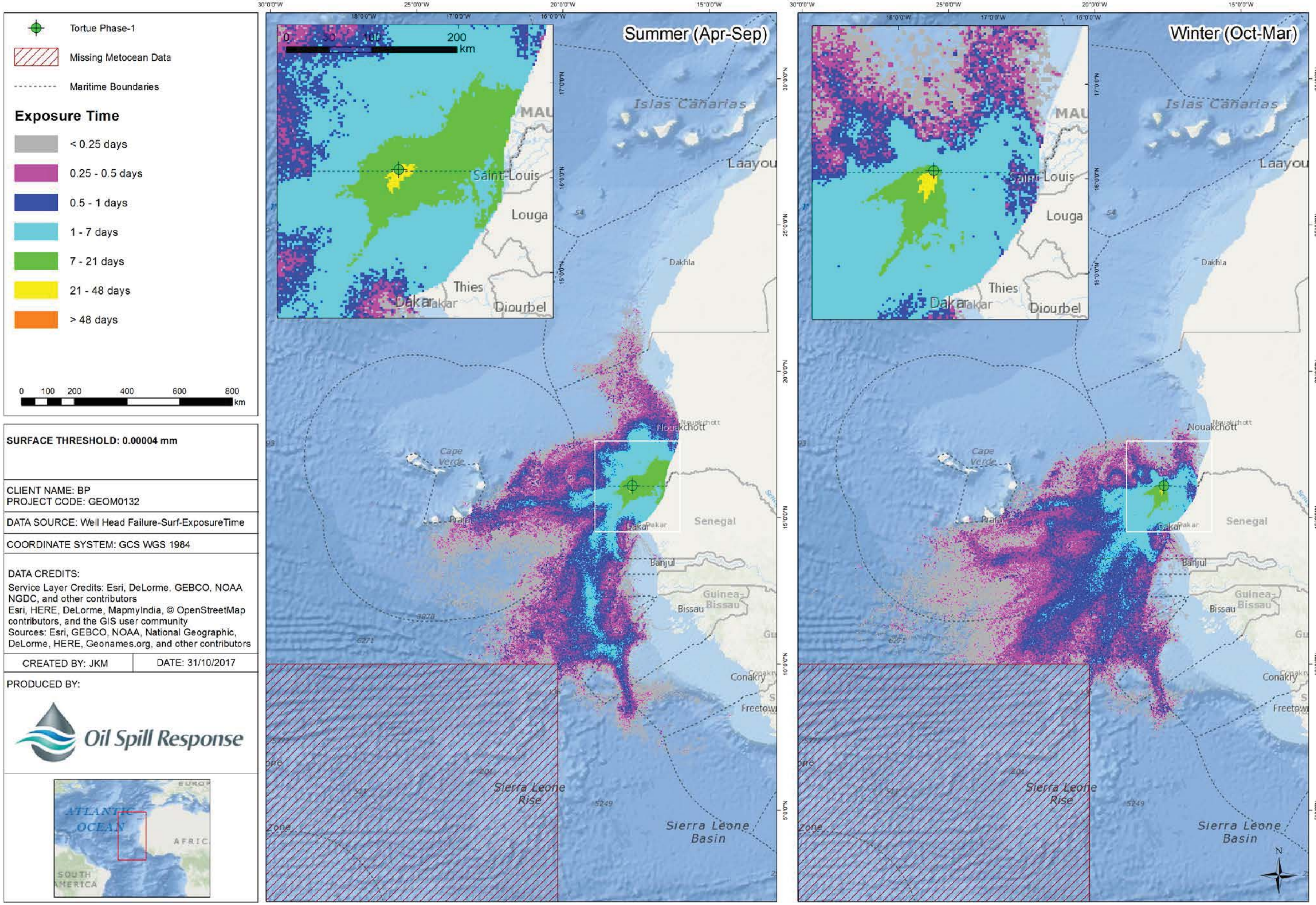


Figure 6: Well Blowout – Surface Maximum Exposure Time – Summer (left) & Winter (right)

Well Blowout
Shoreline

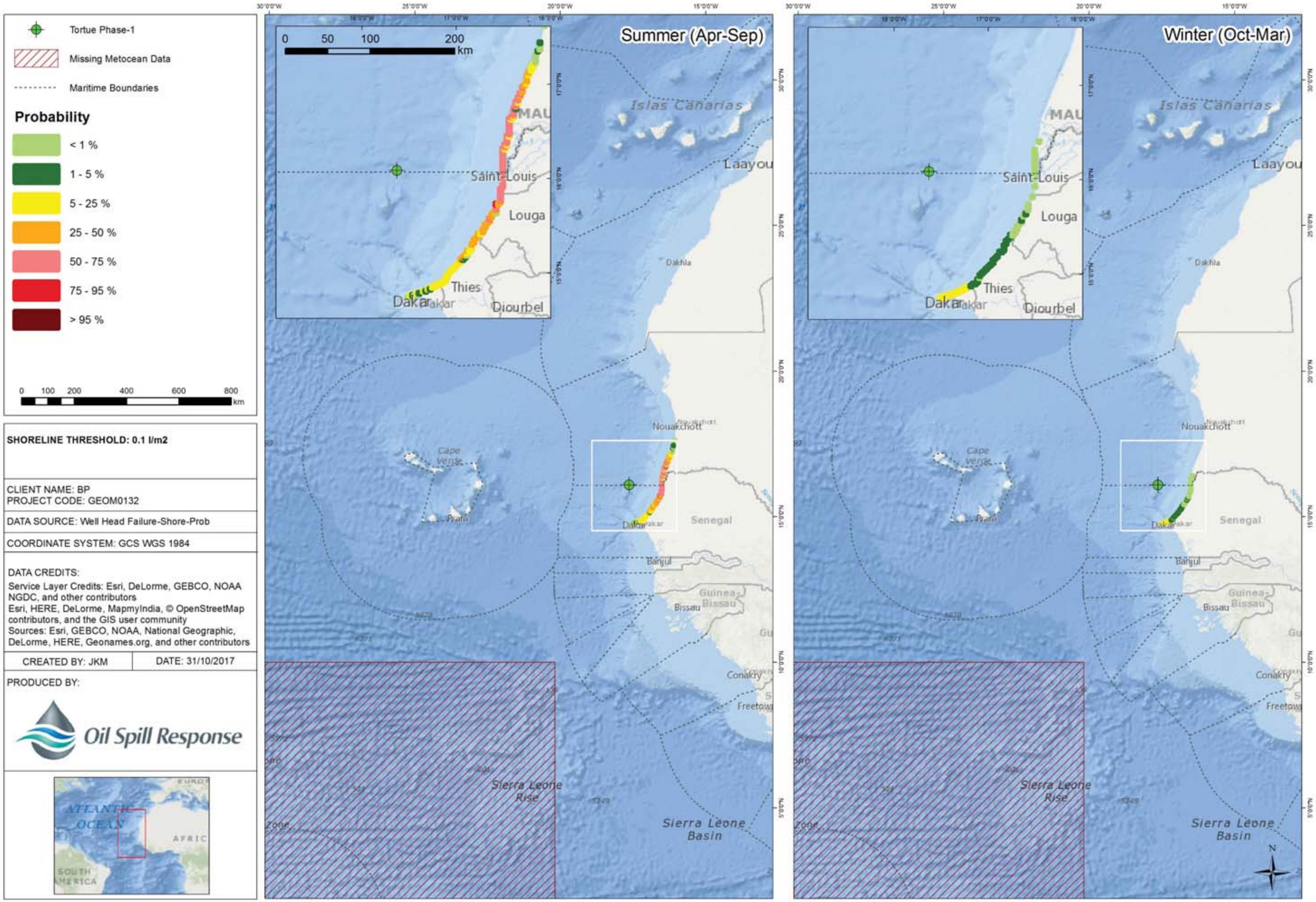


Figure 7: Well Blowout – Shoreline Probability of Cell Impact – Summer (left) & Winter (right)

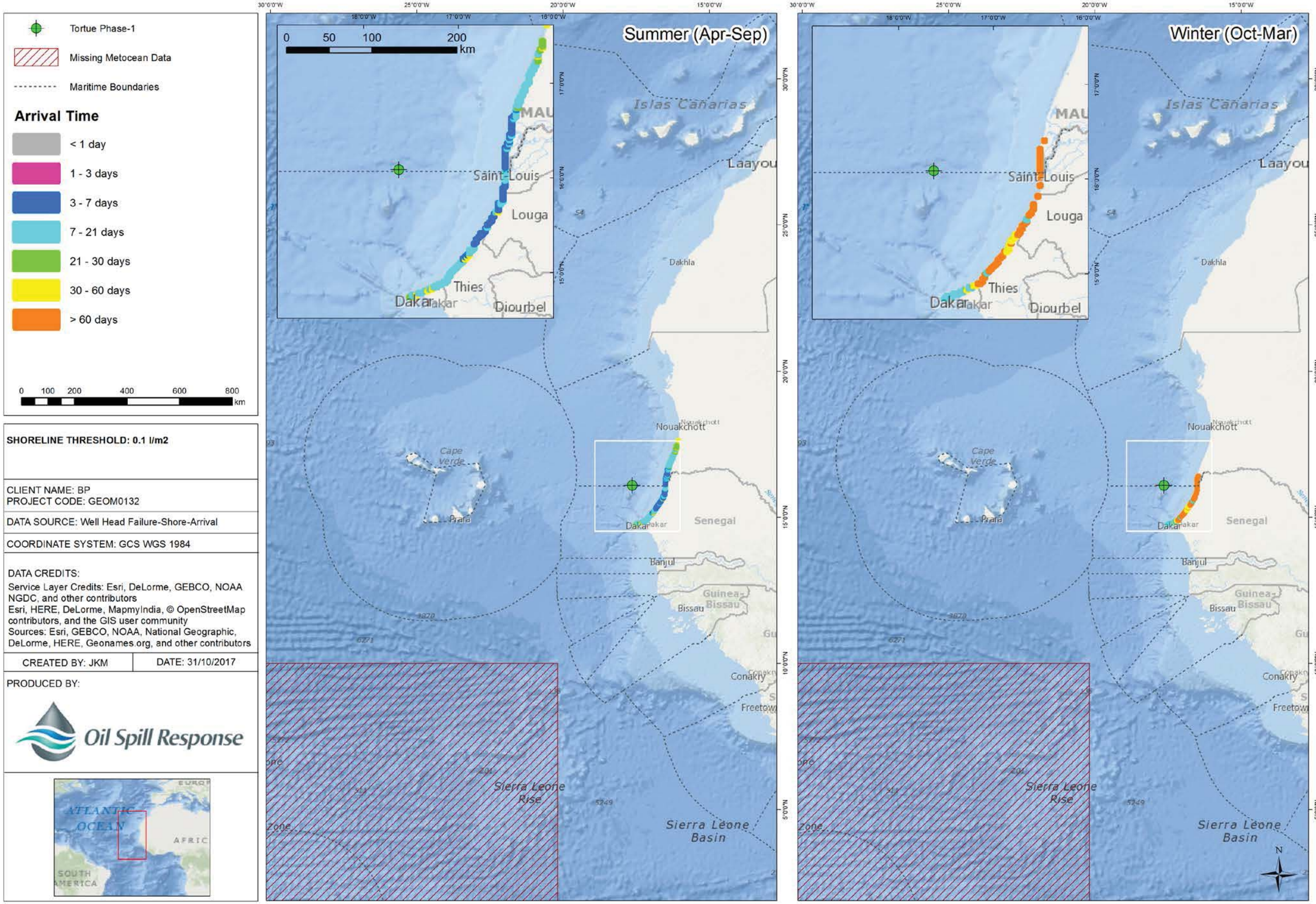


Figure 8: Well Blowout – Shoreline Minimum Arrival Time – Summer (left) & Winter (right)

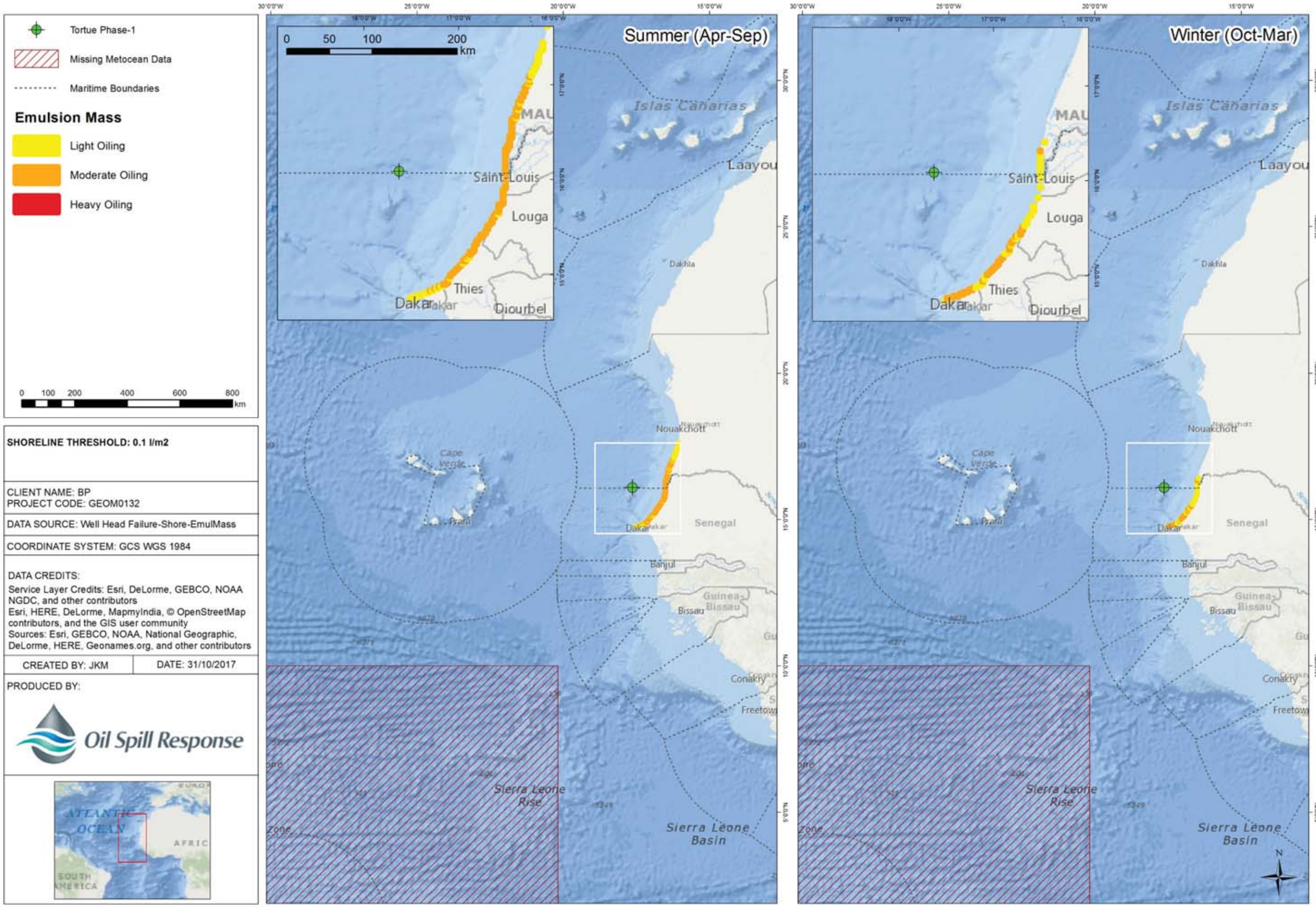


Figure 9: Well Blowout – Shoreline Impact – Summer (left) & Winter (right)

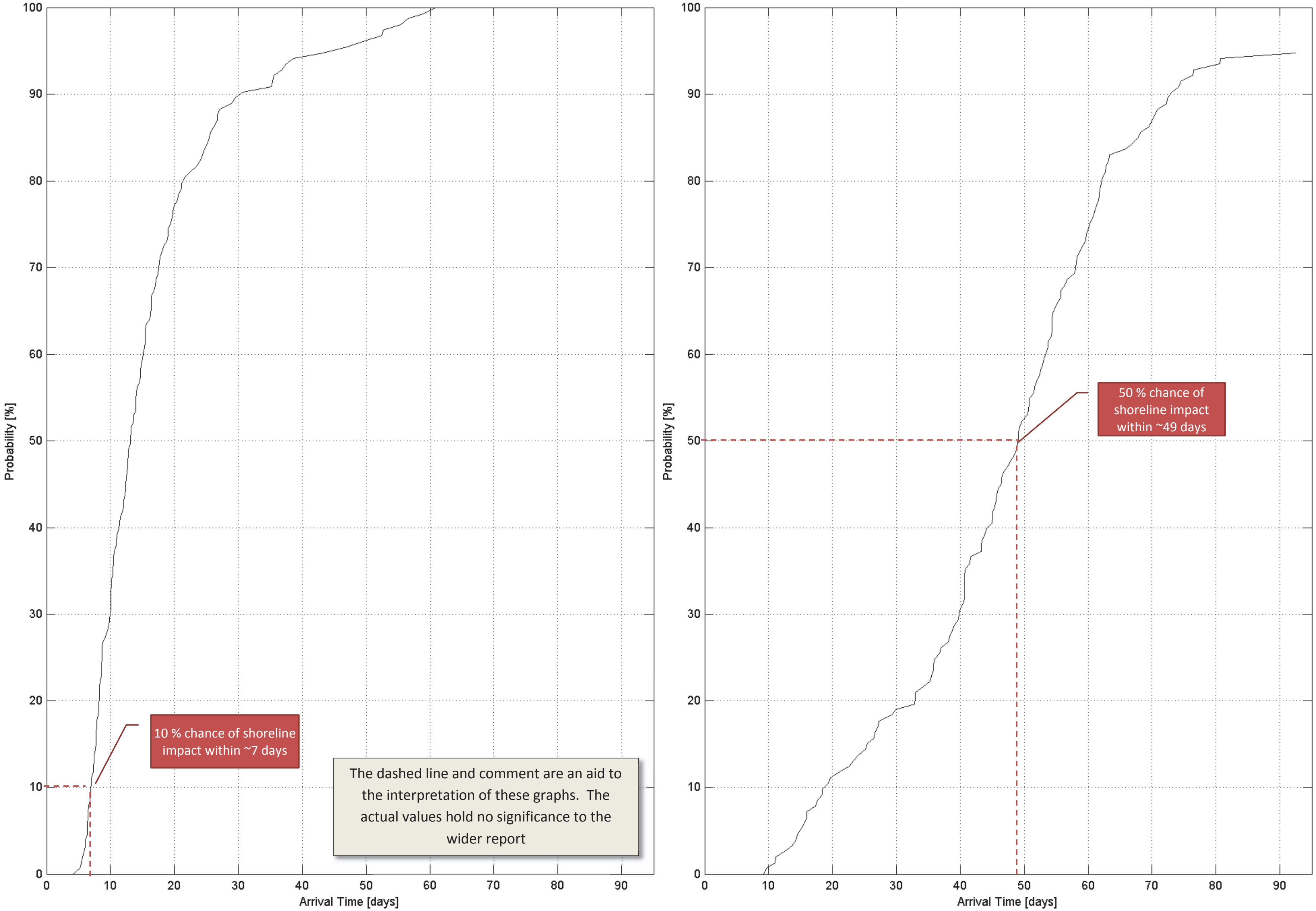


Figure 10: Well Blowout – Shoreline Impact – Shoreline Arrival Time Probability - Summer (left) & Winter (right)

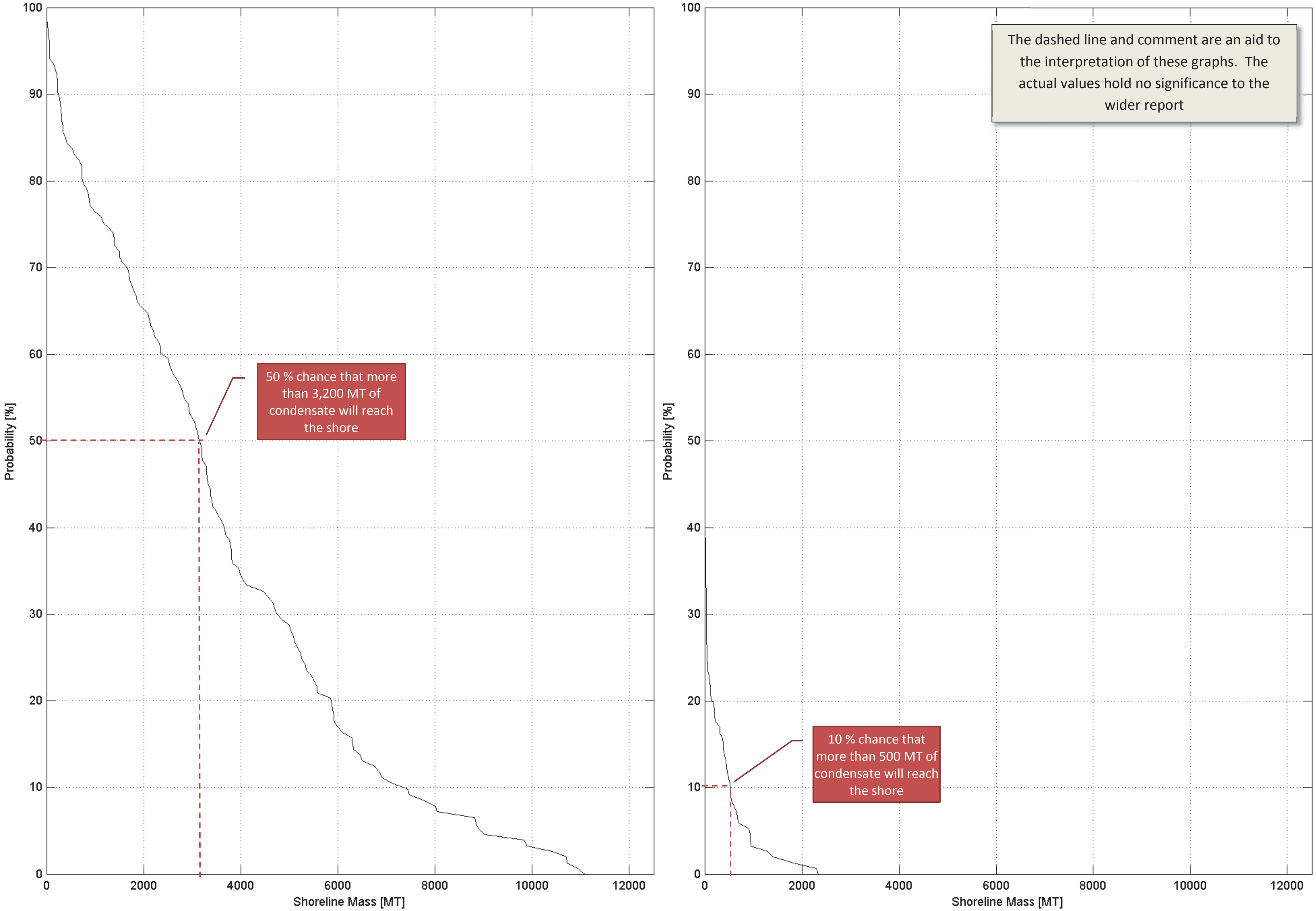


Figure 11: Well Blowout – Shoreline Impact –Probability Shoreline Mass- Summer (left) & Winter (right)

Table 8 and Table 9 show how many of the simulations result in different levels of shoreline impact based on ITOPF's Technical Information Paper (TIP) no. 6, "Recognition of Oil on Shorelines" and the length of shoreline impacted. For further information see Thresholds in Section 1.4.

Table 8: Severity of shoreline oiling following a well blowout from the Tortue Phase 1a Well

ITOPF Reference	Light, Moderate & Heavy Oiling		Light & Moderate Oiling		Light Oiling		No Significant Impact	
OSRL's SCAT Reference	Thick		Cover		Coat			
Season	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Number of Simulations	0 of 154	0 of 154	130 of 154	29 of 154	18 of 154	22 of 154	6 of 154	103 of 154
Probability	0%	0%	84%	19%	12%	14%	4%	67%

Each of the 154 trajectories is put into a single category based on its most severe shoreline oiling. For example, a trajectory that has at least one cell classified as *Heavy Oiling* will be placed in the heavy oiling category regardless of how many of the other cells have *Moderate* or *Light* oiling.

Table 9: Length of shoreline impacted following a well blowout from the Tortue Phase 1a Well

			Best case	Average (50th Percentile)	Worst case
Length of Shoreline Impacted	Heavy	Summer	0 km	0 km	0 km
		Winter	0 km	0 km	0 km
	Moderate	Summer	0 km	87 km	294 km
		Winter	0 km	3 km	54 km
	Light	Summer	0 km	99 km	185 km
		Winter	0 km	8 km	98 km

The data presented in these tables can be interpreted as follows

- In the best-case scenario, there will be no shoreline impact (4% chance of this occurring in Summer and 67% chance of this occurring in Winter).
- In a "typical case" (50th percentile), there will be:
  - Summer = No heavy oiling, 87 km of moderate oiling, and 99 km of light oiling.
  - Winter = No heavy oiling, 3 km of moderate oiling and 8 km of light oiling.
- In a "worst-case" (maximum value[1]), there will be:
  - Summer = No heavy oiling, 294 km of moderate oiling, and 185 km of light oiling.
  - Winter = No heavy oiling, 54 km of moderate oiling and 98 km of light oiling.

[1] Note that this presents the maximum shoreline length in each category. It does not refer to 1 trajectory extracted from the stochastic.

Well Blowout

Water Column Maps

Dissolved Concentrations

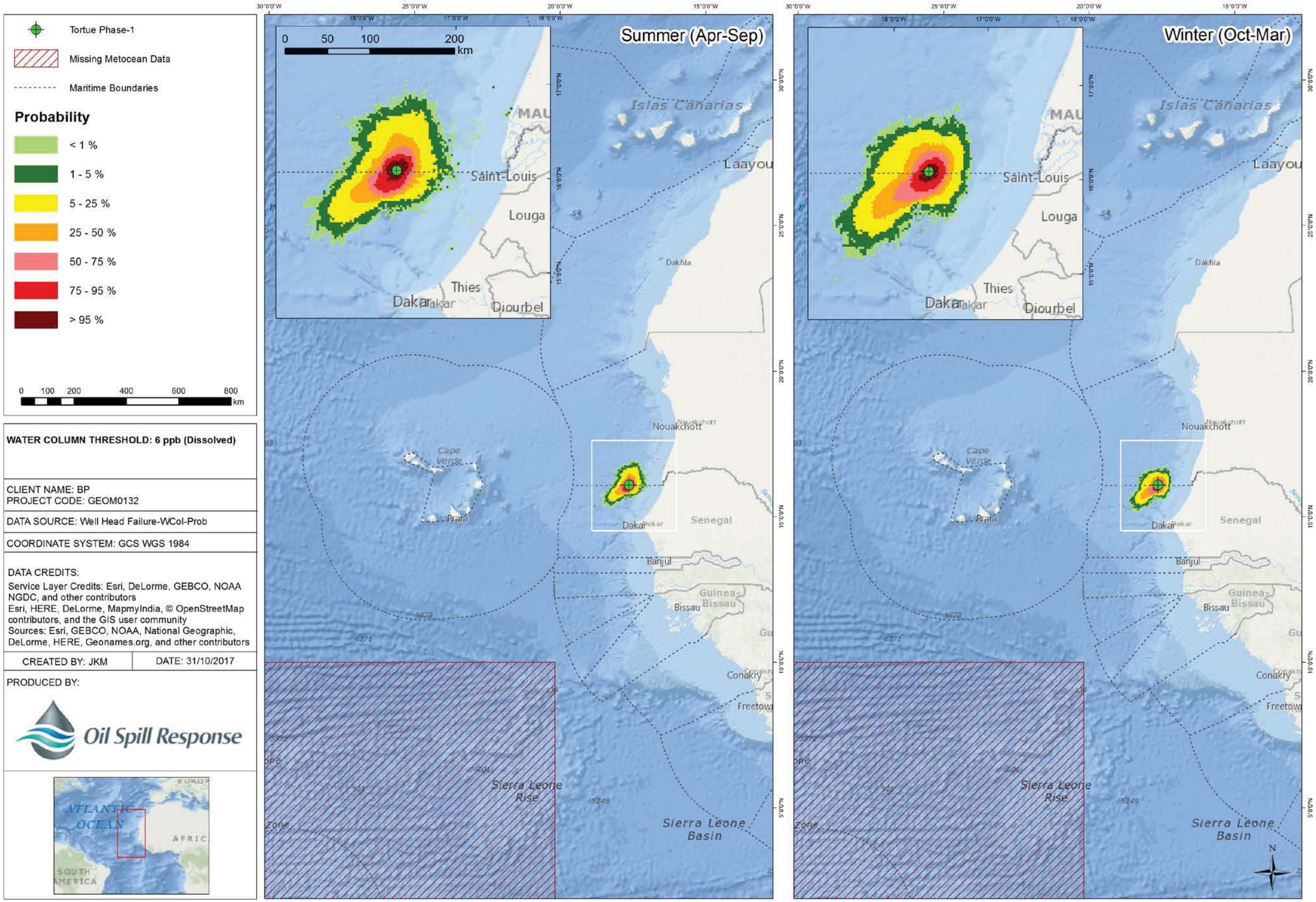


Figure 12: Well Blowout – Water Column (Dissolved) Probability of Cell Impact – Summer (left) & Winter (right)

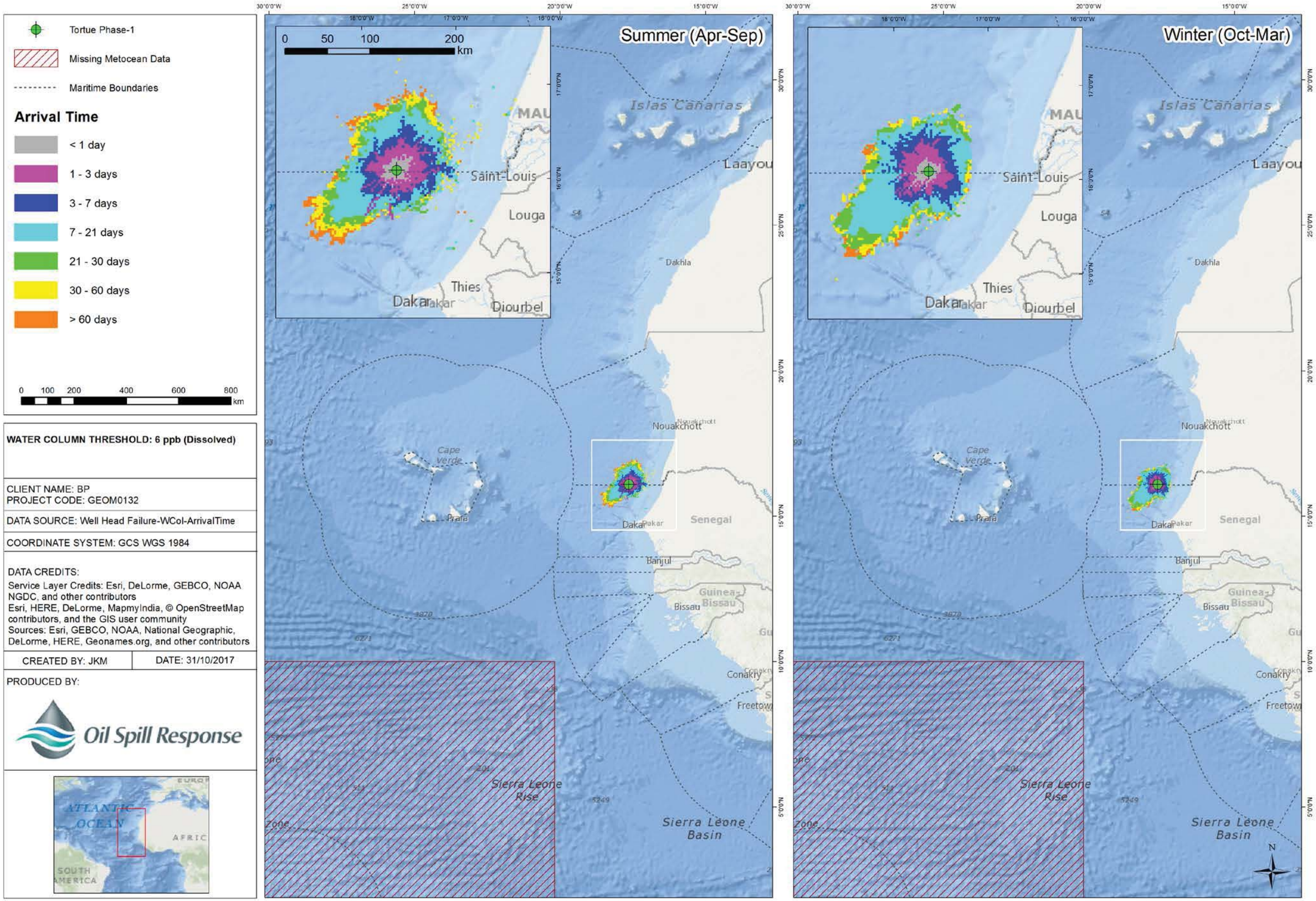


Figure 13: Well Blowout – Water Column (Dissolved) Minimum Arrival Time – Summer (left) & Winter (right)

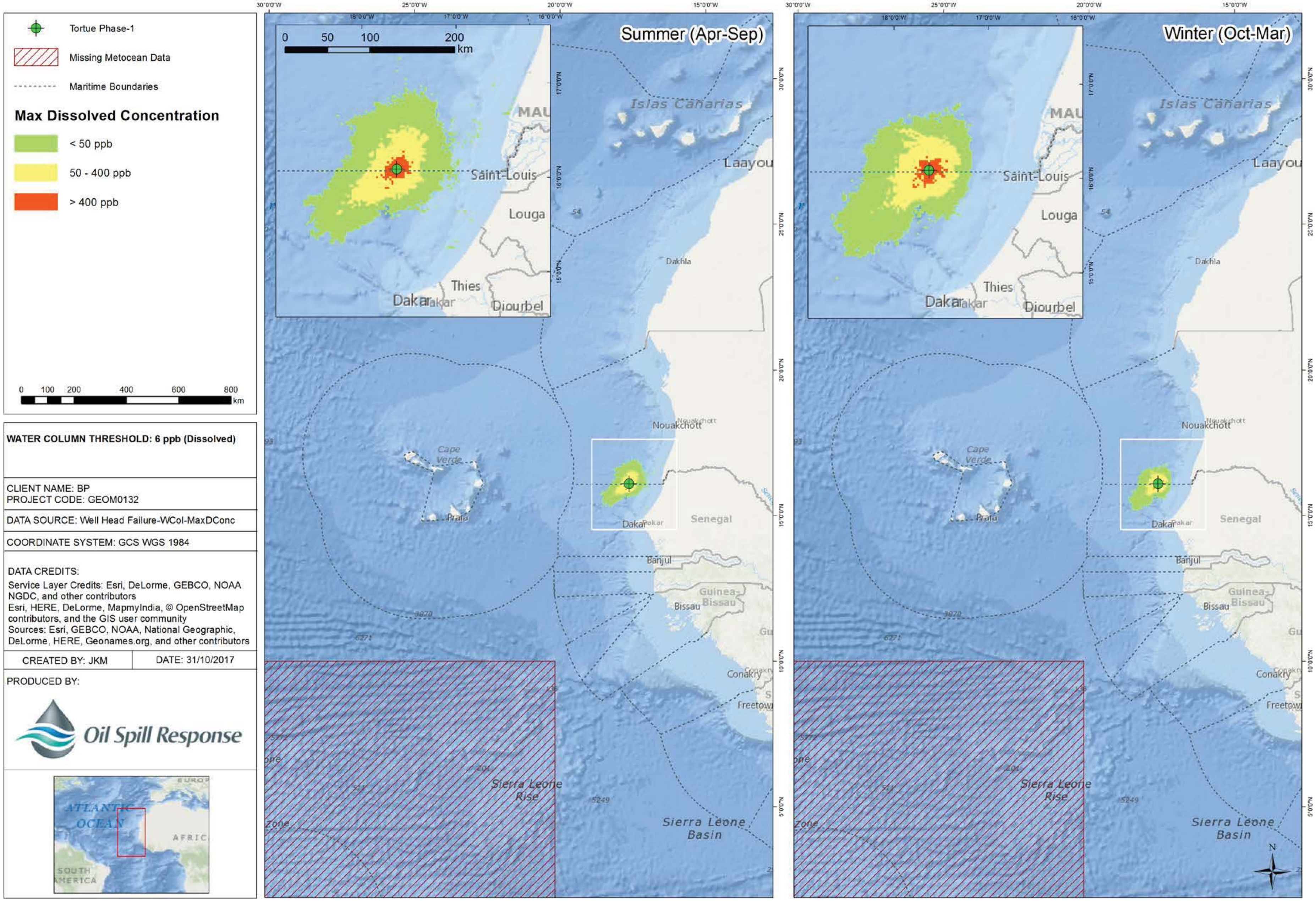


Figure 14: Well Blowout – Water Column (Dissolved) Concentrations – Summer (left) & Winter (right)

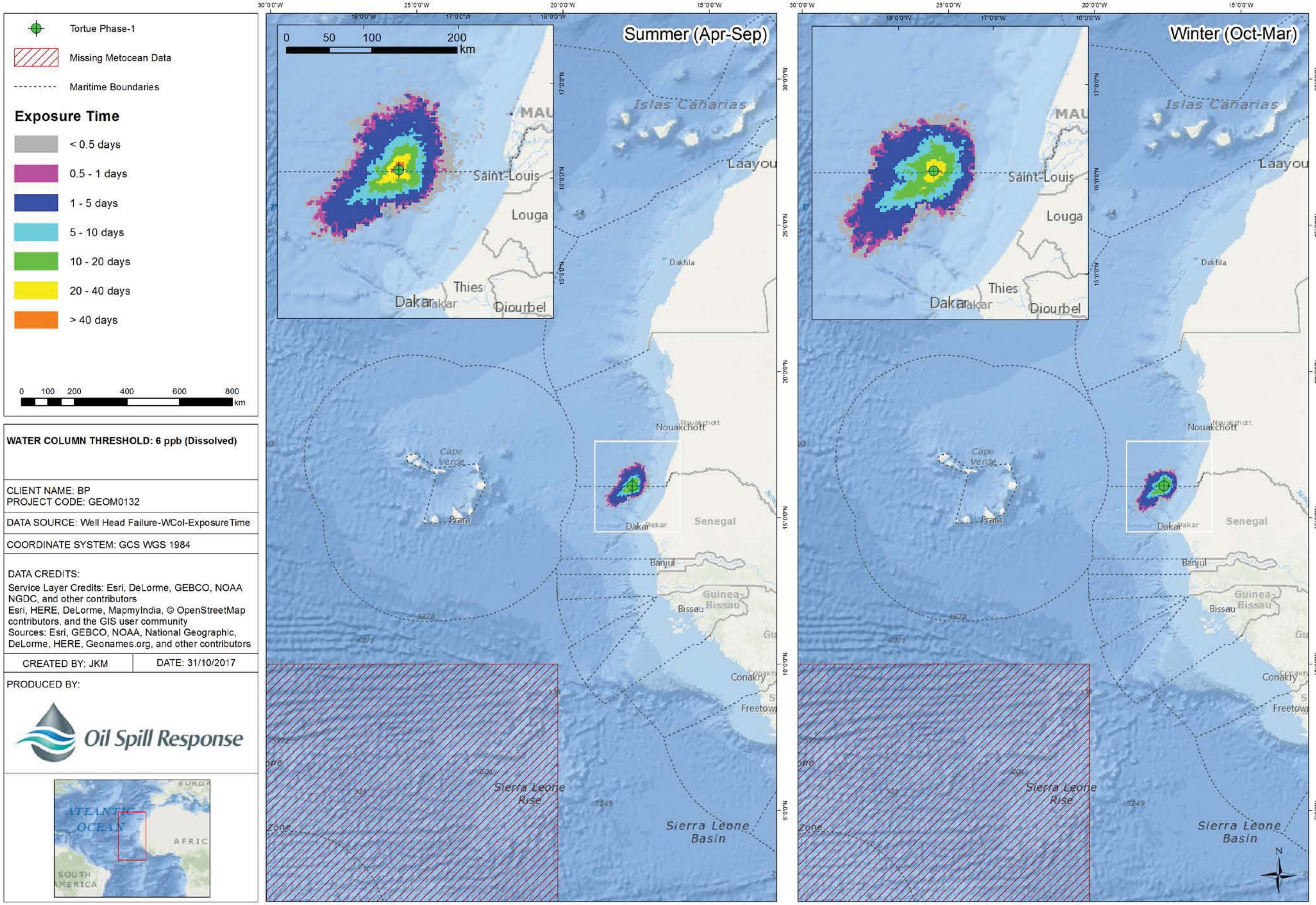


Figure 15: Well Blowout – Water Column (Dissolved) Maximum Exposure Time– Summer (left) & Winter (right)

Well Blowout

Water Column Maps

Total Concentrations

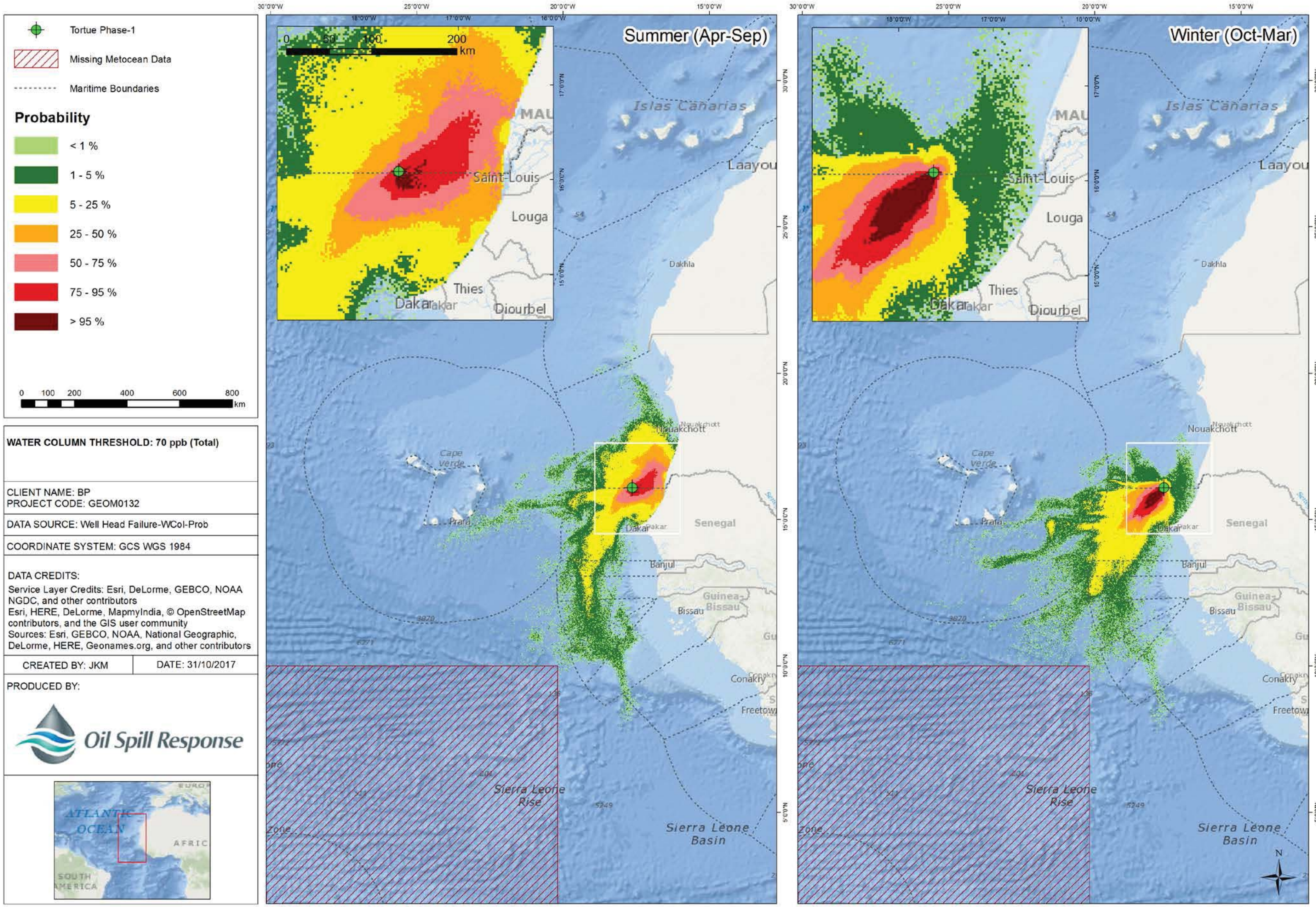


Figure 16: Well Blowout – Water Column (Total) Probability of Cell Impact – Summer (left) & Winter (right)

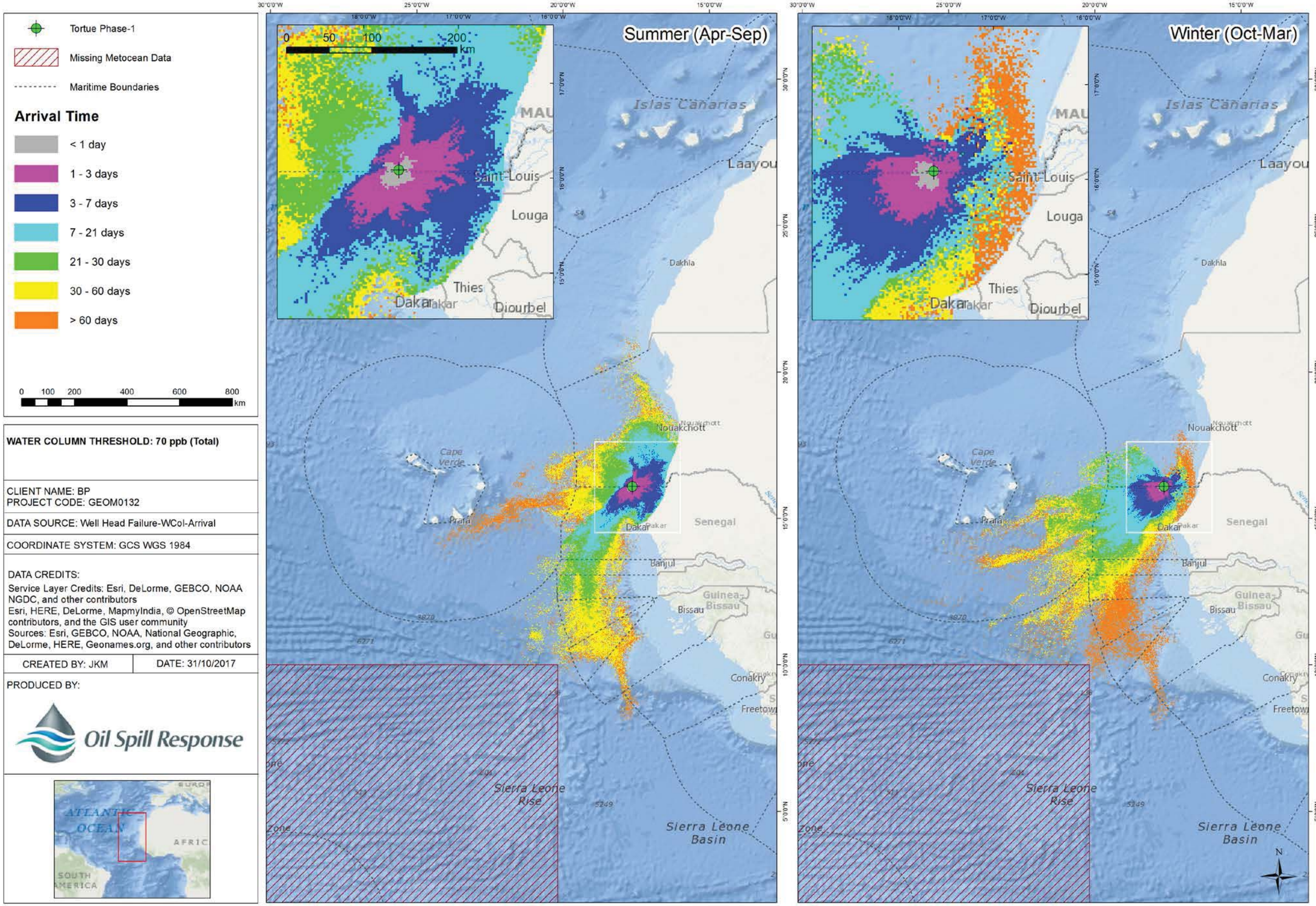


Figure 17: Well Blowout – Water Column (Total) Minimum Arrival Time – Summer (left) & Winter (right)

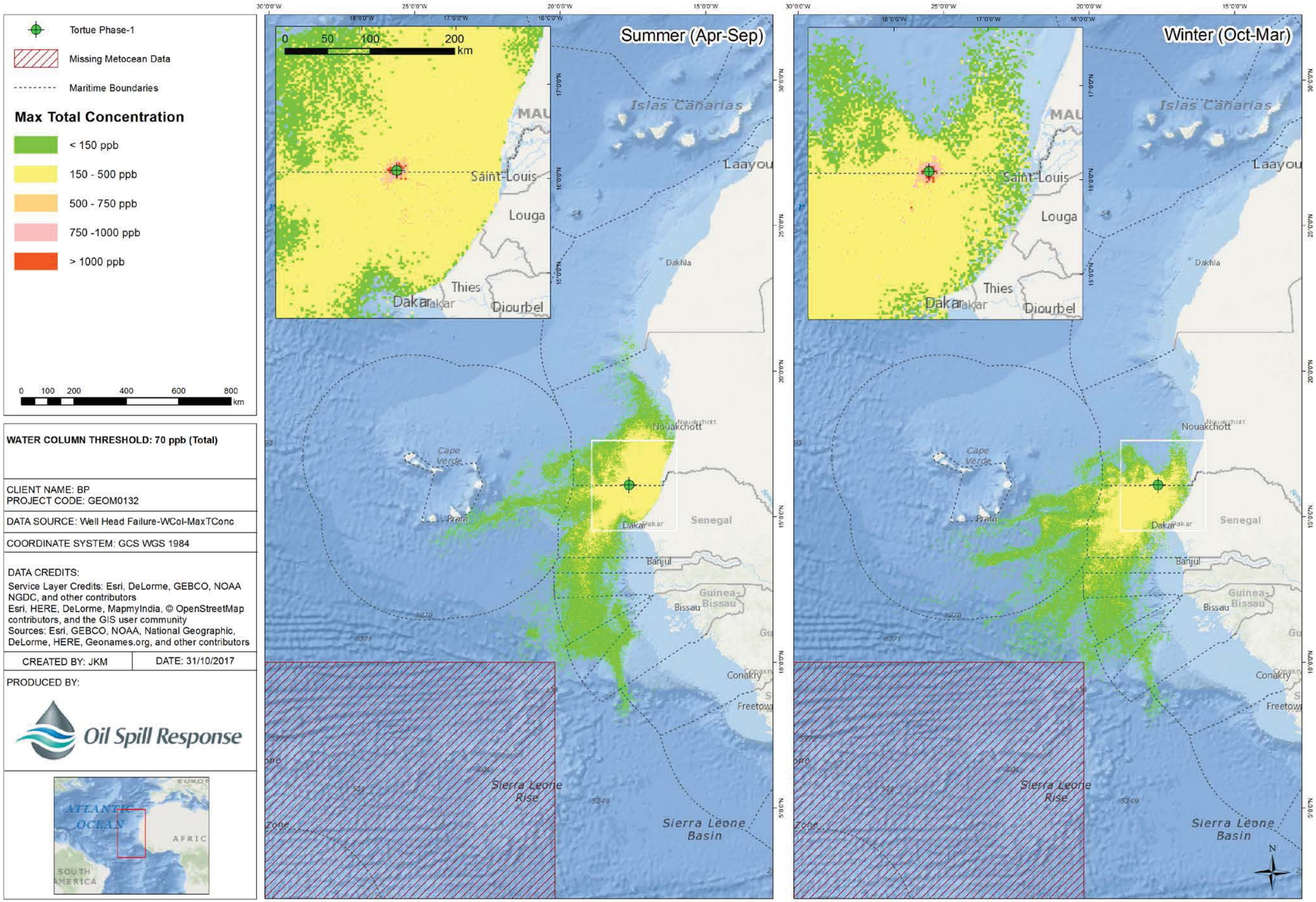


Figure 18: Well Blowout – Water Column (Total) Concentrations – Summer (left) & Winter (right)

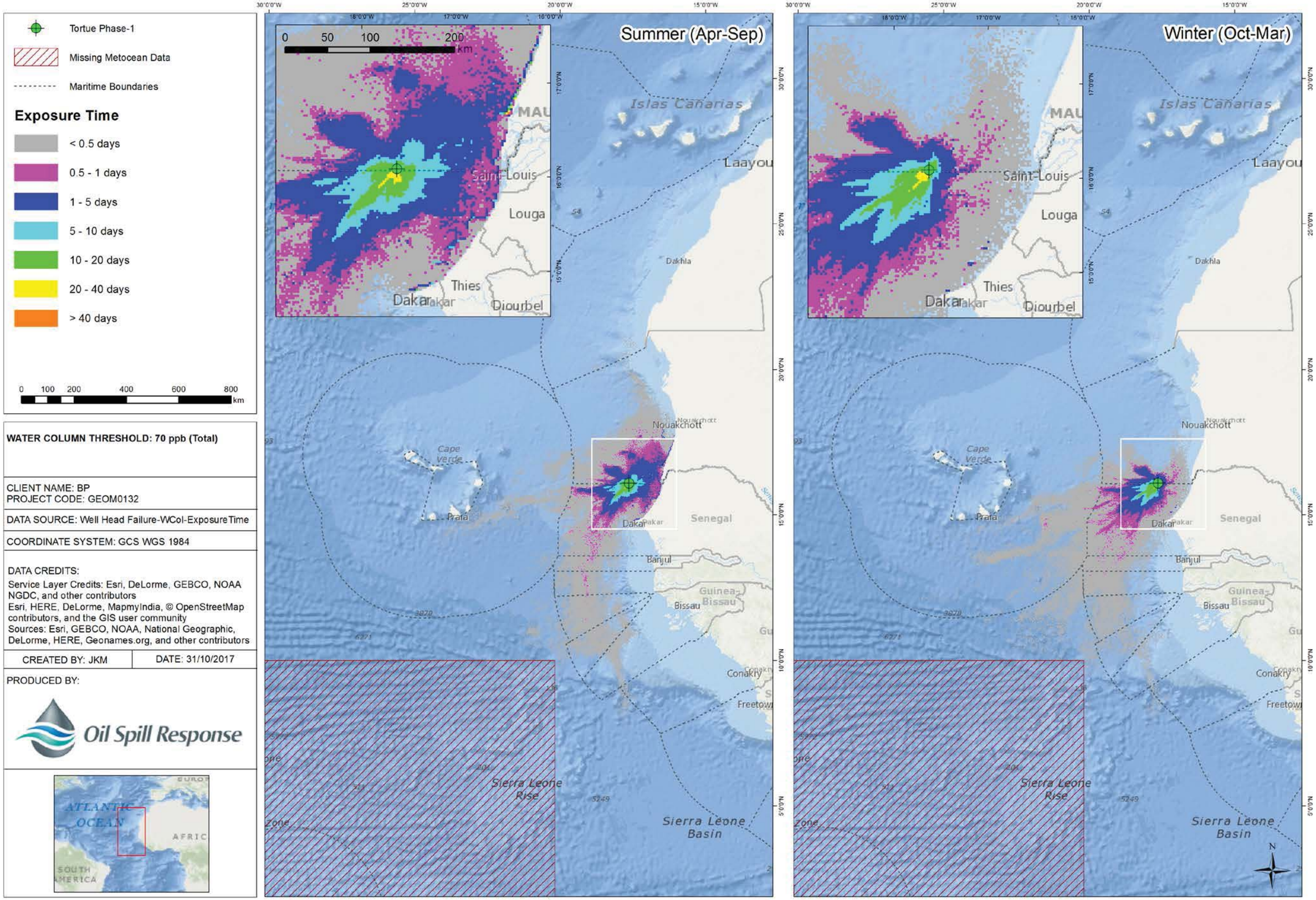


Figure 19: Well Blowout – Water Column (Total) Maximum Exposure Time – Summer (left) & Winter (right)

2.2 Comparison between Winter and Summer

Table 9 summarises the results of the stochastic simulations run for each scenario offshore Senegal. For more information on the thresholds used when post-processing the data see Section 1.4.

Table 10: Summary of stochastic results

Oil Spill Modelling Summary		
Spill Scenario/Description	Well blowout - Summer	Well blowout - Winter
Crosses a Maritime Boundary		
Cape Verde	51 % 15 days, 9 hours	100 % 9 days
Disputed Western Sahara / Mauritania	37 % 25 days, 9 hours	- -
Guinea	19 % 44 days	6 % 78 days
Guinea-Bissau	25 % 28 days, 9 hours	16 % 60 days, 6 hours
Mauritania	100 % <1 hour	100 % <1 hour
Senegal	100 % <1 hour	100 % 3 hours
Sierra Leone	6 % 68 days, 12 hours	- -
The Gambia	42 % 11 days, 15 hours	92 % 10 days, 18 hours
Western Sahara	17 % 33 days, 9 hours	- -
Shoreline Impact		
Mauritania	86 % 4 days, 1 hours	< 1 % 63 days, 3 hours
Senegal	94 % 5 days, 5 hours	33 % 11 days, 12 hours
Worst-Case Shoreline Impact		
Mass of oil onshore	11,091 MT	2,341 MT
Volume of oil onshore	14,057 m^3	2,967 m^3
Water content	0 %	0 %
Volume of emulsion onshore	14,057 m^3	2,967 m^3

Oil Spill Modelling Summary		
Spill Scenario/Description	Well blowout - Summer	Well blowout - Winter
Areas of Conservation Interest		
Cayar Canyon	77 % 3 days	100 % 3 days
Cayar MPA	34 % 7 days	18 % 9 days, 3 hours
Cayar Seamount Complex	98 % 1 day	100 % 1 day, 3 hours
Chatt Tboul Nature Reserve	76 % 6 days, 3 hours	- -
Coastal Habitats Neritic Zone MRT Extreme North	95 % 3 days, 12 hours	3 % 61 days, 18 hours
Cold Water Reefs	86 % 4 days, 6 hours	3 % 62 days, 18 hours
Conv Zone Canary Guinea EBSA	44 % 11 days, 21 hours	90 % 10 days, 21 hours
Diawling National Park	69 % 5 days, 1 hour	< 1 % 73 days, 12 hours
N Senegal Shelf Break IBA	99 % 2 days	66 % 3 days
Saint Louis MPA	98 % 3 days, 9 hours	7 % 7 days
Timris Canyon System	31 % 21 days, 3 hours	- -

2.3 Worst-Case Oil Spill Scenario

Trajectory results are generated by simulating a single spill scenario under specific conditions on a particular date. One 'worst case' trajectory was selected, from each pool of trajectories that make up the stochastics, to investigate the fate and behaviour of oil during the simulation in more detail.

In this report, the 'worst-case' trajectories are defined as:

- The trajectory that results in the **most oil to reach the shore**

Table 11: Key results from Scenario 1

		TrajSim(114) Summer	TrajSim(29) Winter
Model Setup	Release Location	Tortue Phase-1	
	Total Mass Spilled	189,747.3 MT	
First Shoreline Impact		27 days, 15 hours	41 days, 21 hours
Maximum Mass of Oil Onshore		11,091 MT	2,341 MT
Time when Maximum Mass of Oil Onshore Occurs		68 days 12 hours	69 days, 21 hours

The following figures are presented:

Most oil ashore trajectory

Figure 20: Mass balance plot for a well head failure during Summer

Figure 21: Mass balance plot for a well head failure during Winter

Figure 22: Overall area impacted for a well head failure – Summer (left) & Winter (right)

Figure 23: Overall maximum dissolved concentration – Summer (left) & Winter (right)

Figure 24: Overall maximum total concentration – Summer (left) & Winter (right)

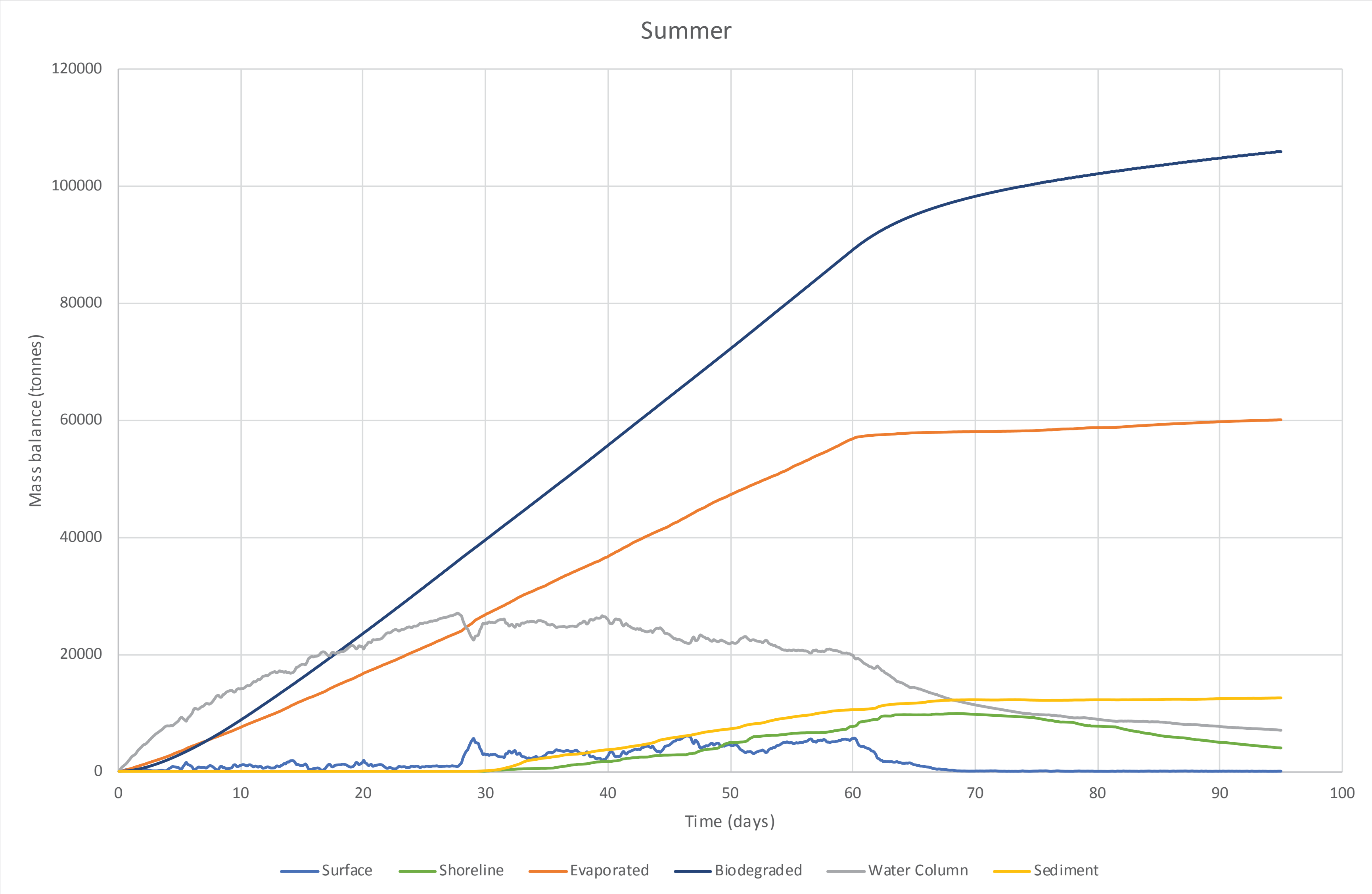


Figure 20: Mass balance plot for a well head failure during Summer

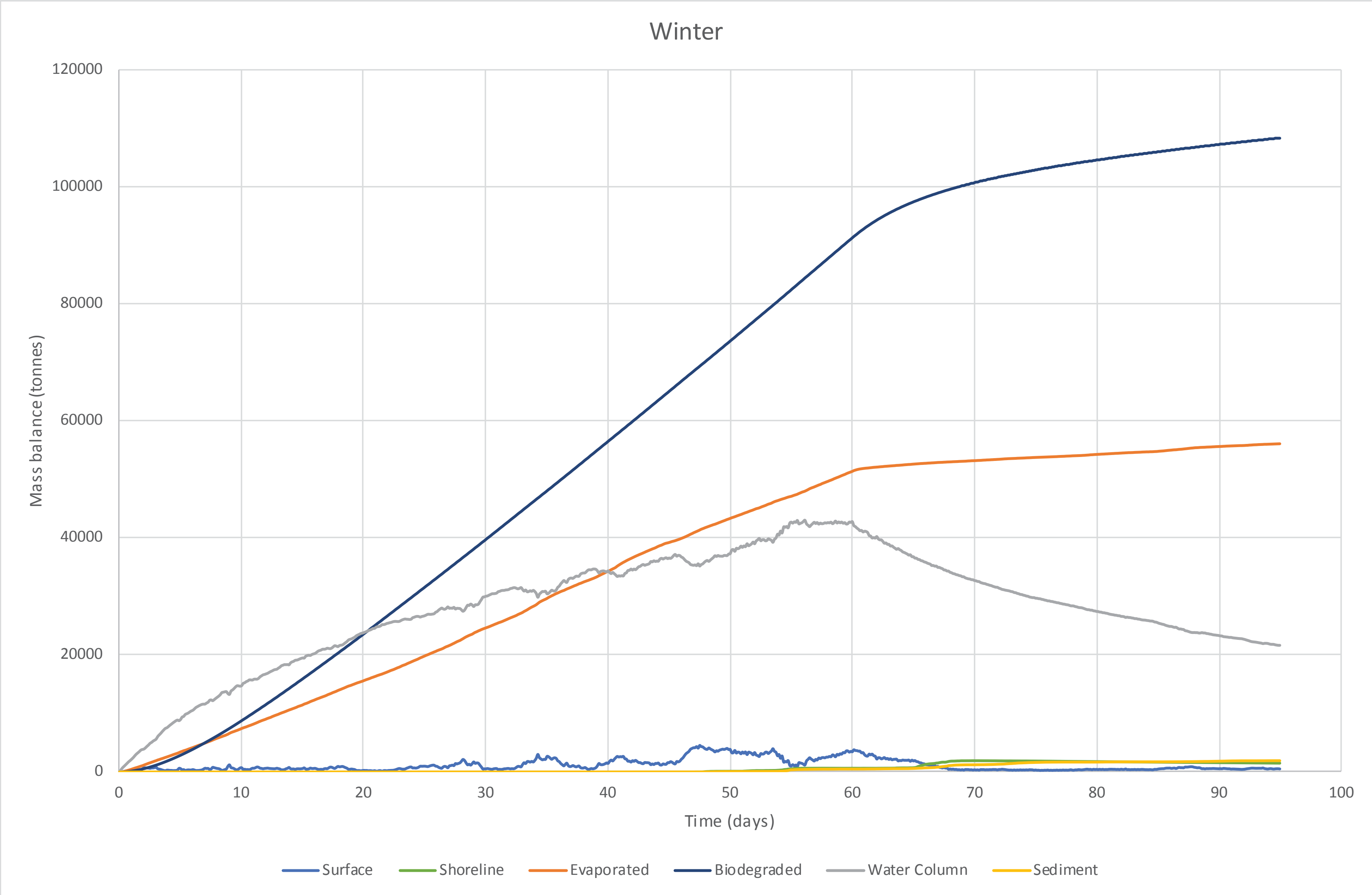


Figure 21: Mass balance plot for a well head failure during Winter

Table 12: Mass balance comparison table for a wellhead failure during summer and winter

	FATES (tonnes)											
	Surface		Shoreline		Evaporated		Biodegraded		Water Column		Sediment	
Time Stamp	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
0.5 days	226.8	152.3	0	0	166.6	152.5	42.45	42.41	1,145	1,234	0	0
1 day	116.7	318.7	0	0	487.5	477.4	158.2	156.1	2,400	2,210	0	0
5 days	390.8	541.4	0	0	3,413	3,422	2892	2,859	9,117	8,990	0	0
10 days	1041	687.8	0	0	7,558	7,412	8833	8,766	14,190	14,760	0	0
20 days	1,864	257.3	0	0	16,740	15,570	23,630	23,600	21,020	23,830	0	0
30 days	2,813	505.3	40.97	0	26,810	24,570	39,620	39,740	25,490	30,060	97.53	0
40 days	2,692	1,413	1,682	0	36,690	34,210	55,750	56,490	25,980	34,390	3704	0.8714
50 days	4,450	3,744	4,937	111	47,240	43,240	72,240	73,640	21,990	37,330	7268	61.31
60 days	5,591	3,353	7,733	570.3	56,790	51,260	89,140	91,280	19,950	42,810	10,540	466.5
70 days	31.05	360.1	9,802	1,720	58,000	53,080	98,270	100,700	11,410	32,740	12,240	1,149
80 days	6.213	424.7	7,770	1,582	58,690	54,140	102,100	104,600	8,935	27,450	12,230	1,580
90 days	25.22	524.5	4,996	1,420	59,690	55,490	104,800	107,200	7,701	23,340	12,420	1,721
95 days	16.12	497.5	4,019	1,343	60,020	55,960	105,900	108,300	7,049	21,660	12,550	1,801

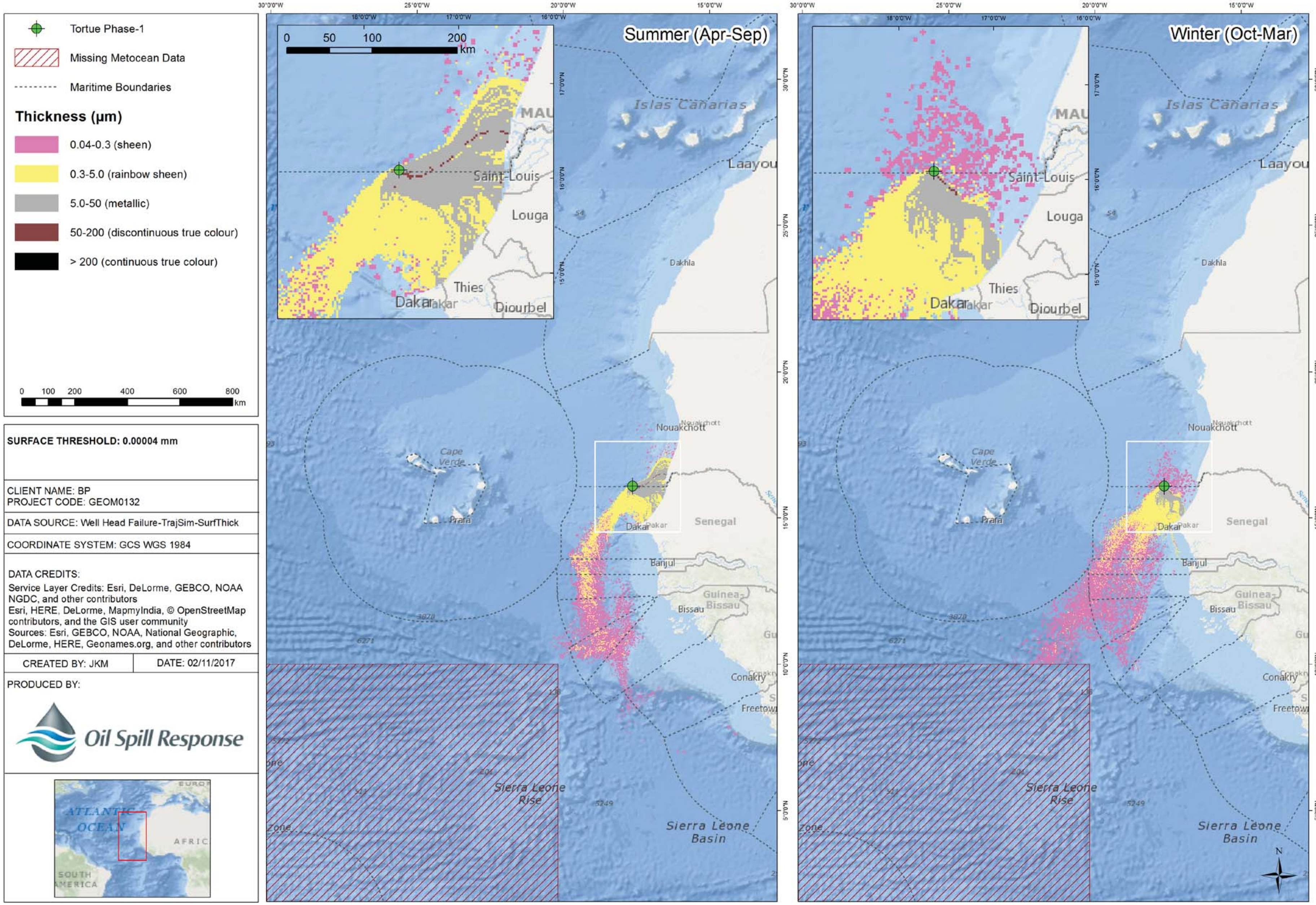


Figure 22: Overall area impacted for a well head failure – Summer (left) & Winter (right)

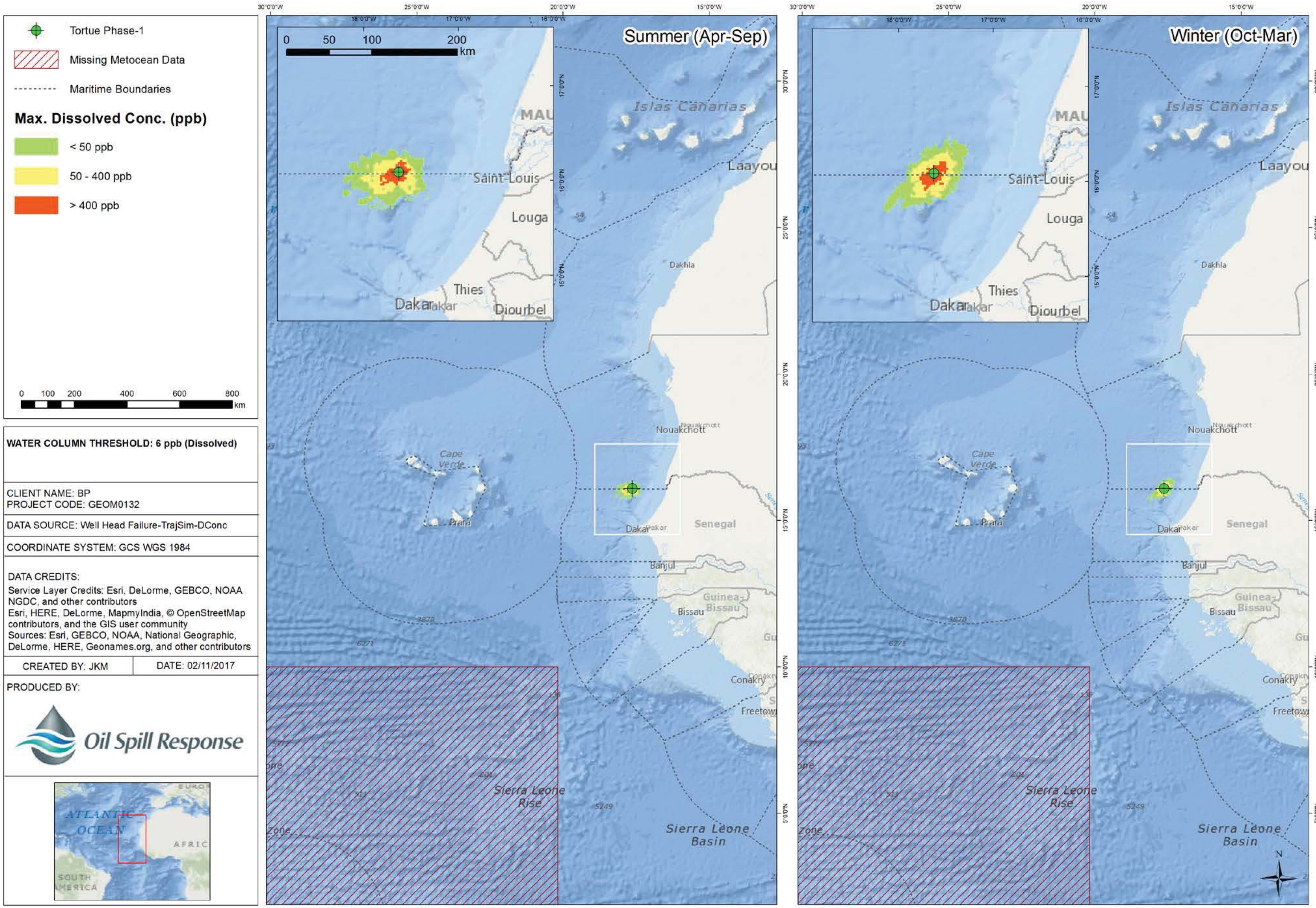


Figure 23: Overall maximum dissolved concentration – Summer (left) & Winter (right)

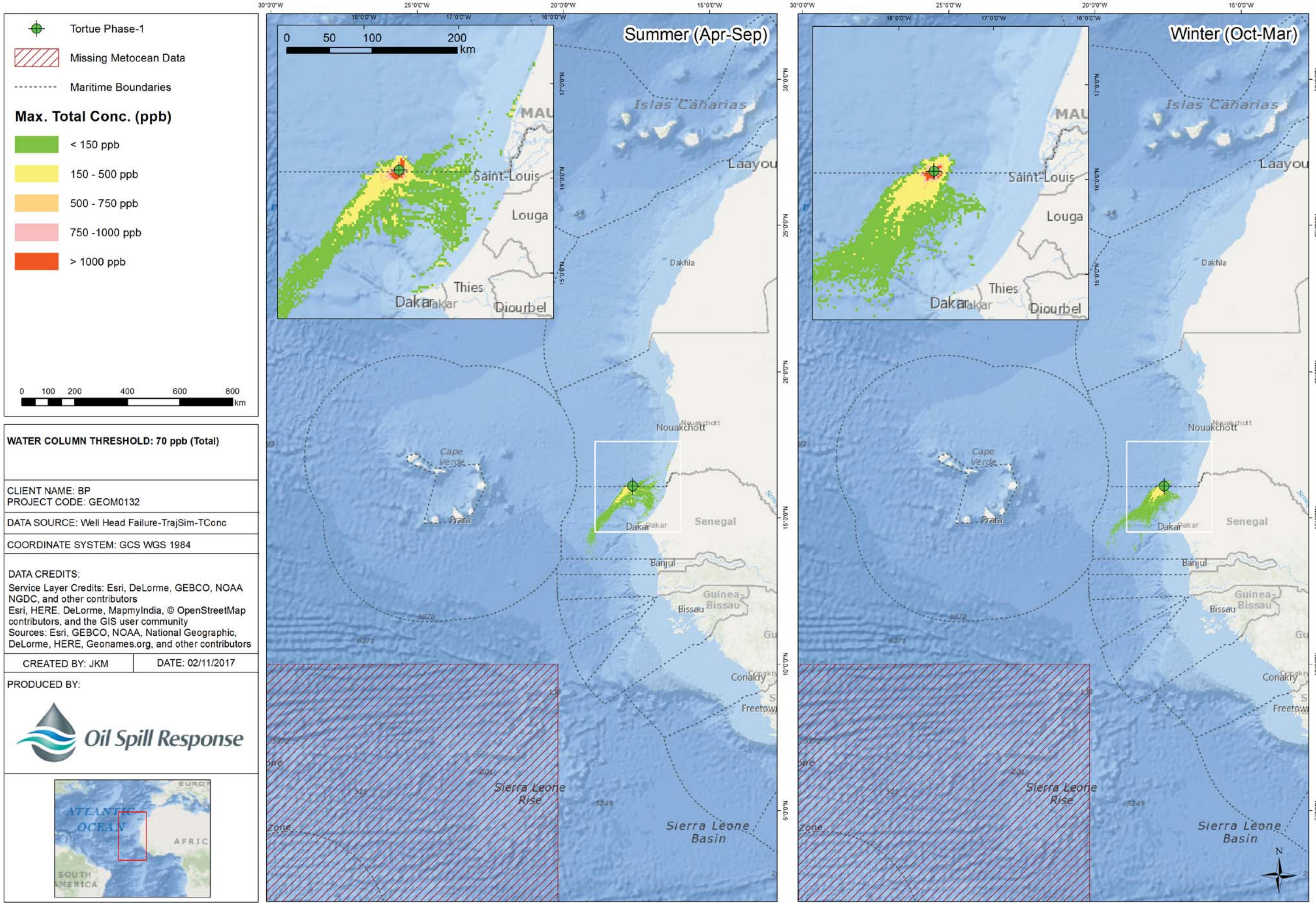


Figure 24: Overall maximum total concentration – Summer (left) & Winter (right)

3 CONCLUSION

One scenario was modelled for the Tortue Phase 1a Well offshore Senegal and Mauritania. This involved the release of 227,000 m^3 of condensate over 60 days because of a well head failure.

3.1 Shoreline Impact

A spill at this location, approximately 120 km from the shore, has a 96% probability of making shoreline impact (light oiling or higher) if the spill happens in Summer and a 33 % chance of shoreline impact if it occurs in Winter. Mauritania and Senegal are the only two countries at risk of shoreline impact, but Senegal is most likely to be more severely impacted.

Summer

Summer has a higher risk to the shoreline of the two seasons.

In the worst-case scenario, a spill in summer may impact the shore in approximately 4 days after the release. However, there is a 50% chance that condensate will not make landfall within approximately 2 weeks and in the best-cast scenario condensate won't reach the shore for 8 ½ weeks.

Similarly, the severity of the shoreline impact in summer ranges from negligible (4% chance) in the best-case scenario, to more than 11,000 MT in the worst-case. There is a 50% chance that more than 3,000 MT may wash ashore.

Whilst no "heavy" shoreline oiling is expected in the summer, there is an 84% chance that moderate shoreline oiling will occur and may extend up to nearly 300 km. There may also be an additional 185 km of light shoreline oiling.

Winter

Winter has a lower risk to the shoreline of the two seasons.

In the worst-case scenario, a spill in winter may impact the shore in approximately 5 days after the release. However, the similarity between summer and winter ends there since there is a 50% chance that condensate will not make landfall within approximately 7 weeks and in the best-cast scenario condensate won't reach the shore at all.

Similarly, the severity of the shoreline impact in winter ranges from no significant impact (67% chance) in the best-case scenario, to more than 2,200 MT in the worst-case.

Whilst no "heavy" shoreline oiling is expected in the winter, there is an 19% chance that moderate shoreline oiling will occur and may extend up to nearly 54 km.

3.2 Surface Impact

Both Mauritania and Senegal Waters' will be impacted by this spill scenario. Whilst more countries will be impacted in the summer scenario (9 countries in summer vs. 6 countries in winter), a winter spill is far more likely to impact Waters' of Cape Verde (51% in summer vs. 100 % in winter) and The Gambia (42 % in summer vs. 92% in winter).

However, the thickness of the condensate spill is limited to mostly sheen and rainbow sheen that will more readily disperse. A small amount of metallic sheen (>5 µm) may be found in the local area around the well (~25 km). Because of the high turbidity created by the gas at the well site, condensate droplets are very small. Consequentially, they rise more slowly and do not concentrate in the same way as if there was an absence of gas.

APPENDIX A. MODEL INPUTS

	Scenario 1	Scenario 2
Description	Well blowout - summer	Well blowout - winter
Latitude	16° 05' 14.7516" N	16° 05' 14.7516" N
Longitude	017° 37' 32.718" W	017° 37' 32.718" W
Time of Year	Apr-Sep	Oct-Mar
Release Depth	2,725 m	
Release Rate	3,783.3 m^3/day	
Release Duration	60 days	
Duration After Cessation	35 days	
Total Model Duration	95 days	
API Gravity	47.8	
Specific Gravity	0.789	
Viscosity (cP)	2.0	
Pour Point (°c)	-6.0	
Wax (%)	6.00	
Asphaltenes (%)	-	
Diameter of Release Hole (m)	0.314	
Gas to Oil Ratio (GOR, Sm^3/m^3)	127,220	
Gas Density (kg/Sm^3)	0.6	

APPENDIX B. METOCEAN DATA

Table 13: Current data – general description

Name	G0132-Curr01		
Description	Sourced from BMT ARGOSS. The dataset consists of an amalgamation of the HYCOM global dataset with the BMT ARGOSS tidal model superimposed		
Start Time	Jan 2009	**Spatial Resolution**	~9 km
End Time	Dec 2011	**Temporal Resolution**	1 hour
Depth Levels [m]	0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1750, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500		

The hydrodynamic database is constructed from 3D current velocity fields, suitable for use in oil model simulations. This comprises of ocean currents (non-tidal residual) from a global ocean circulation model, combined with tidal current velocities.

Tidal current information is obtained from BMT ARGOSS from the integration of approximately 5,000 tidal stations and 15 years of satellite radar altimeter into depth averaged global and regional tidal models (2DH model). The tidal model provides tidal currents (u, v components) as well as surface elevation. The spatial resolution of the tidal model varies from 1/60 to 1/12 degrees globally.

The vertical structure of the tidal current component is established using a logarithmic profile which provides a reliable representation of tidal currents at different depths in shelf seas. The tidal model provides data at a spatial resolution of 4 minutes in the area of interest and can be provided in time steps as required by the client.

Ocean currents are obtained from a global ocean current model (HYCOM), which has the following characteristics:

Spatial resolution: 1/12 degree (can not be refined further)

Temporal resolution: Daily (cannot be refined further, other than by interpolation)

Data type: 3D current speed and direction

Depth: 3D datasets consist of up 33 depth layers from surface to seabed and spread across the water column. Individual layers and their distribution over the water column vary and depend on the local depth.

Availability: 2009 – 2012

The resultant data, representative of total current velocity, is provided as hourly current vectors, at selected depth levels, at 1/12 degree spatial resolution across the area of interest. It should be noted that in deep water, beyond the continental slope, tidal current velocity would be negligible.

Temporal resolutions of one hour are considered to be an optimal resolution, as coarser temporal resolutions would not adequately capture the data variability in areas where tidal currents form a key component of the total current

Table 14: Wind data – general description

Name	G0132-Wind01		
Description	Sourced from BMT ARGOSS. The dataset consists of the NCEP CFRS global dataset, calibrated by BMT ARGOSS against satellite altimeter and scatterometer measurements.		
Start Time	Jan 2009	**Spatial Resolution**	~35 km
End Time	Dec 2011	**Temporal Resolution**	3 hours
Altitude Level	The dataset includes hourly mean values of wind velocity at 10 m above sea level.		

Winds are provided as hourly mean values of north and east velocity components at 10m above sea level. Data is from the NCEP global dataset, calibrated by BMT ARGOSS against satellite altimeter and scatterometer measurements. The source data are available at spatial resolution of 0.5°x 0.5°, and at 3 hourly time steps.

APPENDIX C. JUSTIFY RELEASE DURATION

Each simulation has been allowed to run for 35 days after the last release of condensate. To determine the length of time after the final release we ran a trajectory with a random start date and monitored the fate of the condensate spill.

Our initial simulation showed that the following is true:

- No condensate remained on the ocean surface after 82 days
- 25,500 MT (13% of the total released) of condensate was submerged in the water column.
- The dissolved concentration of submerged condensate dropped below the 6 ppb threshold after approximately 11 days.
- The total concentration of submerged condensate dropped below the 70 ppb threshold after approximately 15 days.

Based on these results we decided on a conservative 35-day (5 week) duration after the final release of condensate will be implemented. This means that the results presented in this report represent a condensate spill tracked until it no longer poses an environmental risk.

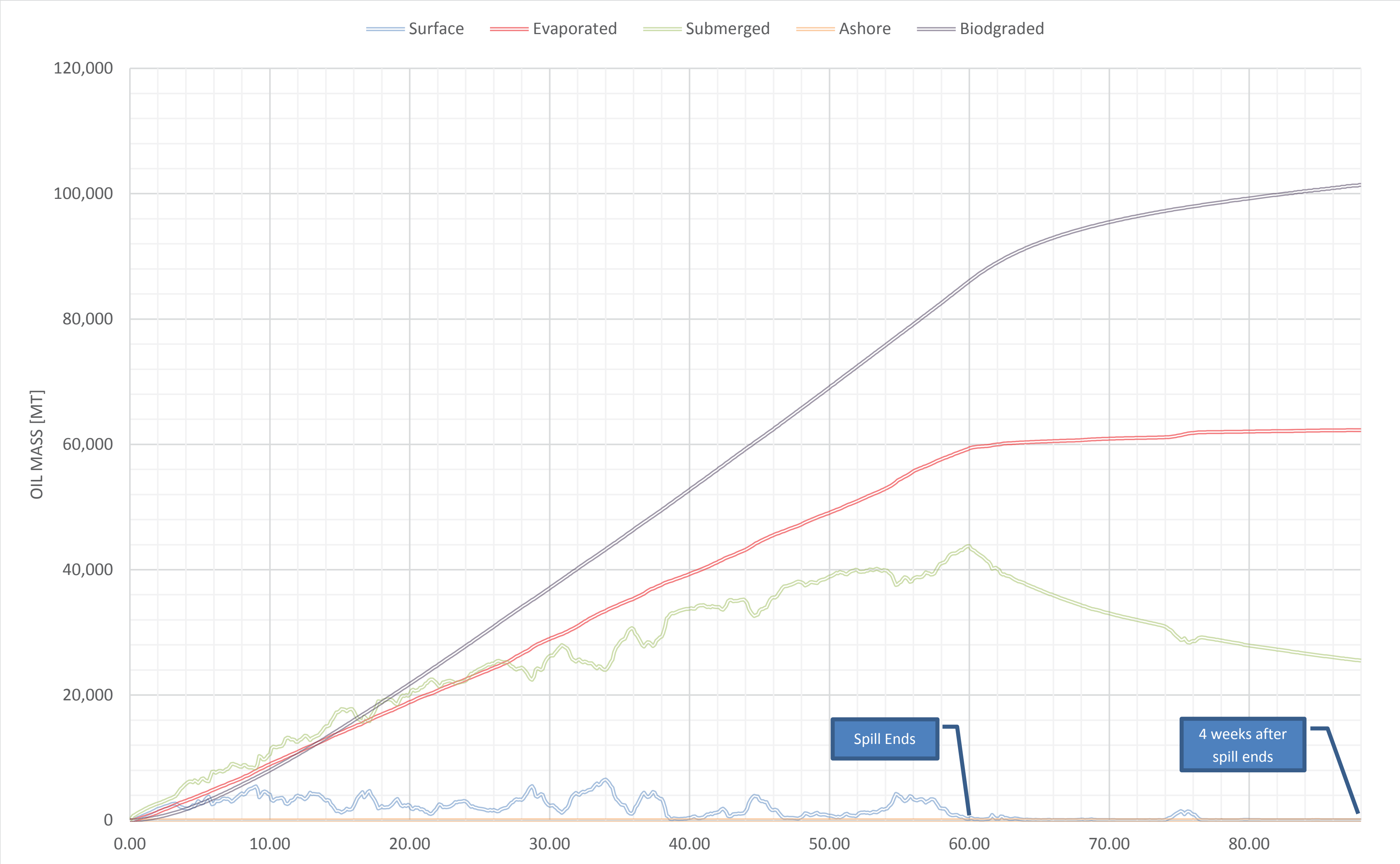


Figure 25: Mass Balance of the Trajectory used to determine the post spill duration

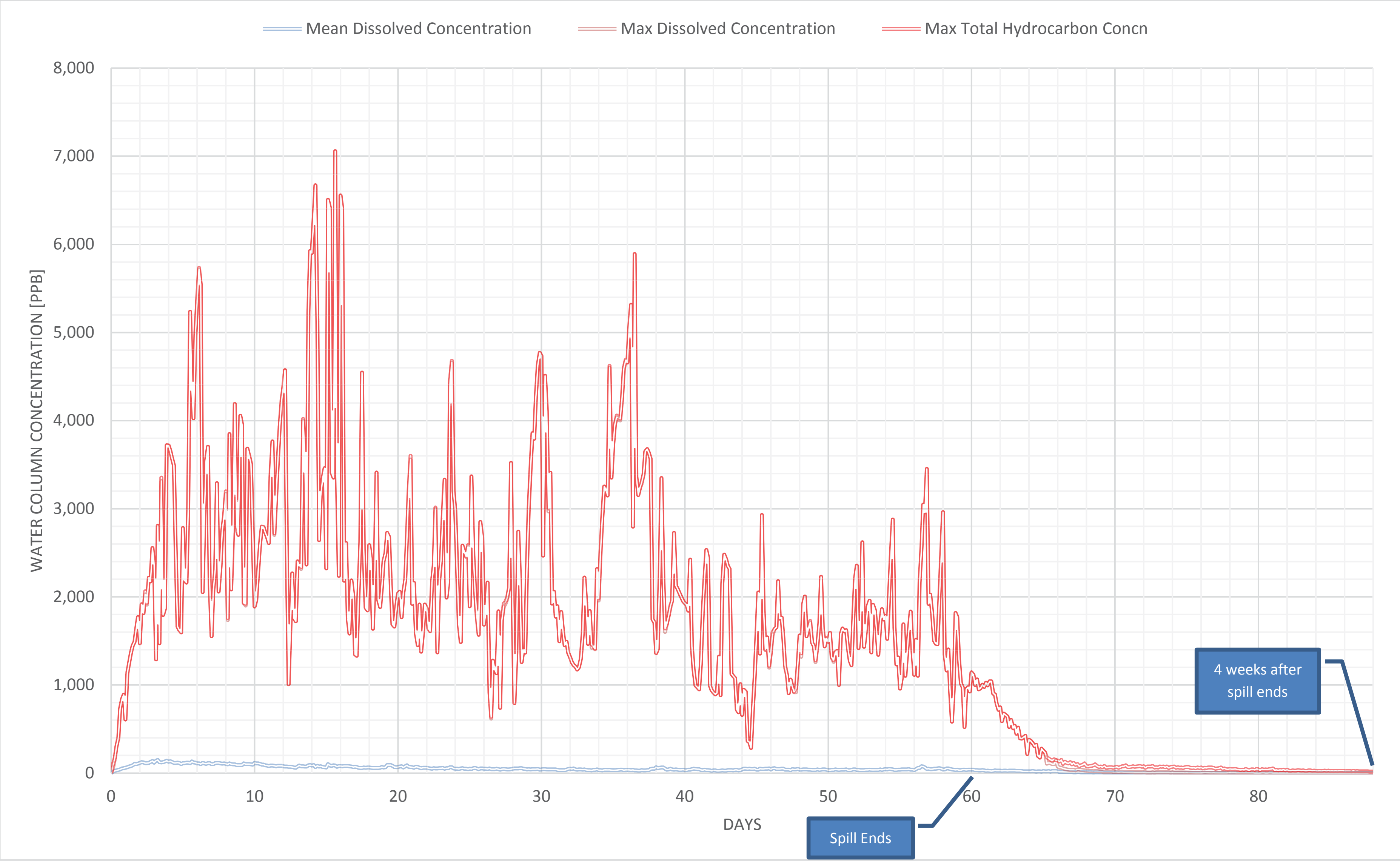


Figure 26: Water Column Concentrations of the Trajectory used to determine the post spill duration

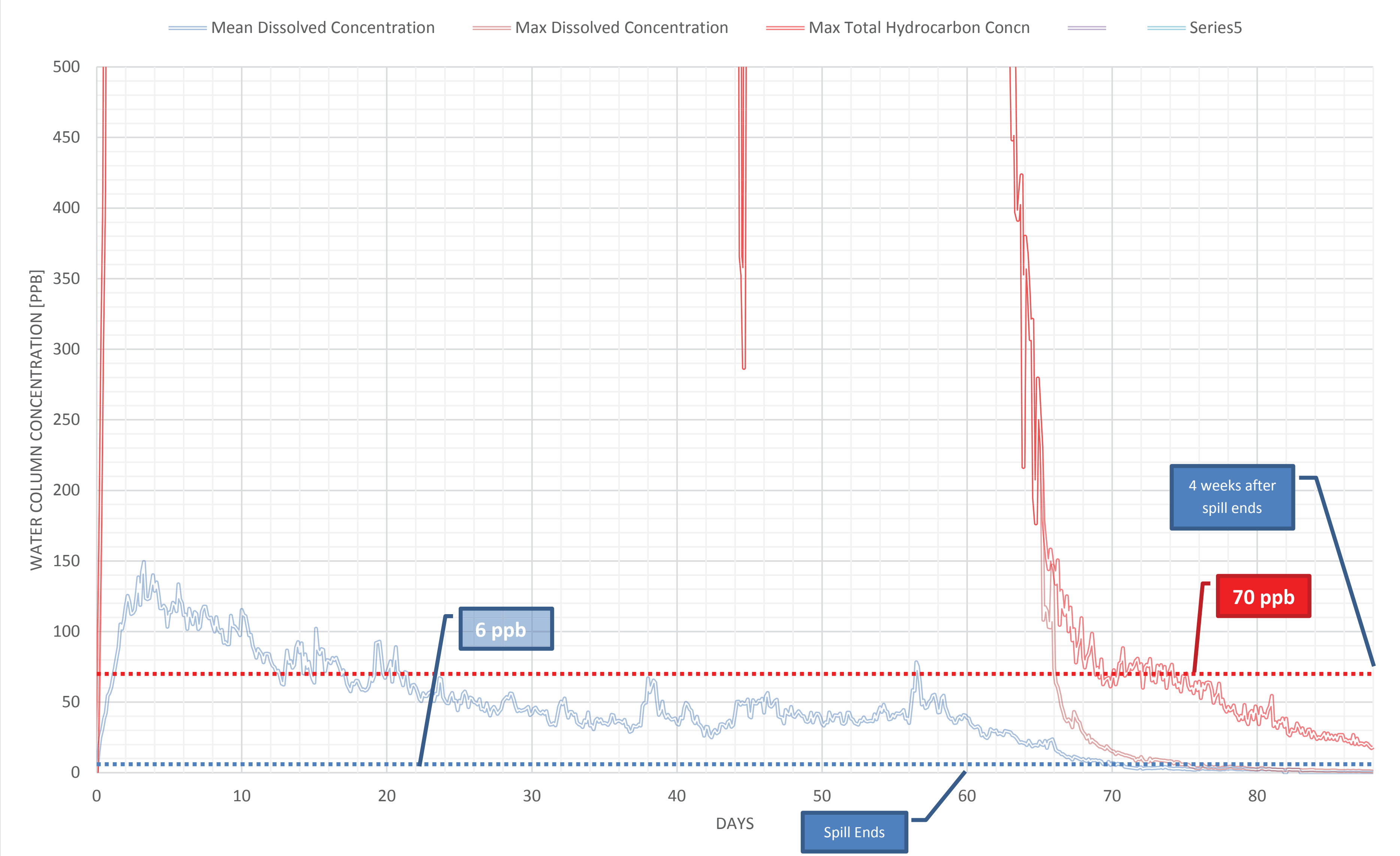


Figure 27: Water Column Concentrations of the Trajectory used to determine the post spill duration

APPENDIX D. HABITAT GRID

Table 15: Habitat domain details

Name	Domain Extent			
G0132-Hab02	Bottom	Top	Left	Right
	05° 00' 00'' N	25° 00' 00'' N	030° 00' 00'' W	010° 00' 00'' W
	Number of Cells		Cell Resolution	
	East to West	North to South	East to West	North to South
	858	888	2,500 km	2,500 km
	Domain Size			
	East to West		North to South	
	2,145 km		2,220 km	

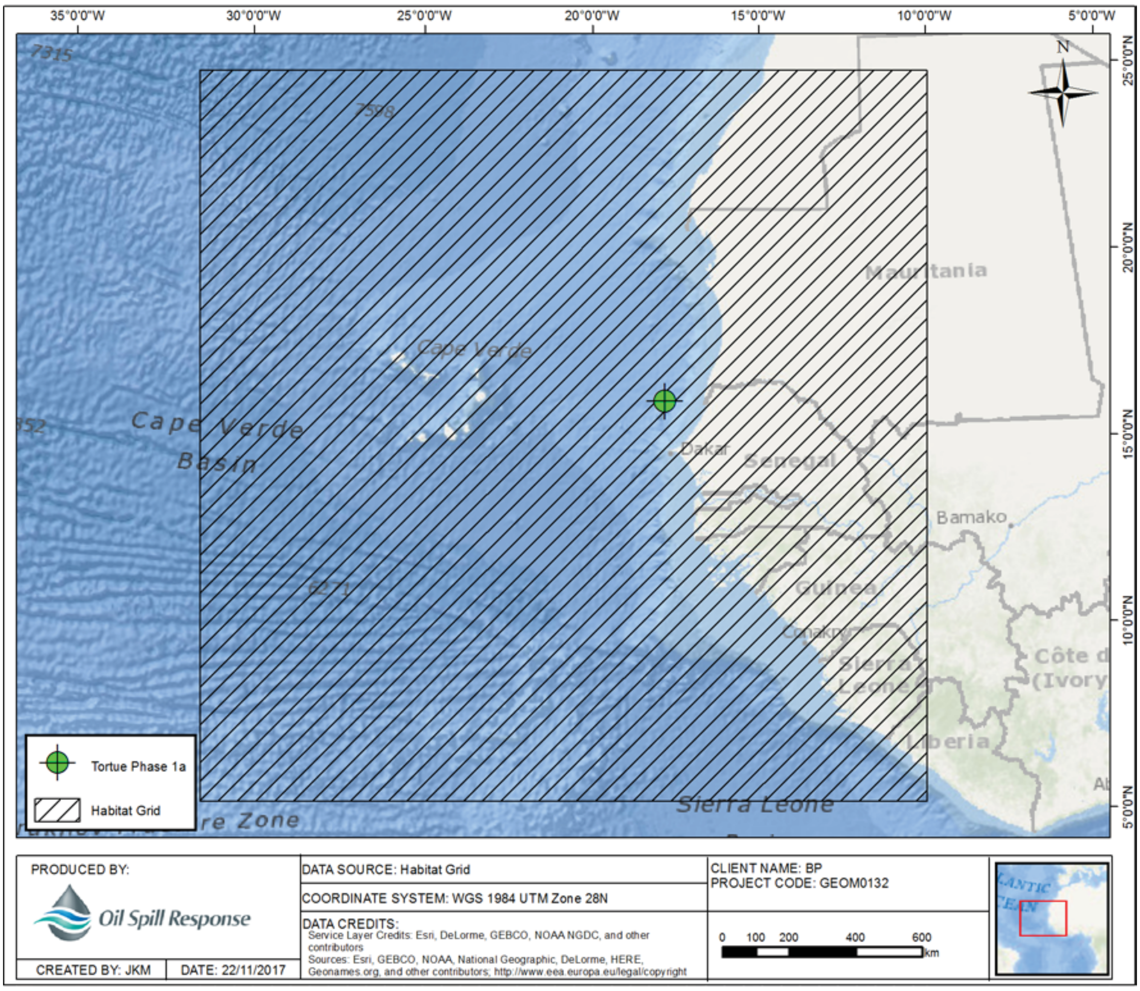


Figure 28:Extent of habitat grid used in this study

APPENDIX E. OIL CHARACTERISTICS AND BEHAVIOUR

The components found in oil are classified into two main groups: hydrocarbons and non-hydrocarbons (see Figure 30). If oil is rich in C1-12 alkanes, it is particularly light, as these are lighter components than the C25+ alkanes. Conversely, if oil contains high quantities of C25+ alkanes, resins and asphaltenes, it is heavy.

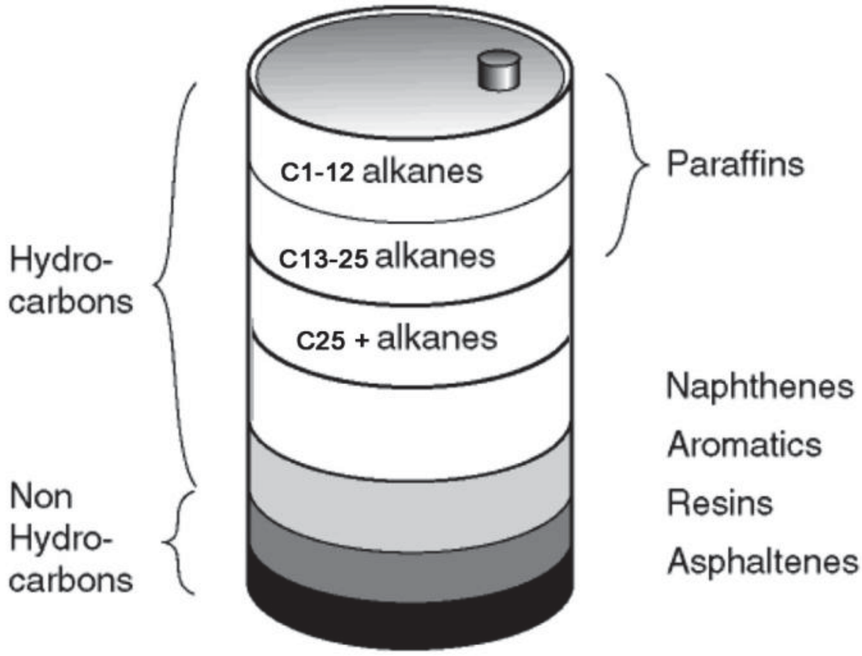


Figure 29:The chemical composition of crude oil

The chemical composition of oil is important when predicting how it will break down or weather. For example, oil containing mostly light components is likely to lose a greater volume to evaporation than heavy oil. Oils with carbon chains exceeding 15 (C15+) cannot evaporate, even during large storms. Long chains (for example, C25+ alkanes) take a long time to degrade in the water column. Asphaltenes can increase the stability of oil, allowing it to take up water but preventing the oil and water emulsion from breaking down.

As oil is a complicated mixture of organic compounds, its components must be analysed to characterise it successfully (LECO Corporation, 2012). The components of oil can be 'identified' and plotted using gas chromatography instruments which are coupled with mass spectrometers (see Bacher, 2014, for further information). The results of gas chromatography and mass spectrometry are converted into a list of 25 sub-components, as broken down in the OSCAR oil database. Each of the 25 sub-components is characterised by molecular weight, density, viscosity, boiling point, solubility in water, vapour pressure, and partition coefficient between oil and water.

The OSCAR Oil Database

A strength of the OSCAR model is its foundation on an observational database of oil weathering properties (maximum water content, viscosity, droplet size distribution, evaporation, emulsification and dispersion, which are measured in a wide range of conditions). The oil database contains complete weathering information for 340 crude oils and petroleum products. It also contains crude assay data for approximately 170 other crude oils (derived from the HPI database - HPI, 1987). But these oils have

not been lab-tested so model estimates of the weathering process are used in place of observational data. This reduces the reliability of the model.

Oil Matching

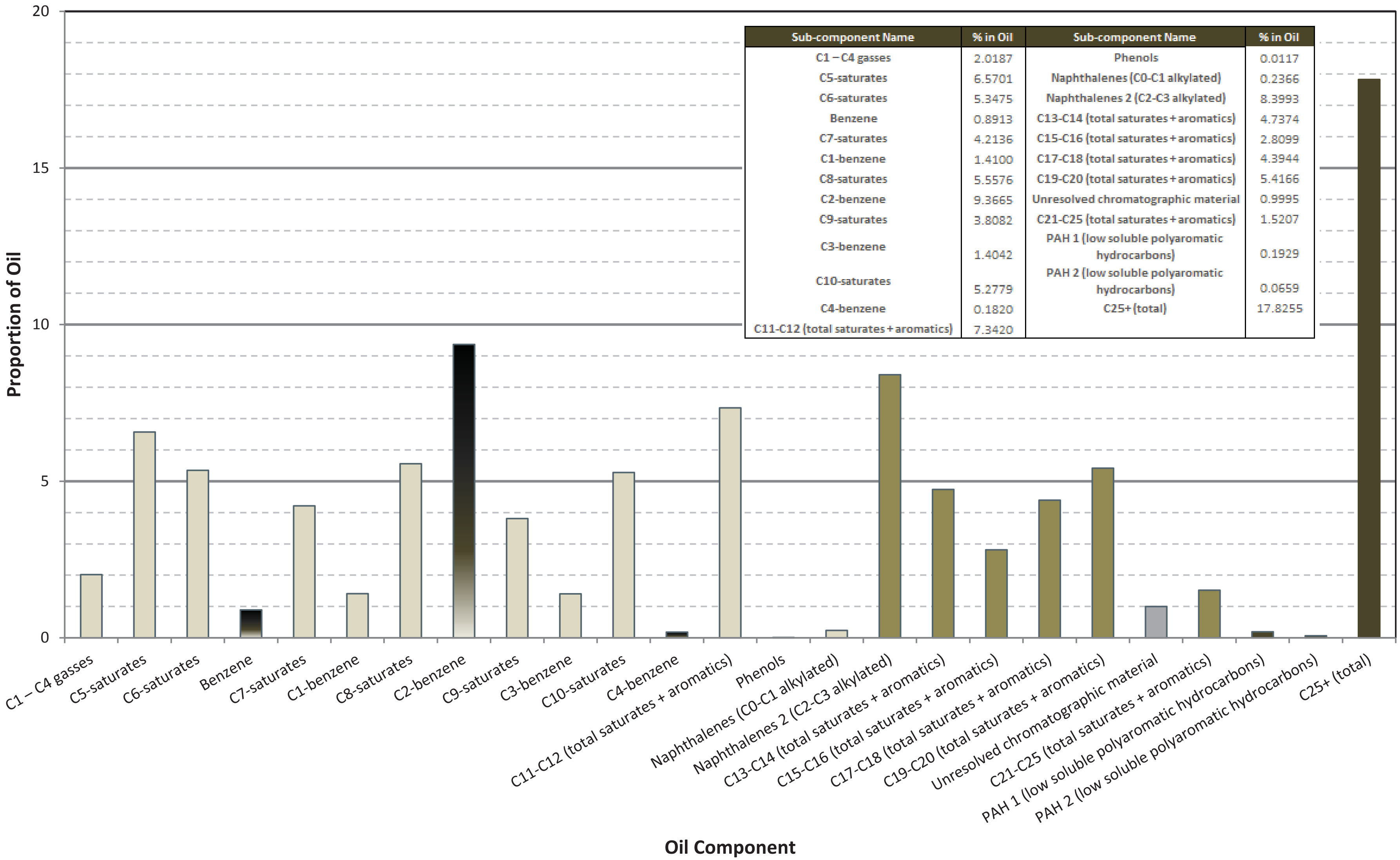
A lab tested condensate was selected for this modelling study based on the information provided by BP for the previous produced condensate.

The properties of the modelled condensate are shown in Table 14. Figure 30 lists the sub-components of the modelled condensate and their percentage fraction.

Table 16: Properties of the modelled oil

Name	Specific Gravity	Viscosity (cP)	Pour Point[2]* (°C)	Wax Content (%)	Asphaltenes (%)
Client condensate	0.735	1.0	< -6	3.0 - 5.0	0
Modelled condensate (Lavrans)	0.789	2.0	-6.0	6	-

[2] Due to the algorithms in the model, Pour Point is of lesser importance when oil matching.



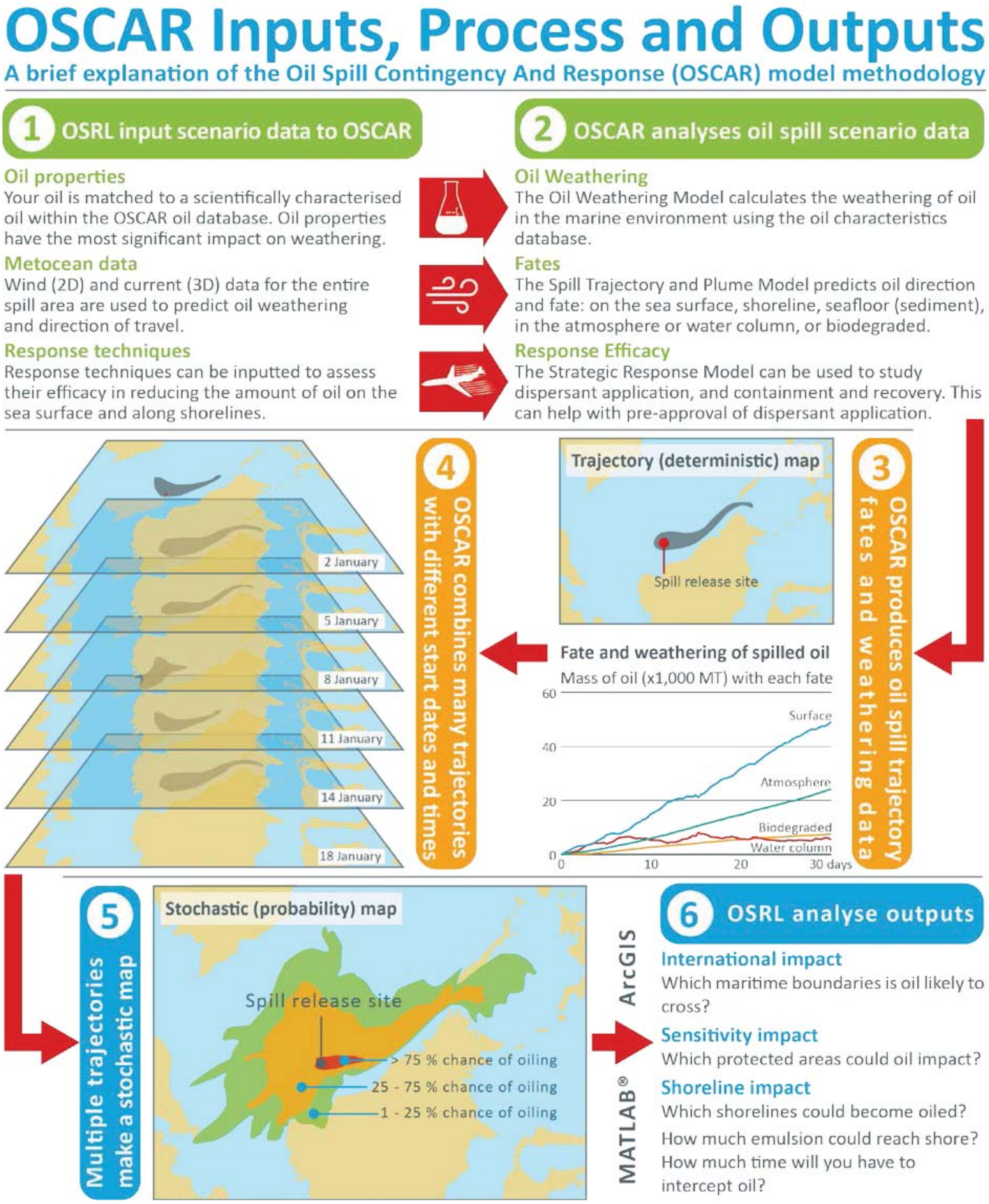
Sub-component Name	% in Oil	Sub-component Name	% in Oil
C1 – C4 gasses	2.0187	Phenols	0.0117
C5-saturates	6.5701	Naphthalenes (C0-C1 alkylated)	0.2366
C6-saturates	5.3475	Naphthalenes 2 (C2-C3 alkylated)	8.3993
Benzene	0.8913	C13-C14 (total saturates + aromatics)	4.7374
C7-saturates	4.2136	C15-C16 (total saturates + aromatics)	2.8099
C1-benzene	1.4100	C17-C18 (total saturates + aromatics)	4.3944
C8-saturates	5.5576	C19-C20 (total saturates + aromatics)	5.4166
C2-benzene	9.3665	Unresolved chromatographic material	0.9995
C9-saturates	3.8082	C21-C25 (total saturates + aromatics)	1.5207
C3-benzene	1.4042	PAH 1 (low soluble polyaromatic hydrocarbons)	0.1929
C10-saturates	5.2779	PAH 2 (low soluble polyaromatic hydrocarbons)	0.0659
C4-benzene	0.1820	C25+ (total)	17.8255
C11-C12 (total saturates + aromatics)	7.3420		

Figure 30:Chemical composition of the modelled condensate

APPENDIX F. OIL SPILL MODELLING SOFTWARE AND METHODOLOGY

This project was completed using the version of OSCAR contained within the Marine Environmental Modelling Workbench (MEMW) 8.0, a model that has been fully validated and calibrated using various field observations from several experimental oil spills (Reed et al., 1995, 1996).

OSCAR predicts the movement of oil at the water's surface and throughout the water column. OSCAR consists of several interlocking modules that are activated as required. The following infographic illustrates the OSCAR modelling process.



APPENDIX G. GLOSSARY OF TERMS, ACRONYMS AND ABBREVIATIONS

°C	Degrees Celsius (1.0°C = 33.8° Fahrenheit)
µm	Micrometre (1.0 µm = 10^{-6} m)
API	American Petroleum Institute
API Gravity	API Gravity, like specific gravity, is a ratio between the densities of oil and water. Unlike specific gravity, API gravity is only used to describe oil, which it characterises as: • Light - API > 31.1 • Medium - API between 22.3 and 31.1 • Heavy - API < 22.3 • Extra Heavy - API < 10.0 API Gravity is converted to Specific Gravity using the following formula: *API gravity = (141.5/Specific Gravity) – 131.5* An API of 10 is equivalent to water, so oils with an API above 10 will float on water while oils with an API below 10 will sink. See also: *Specific Gravity, API*
ArcGIS	A geographic Information System (GIS) used to present OSCAR outputs on maps.
Asphaltene Content	The asphaltenes present the crude oil components that are (1) insoluble in n-heptane at a dilution ratio of 40 parts alkane to 1 part crude oil and (2) re-dissolves in toluene. The asphaltenes include the crude oil material highest in molecular weight, polarity and aromaticity.
bbls	Barrels of oil (a unit of volume). (1.0 bbls = 0.15899 m^3 and 1.0 m^3 = 6.2898 bbls) The conversion between mass and volume requires knowledge of the oil density. See also: *MT, API Gravity, Specific Gravity*
bbls/day	Barrels of oil per day (rate).
BONN Agreement	The BONN Agreement is an international standard and agreement on how to characterise and respond to pollution. Although aimed at pollution in the North Sea (Europe) many of the characterisation standards are internationally recognised.
FPSO	Floating Production Storage and Offloading - a floating vessel used for producing, processing and storing oil.
GOR	Gas to Oil Ratio - the ratio of volumetric flow of produced gas to the volumetric flow of oil. Although GOR is a ratio, the volume units must be known since gas and oil volumes are measured differently. GOR changes with temperature and pressure so the condition under which GOR is measured must be known.
ITOPF	The International Tanker Owners Pollution Federation Limited
km	Kilometres (1.0 km = 1,000 m) See also: *m*
m	Metres (1.0 km = 1,000 m) See also: *µm, km*
MATLAB	Matrix Laboratory - a multi-paradigm numerical computing environment and programming language used in this study for the manipulation of data outputs from OSCAR.

MEMW	Marine Environmental Modelling Workbench - the modelling software package developed by SINTEF. The MEMW consists of three models: • **DREAM (Dose, Risk and Effects Assessment Model)** • **OSCAR (Oil Spill Contingency and Response Model)** • **ParTrack Model** When combined, these three models quantify the environmental effect of most chemical pollution activities. See also: *OSCAR, SINTEF*
MT	Metric Tonnes - this is a unit of oil mass. (1.0 MT = 1,000 kg) The conversion between mass and volume requires knowledge of the oil's API or Specific Gravity as follows: *Barrels per metric ton = 1/[(141.5/(API + 131.5) x 0.159]* See also: *bbls, API Gravity, Specific Gravity*
NOAA	National Oceanic and Atmospheric Administration – an American scientific agency focussed on metocean conditions
OSCAR	Oil Spill Contingency And Response A state of the art 3D oil spill model and simulation tool for predicting the fates and effects of oil released into the marine environment. Developed by SINTEF, it sits within the larger MEMW application. See also: *SINTEF, MEMW*
OSRL	Oil Spill Response Limited
Pour Point	The pour point of a liquid is the lowest temperature at which it shows flow characteristics. If ambient temperature is less than the liquid's pour point it will begin to solidify.
SCAT	Shoreline Cleanup Assessment Technique
SINTEF	SINTEF is an independent research organisation in Norway which develops the OSCAR model used in this study.
Specific Gravity	Specific gravity is a ratio of the density of one substance to the density of a reference substance, usually water. Specific gravity of oil is a ratio of the density of oil to the density of water. See also: *API Gravity, bbls, MT*
Stochastic	Stochastic (or probabilistic) results show the probability or likelihood of an event occurring. They provide statistical data that can be used to assess risk and identify worst-case scenarios. Stochastic results are achieved by combining many different trajectory simulations. See also: *Trajectory*
Trajectory	Trajectory or deterministic results show the impact of a single spill event over time. Can be used to assess different response options such as booms, skimmers and dispersant. See also: *Stochastic*
UTC	Coordinated Universal Time
Wax Content	Represents the crude oil components that are soluble in higher molecular weight normal alkanes (n-heptane) but are insoluble in lower molecular weight alkanes (n-pentane).

APPENDIX H. REFERENCES

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APPENDIX N-1b : OIL SPILL MODELING REPORT – FPSO FAILURE DUE TO A VESSEL COLLISION

Oil Spill Modelling Report – FPSO Storage Tank & Diesel Tank Failure
Tortue Phase 1a

BP p.l.c.

Document Number: GEOM0132g R03

Issued: 19 January 2018

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EXECUTIVE SUMMARY

Oil spill modelling was completed by Oil Spill Response Ltd. (OSRL) on behalf of BP for the Tortue Phase 1a project, offshore Senegal and Mauritania (Figure 1). The results of this analysis will support the Oil Spill Contingency Plan and the Environmental Impact Assessment for the area. The modelled scenarios are summarised in Table 1.

Scenario 1. FPSO storage tank and diesel tank failure resulting in release of 163,200 m^3 over 160 hours during summer (Apr-Sep)

Scenario 2. FPSO storage tank and diesel tank failure resulting in release of 163,200 m^3 over 160 hours during winter (Oct-Mar)

The coastlines of Senegal and Mauritania are at risk due to a FPSO storage tank and diesel tank failure. Summer is worse than winter with condensate and diesel almost certainly reaching the shore within 8 days and in the worst-case in less than 2 days. Summer also has a greater chance of a more considerable impact with a 50% chance that the amount of condensate and diesel reaching the shore will exceed 9,500 MT. Winter has only a 13% chance that the same amount of condensate and diesel will reach the shore.

Senegal is expected to see more oiling than Mauritania. A summer spill may also result in 'heavy' shoreline oiling (using ITOPF's recognition of shoreline oiling (See Thresholds)). However, the length of shoreline that could be impacted by heavy oiling is restricted to less than 7 km.

The trajectories undertaken shows that evaporation of the condensate and diesel is considerable within the first 7 days. Shoreline oiling, sedimentation and biodegradation then become the dominant processes.

In the worst-case winter scenario, the amount of condensate and diesel on the shore peaks at 21,536 MT (27,295 m^3) after 28 days.

The waters of Senegal and Mauritania could experience a spill with a surface thickness more than 5 µm making them candidates for containment and recovery techniques.

DOCUMENT HISTORY

Document Number	Revision	Document Type	Author	Technical Review	Format Review	Date of Issue
GEOM0132g	R01	Draft Modelling Report	JKM	LHM	SJB	08-Dec-17
GEOM0132g	R02	Response to Comments	JKM	LHM	SJB	12-Jan-18
GEOM0132g	R03	Response to Comments	LHM	N/A	N/A	19-Jan-18

JKM – Jenny Kirsty Mitchell LHM – Liam Harrington-Missin SJB – Simon Blaen

DISCLAIMERS

- Modelling results are to be used for guidance purposes only and response strategies should not be based on these results alone.
- The resolution / quality of wind and current data vary between regions and models. As with any model, the quality and reliability of the results are dependent on the quality of the input data.

Considering the above, all advice, modelling, and other information provided is generic and illustrative only and not intended to be relied upon in any specific instance. The recipient of any advice, modelling or other information from, or on behalf of, OSRL acknowledges and agrees that any number of variables may impact on an oil spill and, as such, should be addressed on an individual basis. OSRL has no liability in relation to such advice, modelling or other information and the recipient of such information hereby fully indemnifies and holds harmless OSRL its officers, employees, shareholders, agents, contractors and sub-contractors against any costs, losses, claims or liabilities arising about such advice, modelling, training or other information.

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1 INTRODUCTION

1.1 Background

Oil spill modelling was completed by Oil Spill Response Ltd. (OSRL) on behalf of BP for the Tortue Phase 1a project, offshore Senegal and Mauritania (Figure 1). The results of this analysis will support the Oil Spill Contingency Plan and the Environmental Impact Assessment for the area. The modelled scenarios are summarised in Table 1.

Scenario 1. FPSO storage tank and diesel tank failure (due to a ship collision) resulting in release of 160,000 m^3 of condensate over 160 hours and 3,200 m^3 of diesel over 3.2 hours during summer (April-September)

Scenario 2. FPSO storage tank and diesel tank failure (due to a ship collision) resulting in release of 160,000 m^3 of condensate over 160 hours and 3,200 m^3 of diesel over 3.2 hours during winter (October-March)

The modelling was carried out using SINTEF's Oil Spill Contingency and Response (OSCAR) model. OSCAR is a 3D modelling tool used to predict the movement and fate of oil on the sea surface and throughout the water column (see APPENDIX F for further details).

1.2 Aims

The aim of this report is to present the risk to the sea surface and shoreline by creating spatial maps of:

1. Probability - to estimate how likely an area is to be impacted.
2. Arrival time - to estimate how quickly an area could be impacted.
3. Emulsion thickness - to estimate how severely an area could be impacted.

The data behind these maps allow us to answer the following questions:

1. How quickly could condensate and diesel reach nearby shorelines and what mass?
2. Which countries are more likely to be affected by a spill from the FPSO?
3. Which environmental sensitivities could be affected by a spill from the FPSO?

Table 1: Scenario setup

Description	FPSO storage tank and diesel tank failure - Summer	FPSO storage tank and diesel tank failure - Winter
Season	April-September	October-March
Latitude	16° 04' 00.0732" N	
Longitude	016° 53' 09.2260" W	
Total Volume Released	163,200 m^3	
Total Mass Released	136,522.4 MT	
Duration of Release	160 hours[1]	
Depth of Release	Surface (0 m)	
Nearest Shoreline	~40 km, St Louis, Senegal	

[1] A realistic worst-case release rate from a collusion is approximately 1,000 m^3/hr meaning that the total volume of 163,200 m^3 will be released in 160 hrs.

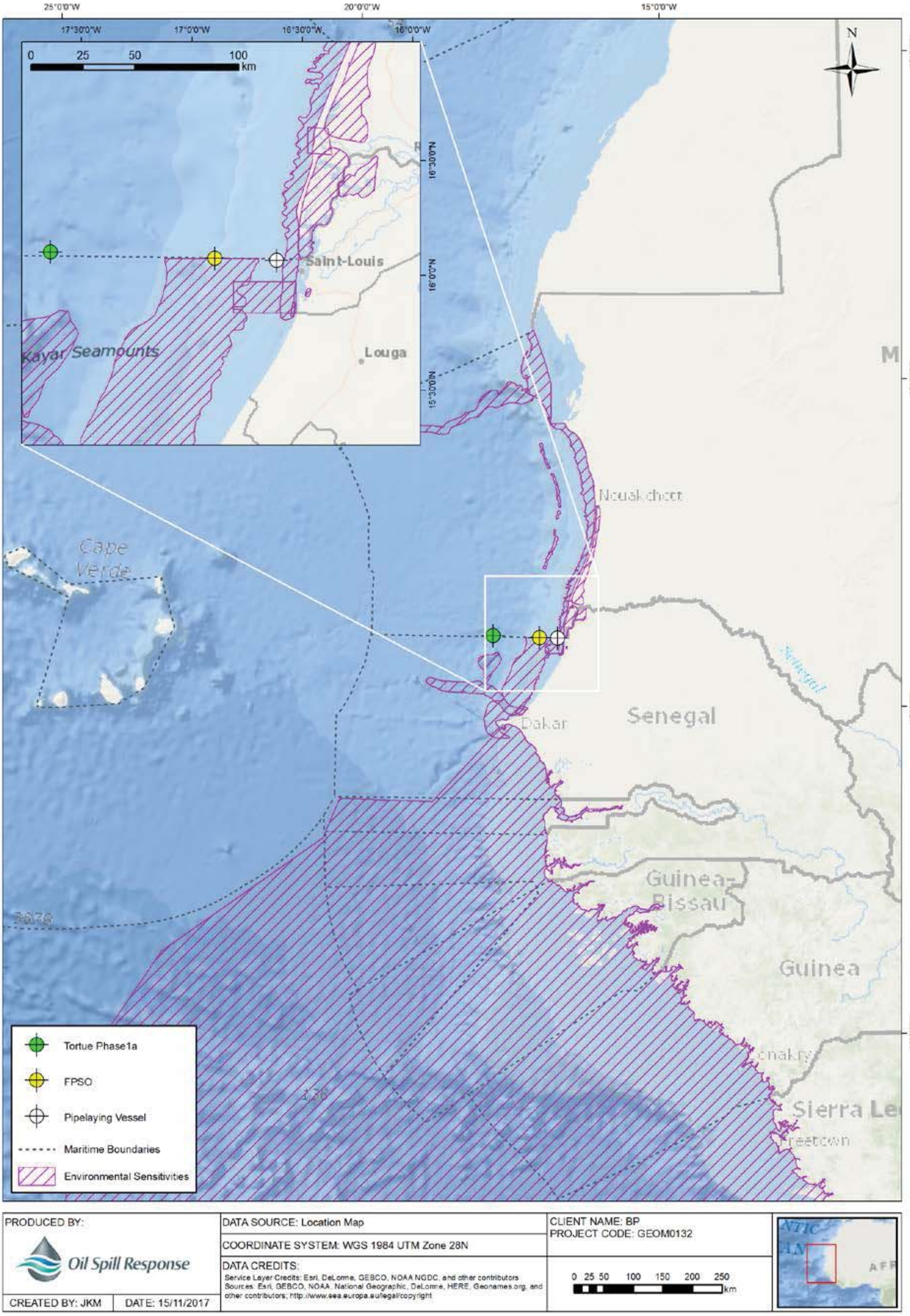


Figure 1: Map showing the release location

1.3 Modelling Setup

Two worst case stochastic simulations were run for the FPSO storage tank and diesel tank failure (Table 2), with a total of 324 individual trajectories post-processed for the scenario to create the stochastic results. Each trajectory began on a different start date, so that each oil spill was simulated using a range of wind and current conditions.

Three years of hydrodynamic data (sourced from Copernicus and NOAA) were used as model inputs. See APPENDIX A to APPENDIX E for more information on the model setup.

Table 2: Summary of stochastic setup for spill scenarios

Description	FPSO storage tank and diesel tank failure in summer	FPSO storage tank and diesel tank failure in winter
Location	16° 04’ 00.0732" N 016° 53’ 09.2260" W	
Time of Year	April-September	October-March
Release Period	3.2 hours - Diesel 160 hours - Condensate	
Release Rate	1,000 m^3/hour	
Total Release (Volume)	163,200 m^3	
Total Run Duration	42 days	
Total Number of Trajectories	162	162
Time Between Trajectories	3 days, 10 hours	3 days, 5 hours

1.4 Thresholds

Thresholds define the point below which data are no longer informative. For example, when surface emulsion thickness is less than 0.04 µm, the oil is no longer visible to the naked eye so may be considered negligible to a response. The thresholds applied to this study are given in Table 3.

Table 3: Thresholds used in the post-processing stage of the modelling

Threshold	Value	Description
Surface	0.04 µm	The Bonn Agreement Oil Appearance Code defines five oil layer thicknesses based on their optic effects and true colours. 0.04 µm is the minimum thickness that can be seen with the naked eye.
Water column	6 ppb (Dissolved)	Low level, in-water dissolved HC exposure.
	70 ppb (Total)	Entrained HC exposure level, OSPAR predicted no effect concentration (PNEC).
Shoreline	0.1 litres/m^2	Lower threshold for light oiling from the ITOPF document "Recognition of oil on shorelines".

The thickness key used in the surface emulsion thickness maps throughout this document is derived from the Bonn Oil Appearance Code (Table 4).

Table 4: Key used for sea surface emulsion thickness outputs

Appearance	Layer Thickness Interval	Colour
Sheen	0.04 µm - 0.3 µm	
Rainbow	0.3 µm -5 µm	
Metallic	5 µm - 50 µm	
Discontinuous True Colour	50 µm - 200 µm	
Continuous True Colour	>200 µm	

The thickness key used in the shoreline maps throughout this document is derived from the ITOPF Technical Information Paper (TIP) No. 6 "Recognition of oil on shorelines" (ITOPF, 2011b; Table 7). Very light oiling is deemed negligible by ITOPF (ITOPF, 2011b); no practical response is required for a very lightly oiled shoreline, apart from monitoring the oil spill.

Table 5: Key used for water column dissolved concentrations

Water Column Classification	Concentration	Colour
Low	< 50 ppb	
Moderate	50 - 400 ppb	
High	> 400 ppb	

Table 6: Key used for water column total concentrations

Concentration	Colour
< 150 ppb	
150 – 500 ppb	
500 – 750 ppb	
750 - 1000 ppb	
> 1000 ppb	

Table 7: Key used for shoreline emulsion thickness outputs

Shoreline Oiling Classification	Concentration	Thickness	Colour
Light Oiling	0.1 – 1 litres/m^2	0.1 mm – 1.0 mm	
Moderate Oiling	1 – 10 litres/m^2	1 mm – 10 mm	
Heavy Oiling	> 10 litres/m^2	> 10 mm	

2 RESULTS

2.1 Stochastic Results

The stochastic results for Scenario 1 were calculated from 324 trajectories. The scenario involves the release of 160,000 m^3 of condensate over 160 hours and 3,200 m^3 of diesel over 3.2 hours during the summer (April to September) and during winter (Oct to March). The release is tracked for a total of 42 days.

The following results are presented:

Sea Surface

Shoreline

Water Column (Dissolved Hydrocarbon)

Water Column (Total Hydrocarbon)

FPSO storage tank and diesel tank failure **Surface**

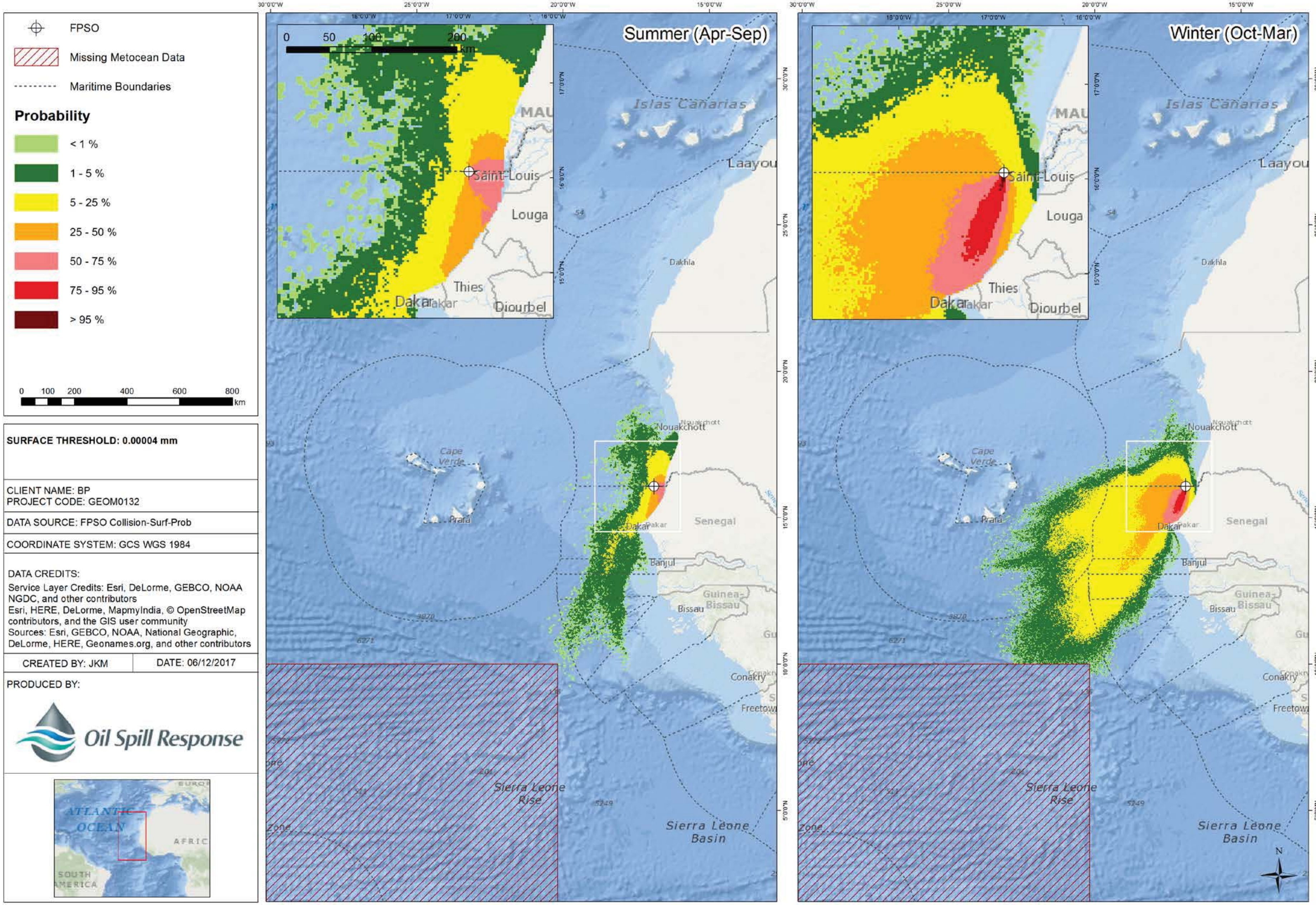


Figure 2: FPSO storage tank and diesel tank failure – Surface Probability of Cell Impact– Summer (left) & Winter (right)

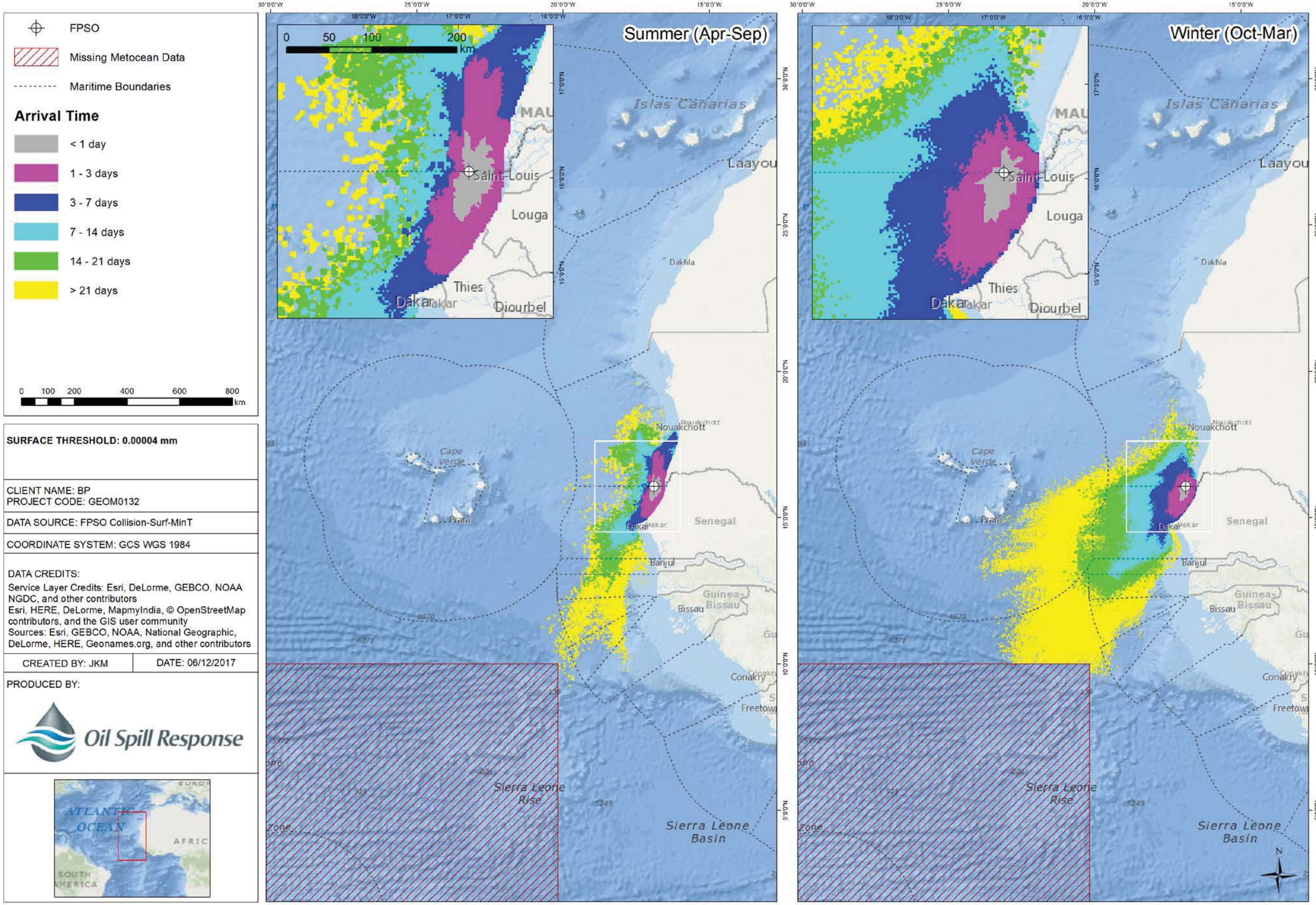


Figure 3: FPSO storage tank and diesel tank failure – Surface Minimum Arrival Time – Summer (left) & Winter (right)

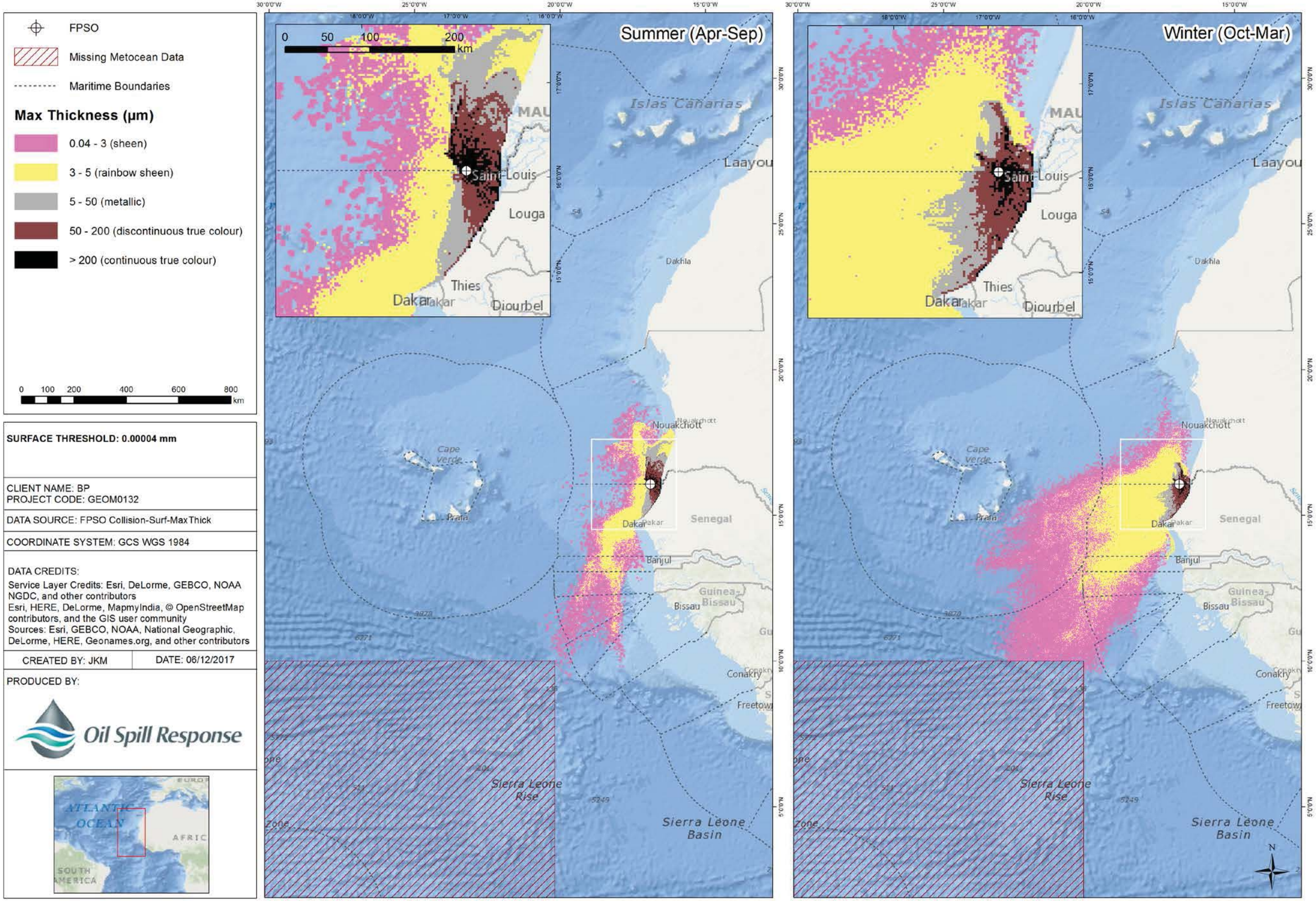


Figure 4: FPSO storage tank and diesel tank failure – Surface Maximum Emulsion Thickness – Summer (left) & Winter (right)

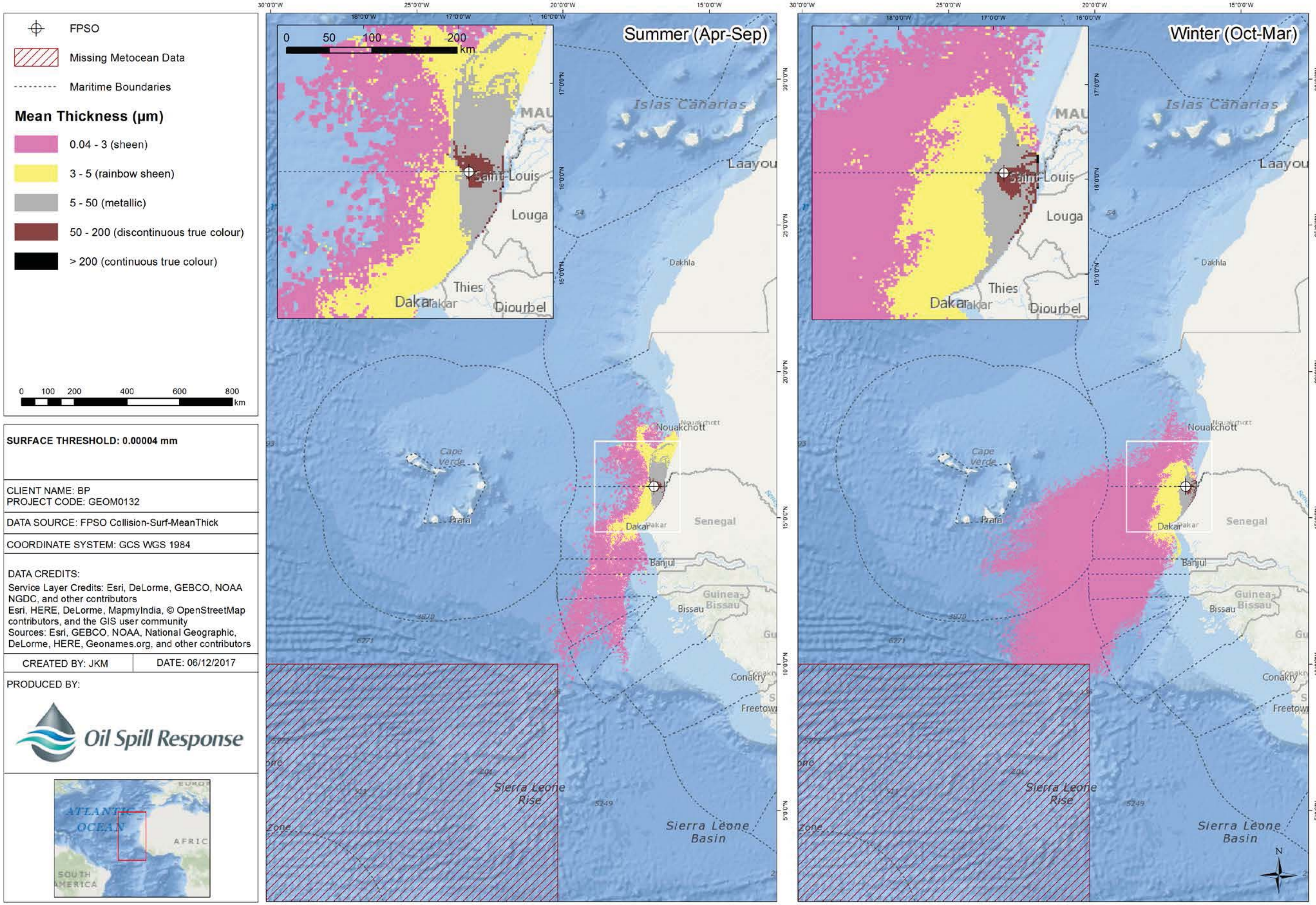


Figure 5: FPSO storage tank and diesel tank failure – Surface Average Emulsion Thickness – Summer (left) & Winter (right)

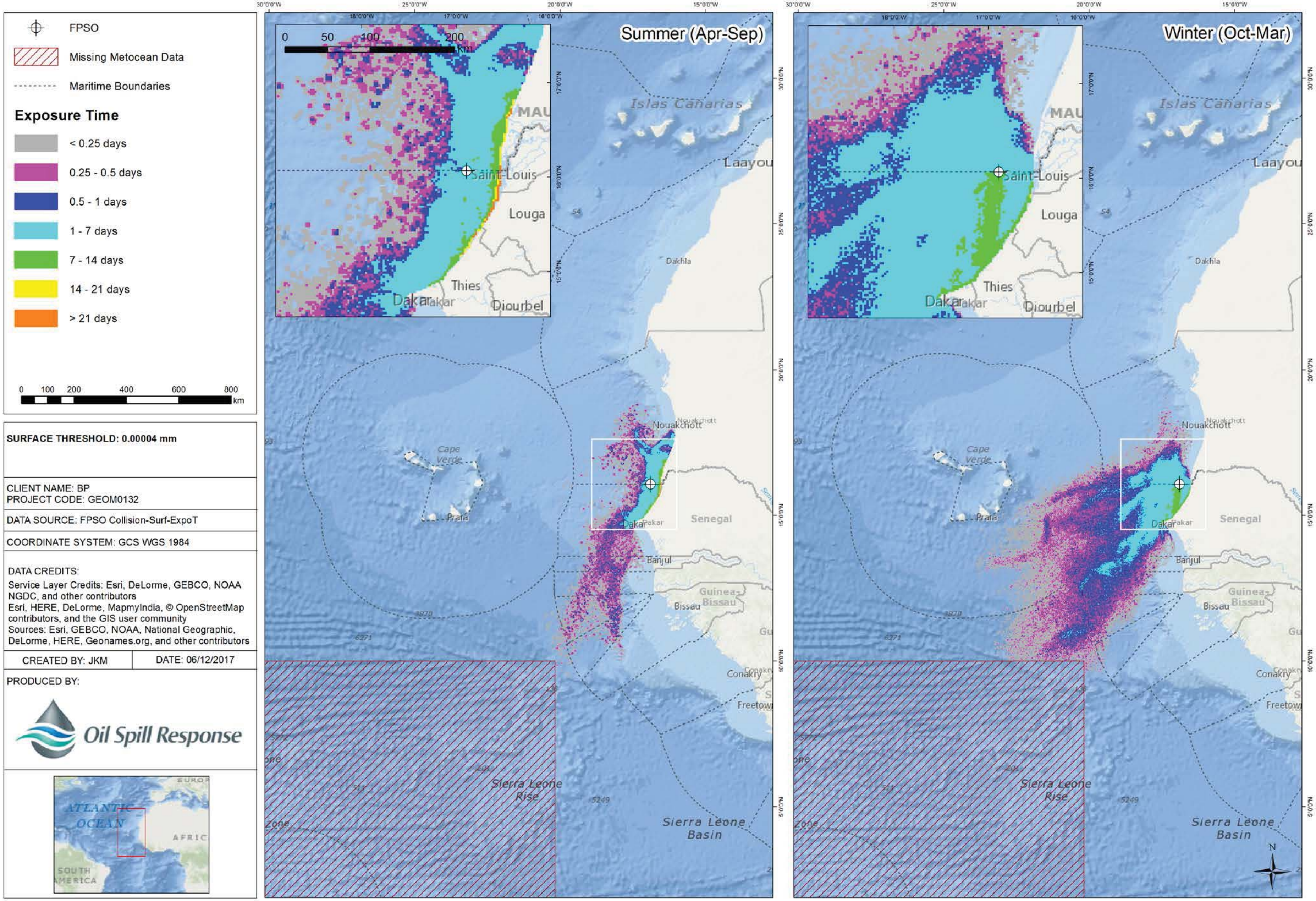


Figure 6: FPSO storage tank and diesel tank failure – Surface Maximum Exposure Time – Summer (left) & Winter (right)

FPSO storage tank and diesel tank failure **Shoreline**

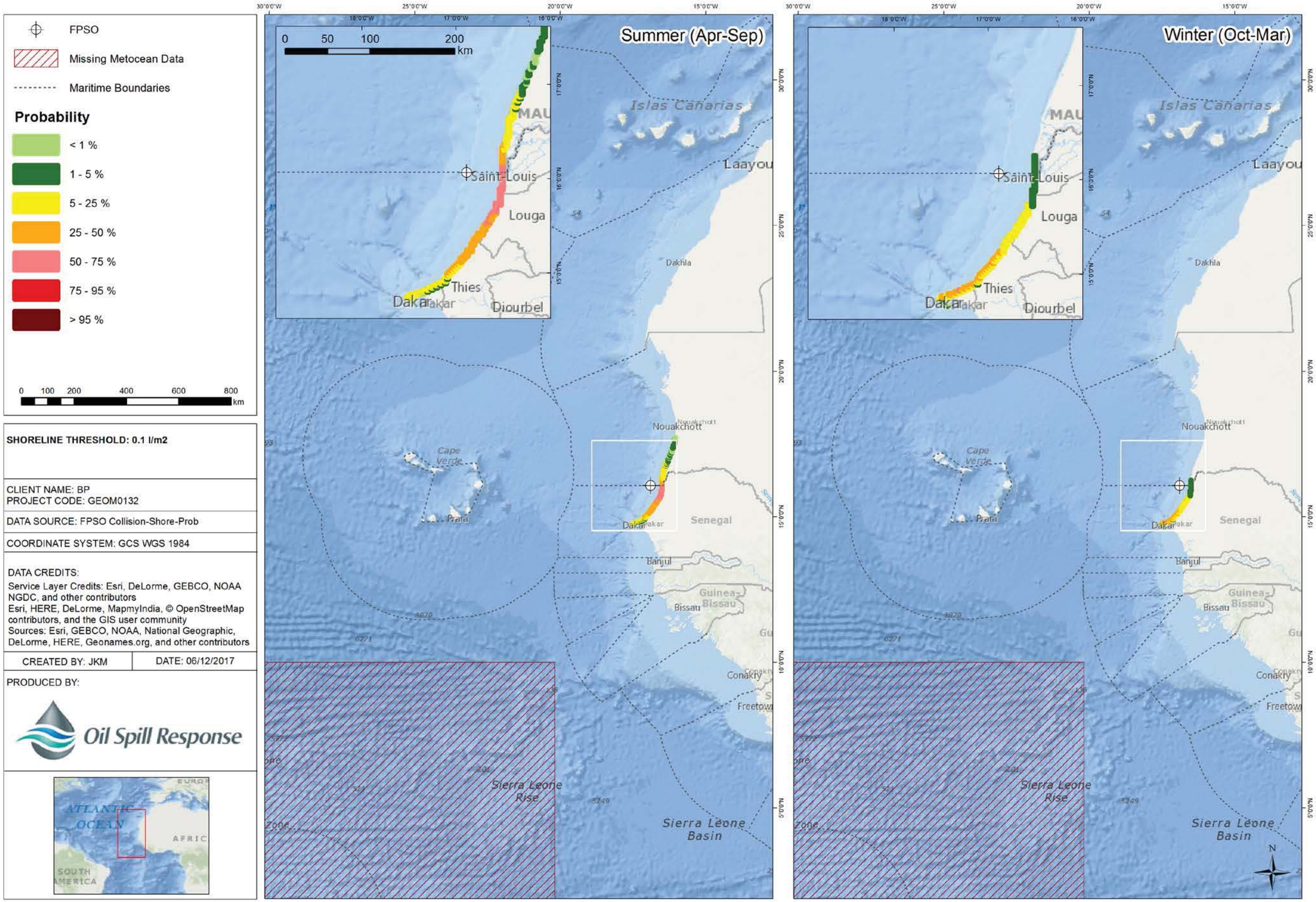


Figure 7: FPSO storage tank and diesel tank failure – Shoreline Probability of Cell Impact – Summer (left) & Winter (right)

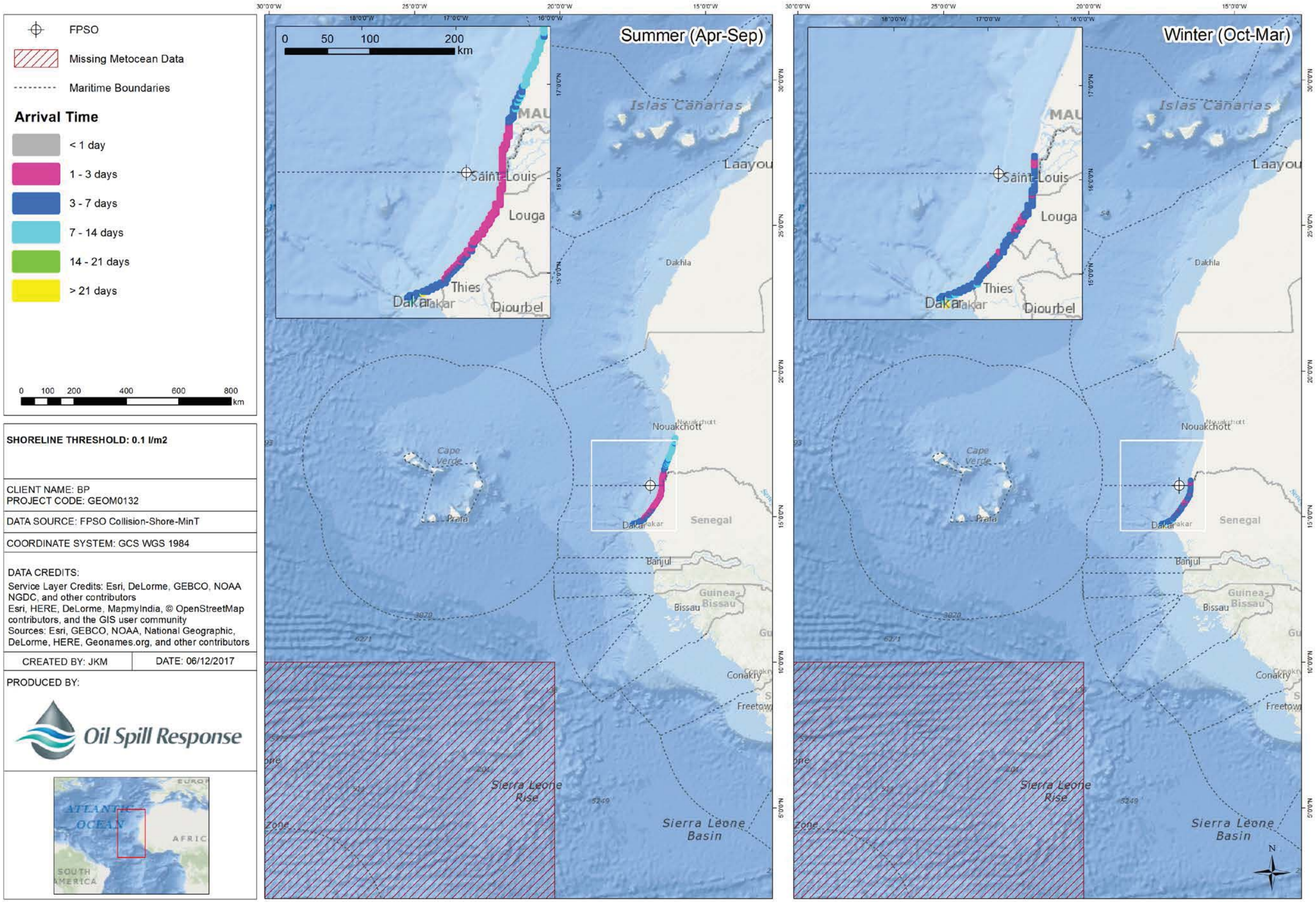


Figure 8: FPSO storage tank and diesel tank failure – Shoreline Minimum Arrival Time – Summer (left) & Winter (right)

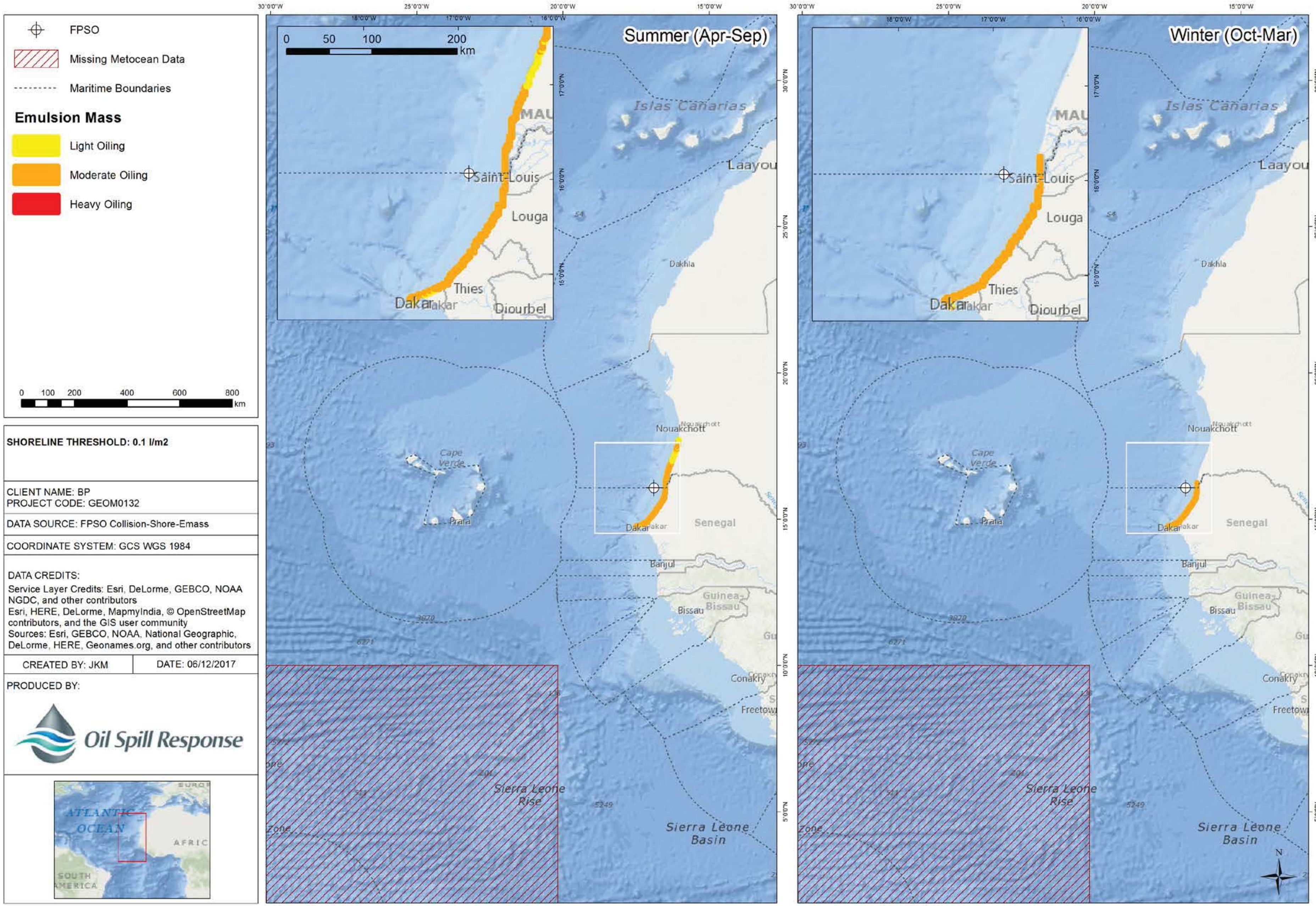


Figure 9: FPSO storage tank and diesel tank failure – Shoreline Impact – Summer (left) & Winter (right)

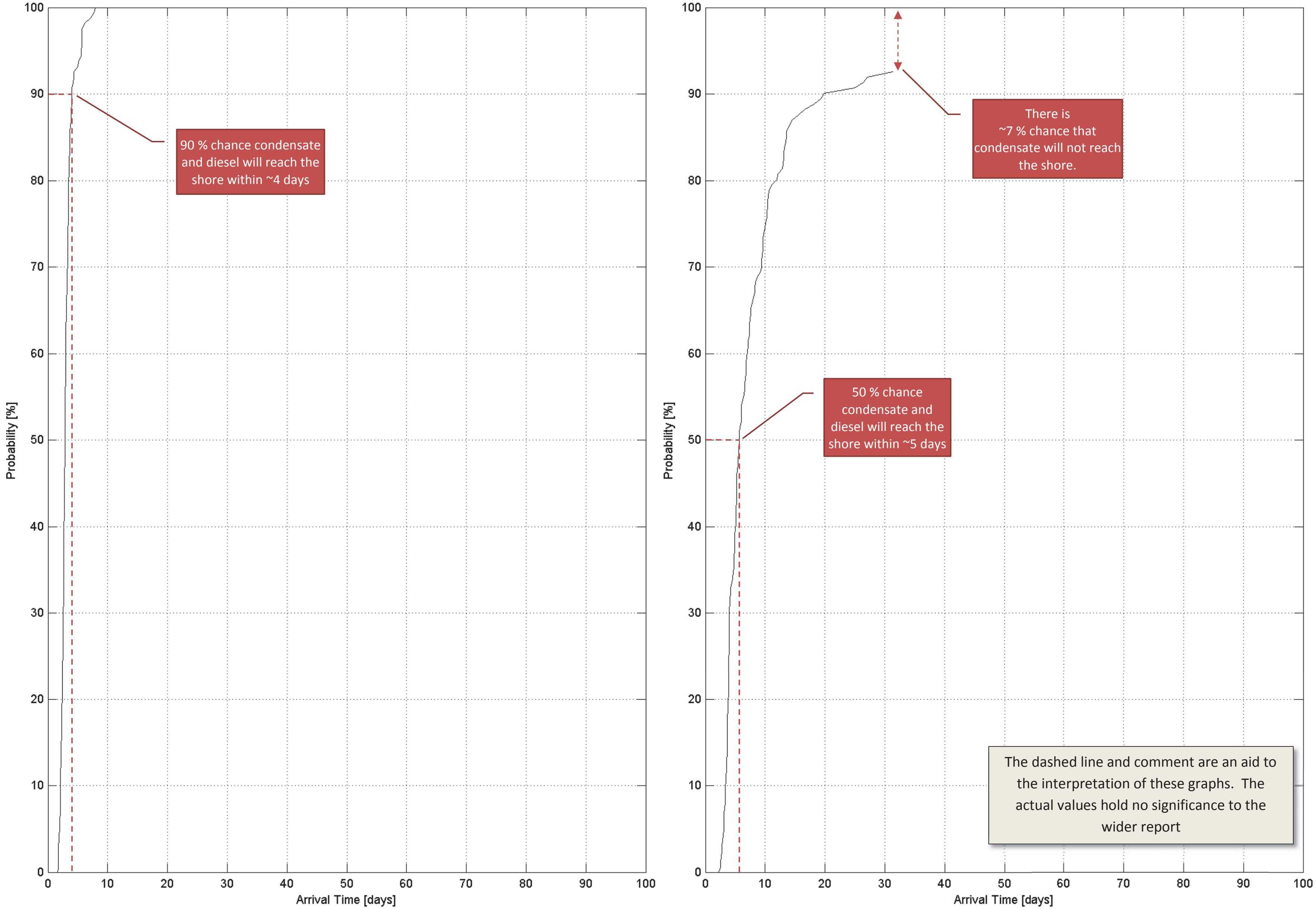


Figure 10: FPSO storage tank and diesel tank failure – Shoreline Impact – Shoreline Arrival Time Probability - Summer (left) & Winter (right)

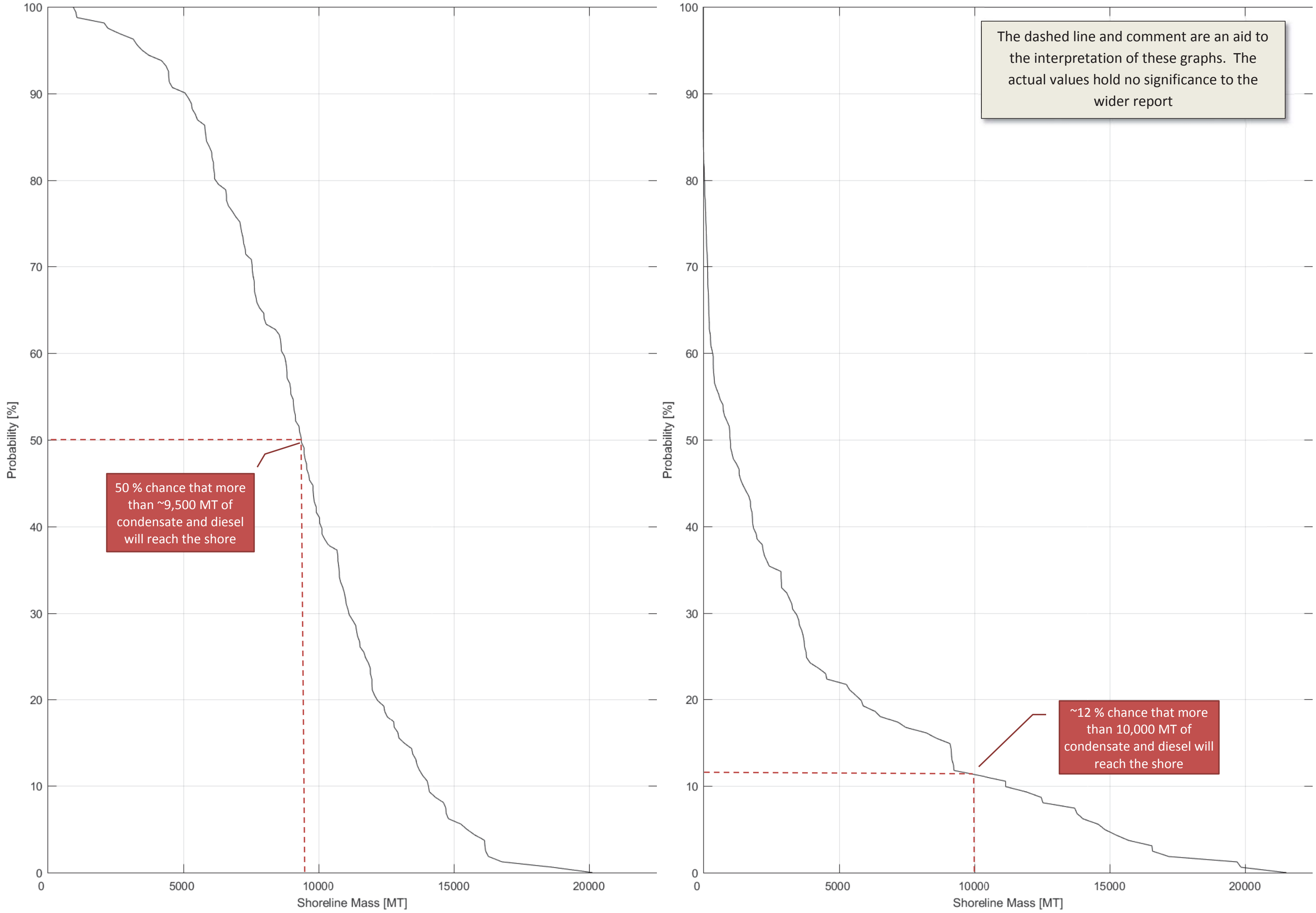


Figure 11: FPSO storage tank and diesel tank failure – Shoreline Impact –Probability Shoreline Mass - Summer (left) & Winter (right)

Table 8 shows how many of the simulations result in different levels of shoreline impact based on ITOPF's Technical Information Paper (TIP) no. 6, "Recognition of Oil on Shorelines" and the length of shoreline impacted. For further information see Thresholds in Section 1.4.

Table 8: Severity of shoreline oiling following a FPSO storage tank and diesel tank failure from the Tortue Phase 1a Well

ITOPF Reference	Light, Moderate & Heavy Oiling		Light & Moderate Oiling		Light Oiling		No Significant Impact	
OSRL's SCAT Reference	Thick		Cover		Coat			
Season	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Number of Simulations	36 of 162	0 of 162	126 of 162	111 of 162	0 of 162	22 of 162	0 of 162	29 of 162
Probability	22%	0%	78%	69%	0%	14%	0%	18%

Each of the 162 trajectories is put into a single category based on its most severe shoreline oiling. For example, a trajectory that has at least one cell classified as *Heavy Oiling* will be placed in the heavy oiling category regardless of how many of the other cells have *Moderate* or *Light* oiling.

Table 9: Length of shoreline impacted following a FPSO storage tank and diesel tank failure from the Tortue Phase 1a Well

			Best case	Average (50th Percentile)	Worst case
Length of Shoreline Impacted	Heavy	Summer	0 km	1 km	7 km
		Winter	0 km	0 km	0 km
	Moderate	Summer	22 km	142 km	323 km
		Winter	0 km	24 km	363 km
	Light	Summer	0 km	20 km	105 km
		Winter	0 km	18 km	54 km

The data presented in these tables can be interpreted as follows

- In the best-case scenario;
  - Summer. There will only be 22 km of moderate oiling on the shoreline.
  - Winter. There is a chance (18%) that there will be no significant impact at all.
- In a "typical case" (50th percentile), there will be:
  - Summer = ~1 km of heavy oiling, 142 km of moderate oiling, and 20 km of light oiling.
  - Winter = No heavy oiling, 24 km of moderate oiling and 18 km of light oiling.
- In a "worst-case" (maximum value[2]), there will be:
  - Summer = 7 km of heavy oiling, 323 km of moderate oiling, and 105 km of light oiling.
  - Winter = No heavy oiling, 363 km of moderate oiling and 54 km of light oiling.

[2] Note that this presents the maximum shoreline length in each category. It does not refer to 1 trajectory extracted from the stochastic.

FPSO storage tank and diesel tank failure

Water Column Maps

Dissolved Concentrations

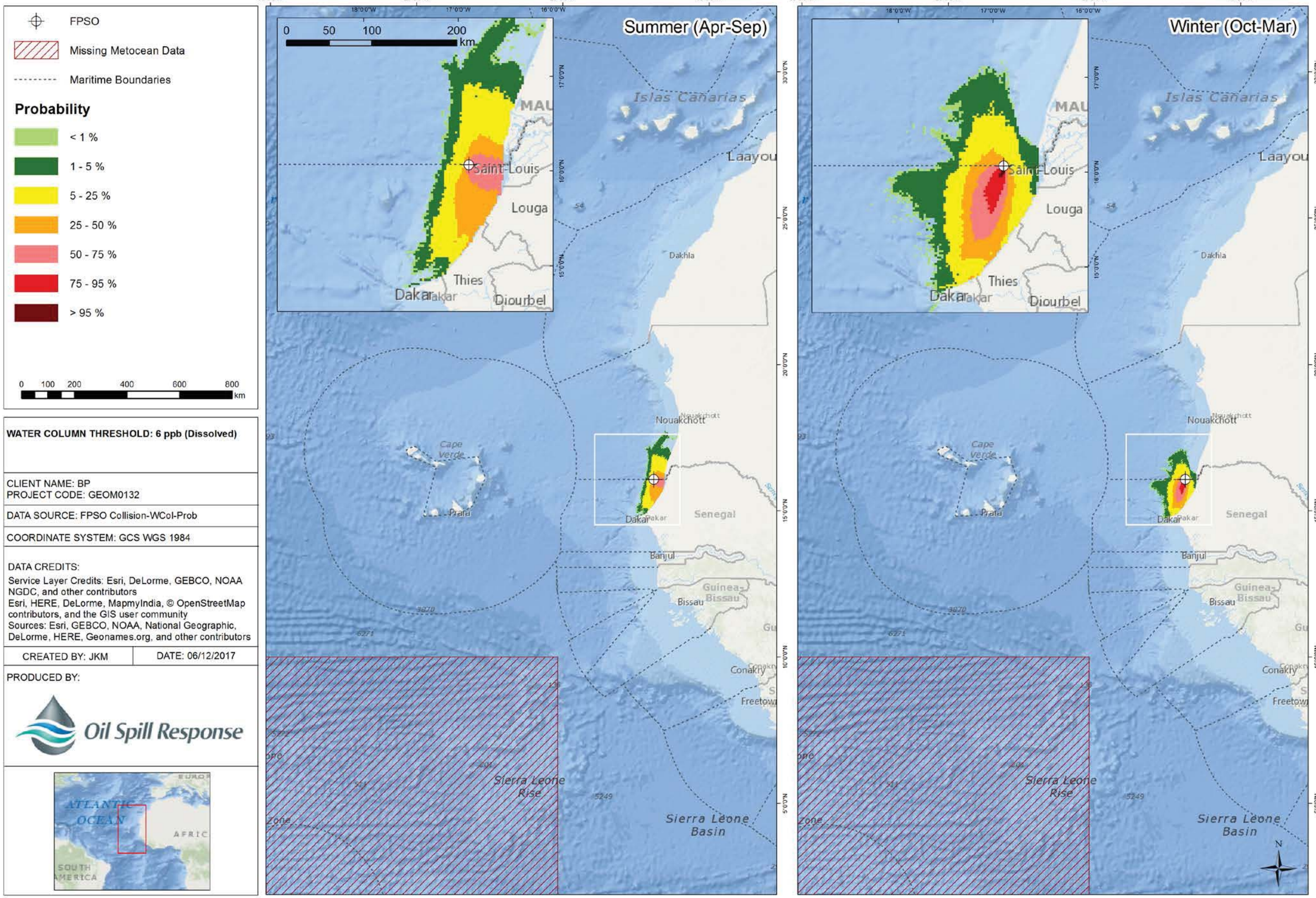


Figure 12: FPSO storage tank and diesel tank failure – Water Column (Dissolved) Probability of Cell Impact – Summer (left) & Winter (right)

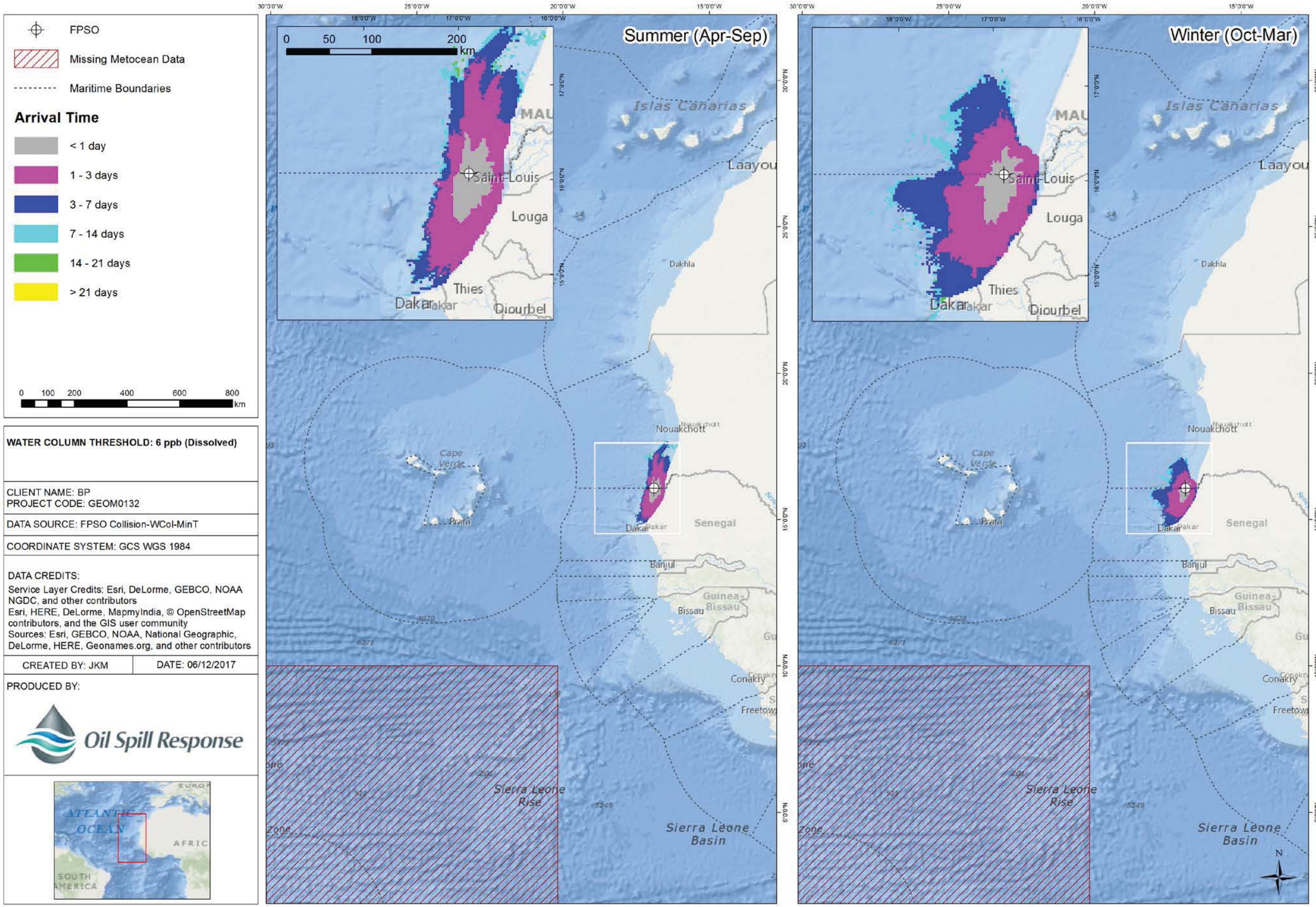


Figure 13: FPSO storage tank and diesel tank failure – Water Column (Dissolved) Minimum Arrival Time – Summer (left) & Winter (right)

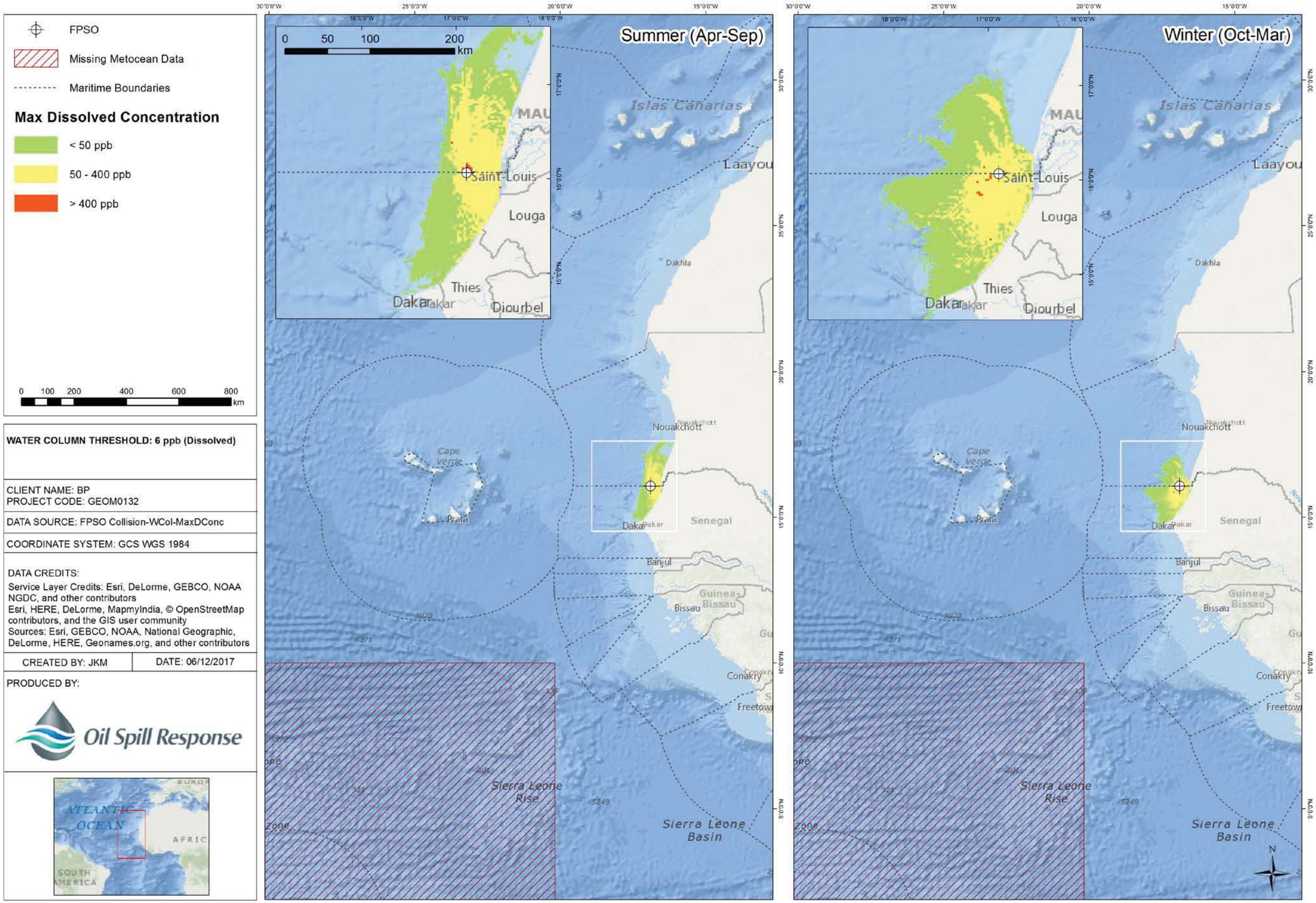


Figure 14: FPSO storage tank and diesel tank failure – Water Column (Dissolved) Concentrations – Summer (left) & Winter (right)

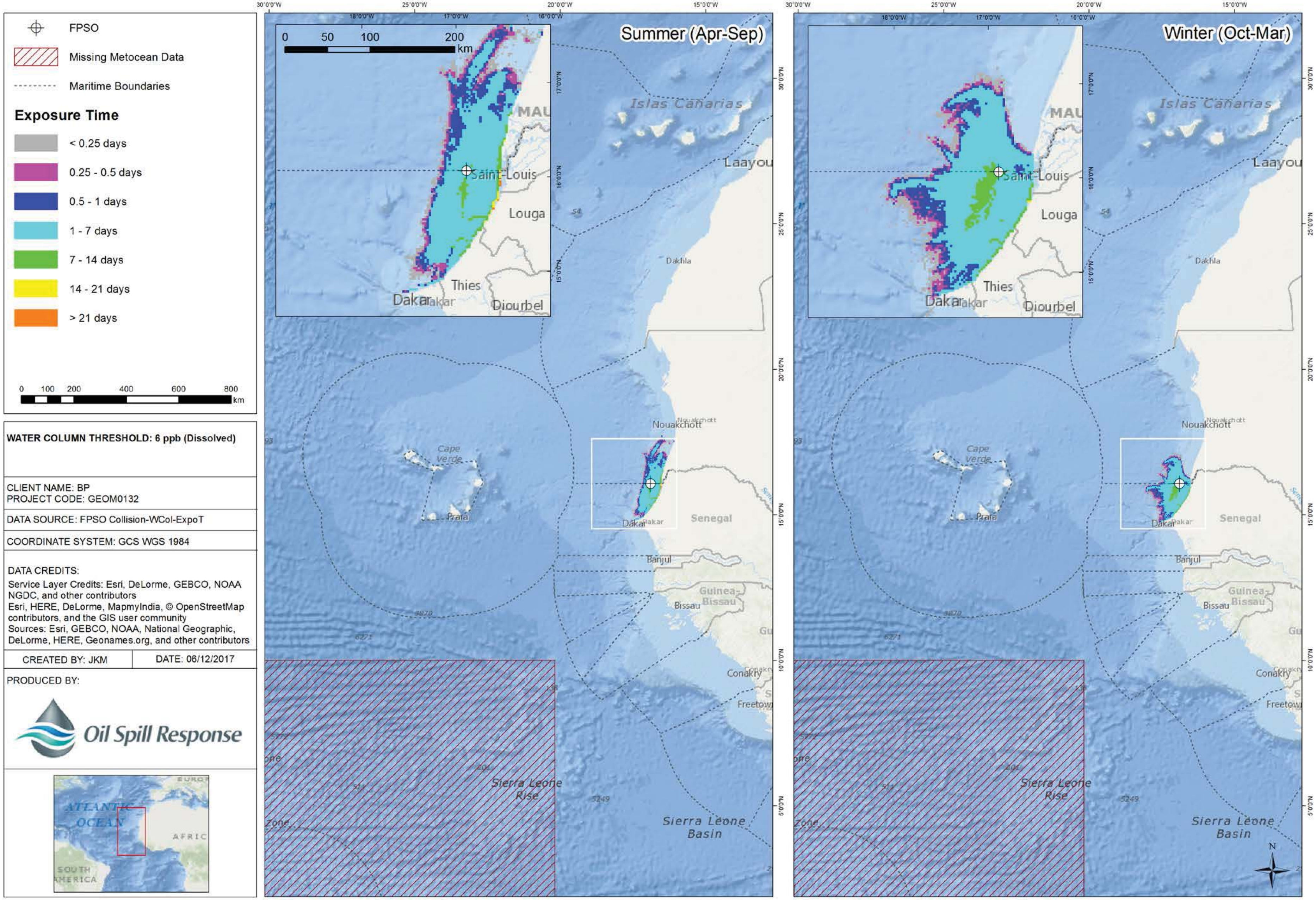


Figure 15: FPSO storage tank and diesel tank failure – Water Column (Dissolved) Maximum Exposure Time– Summer (left) & Winter (right)

FPSO storage tank and diesel tank failure

Water Column Maps

Total Concentrations

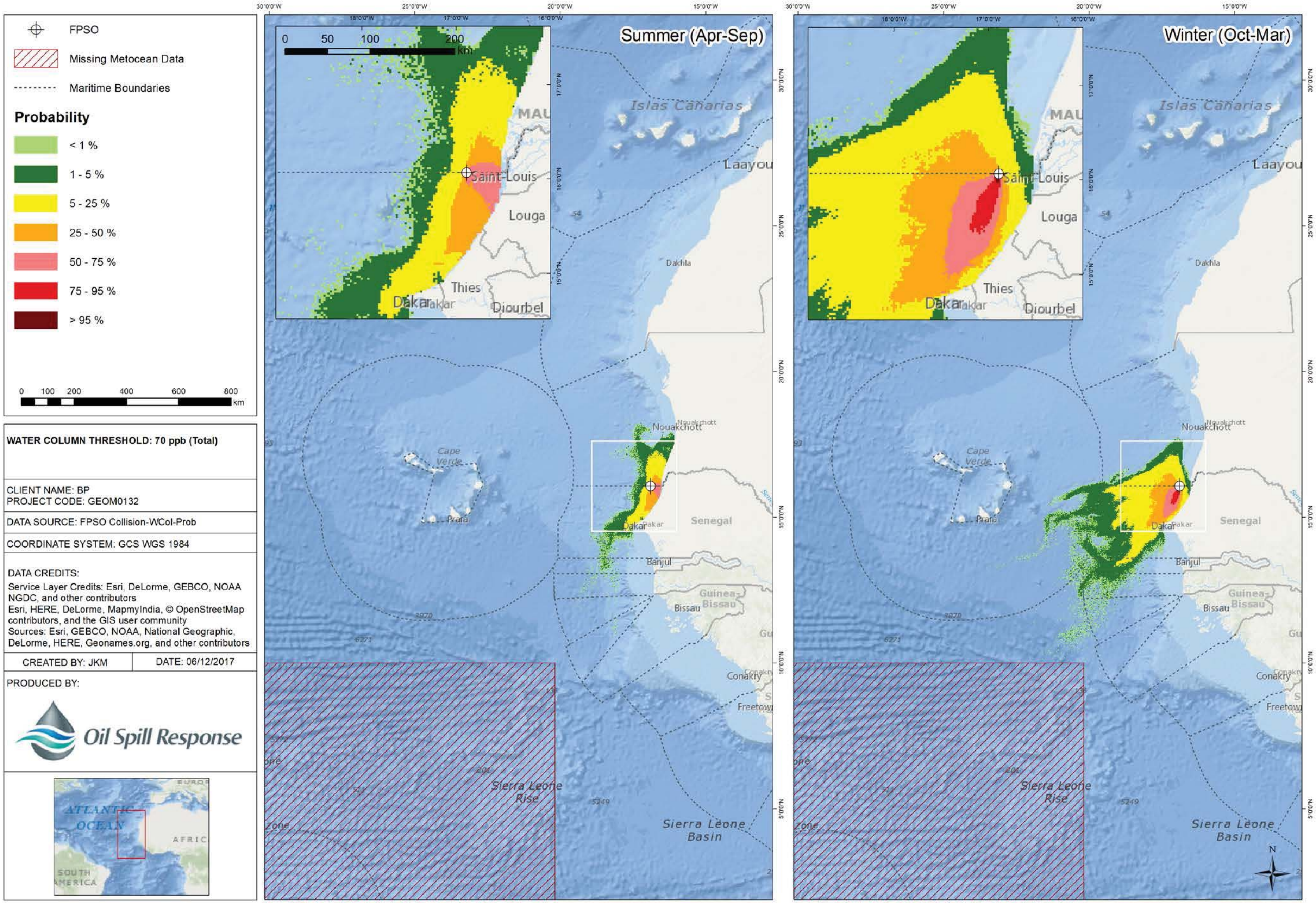


Figure 16: FPSO storage tank and diesel tank failure – Water Column (Total) Probability of Cell Impact – Summer (left) & Winter (right)

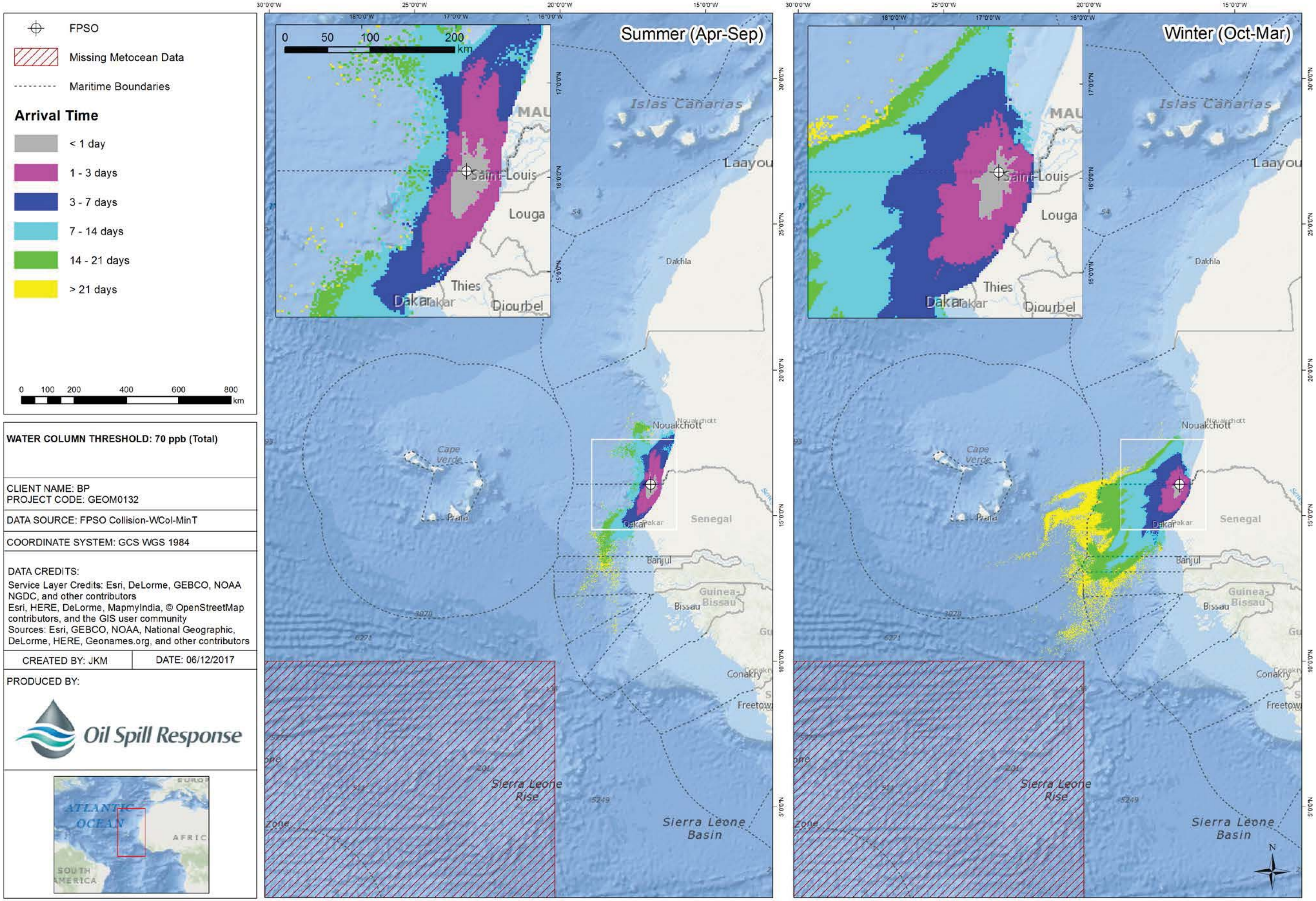


Figure 17: FPSO storage tank and diesel tank failure – Water Column (Total) Minimum Arrival Time – Summer (left) & Winter (right)

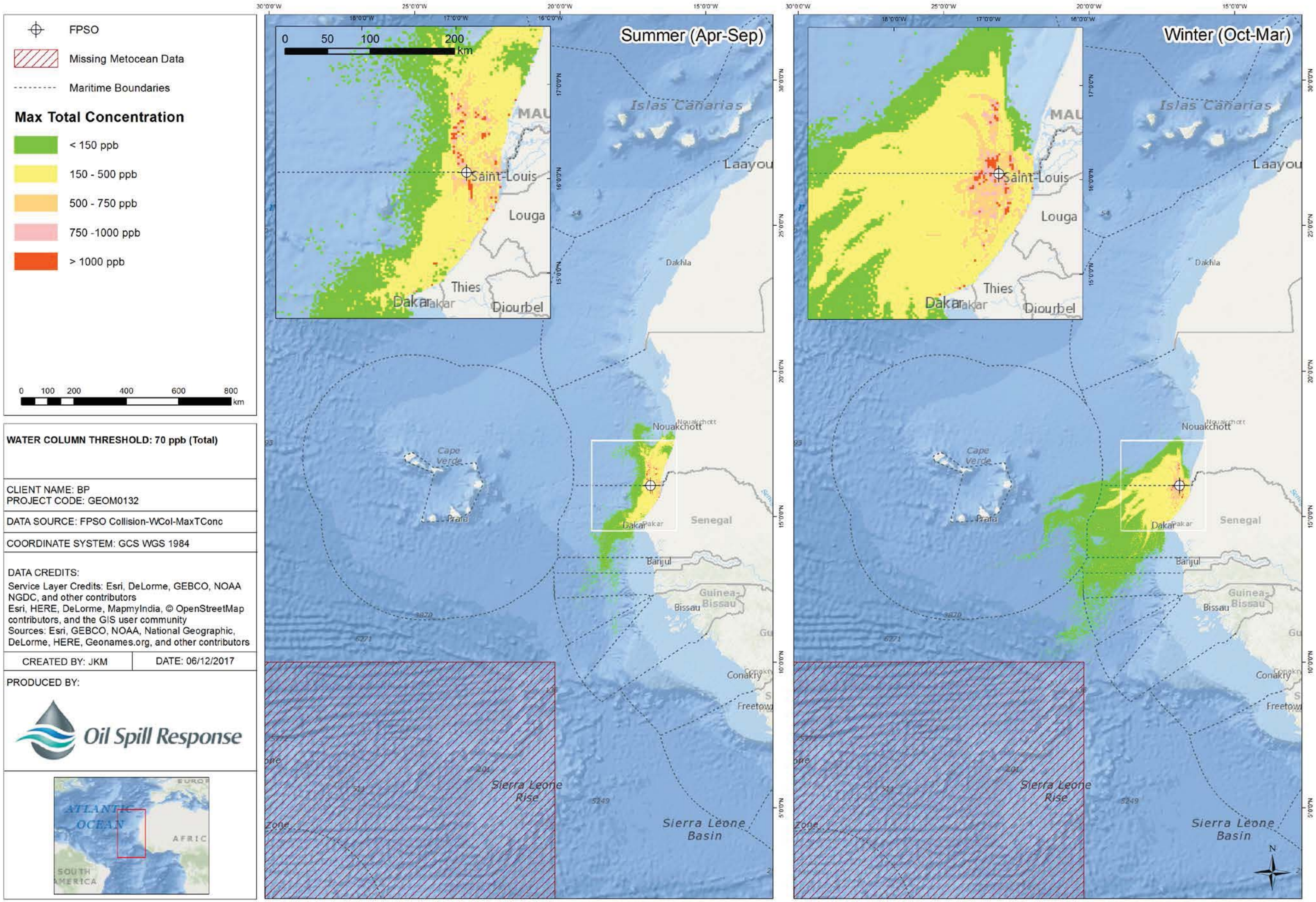


Figure 18: FPSO storage tank and diesel tank failure – Water Column (Total) Concentrations – Summer (left) & Winter (right)

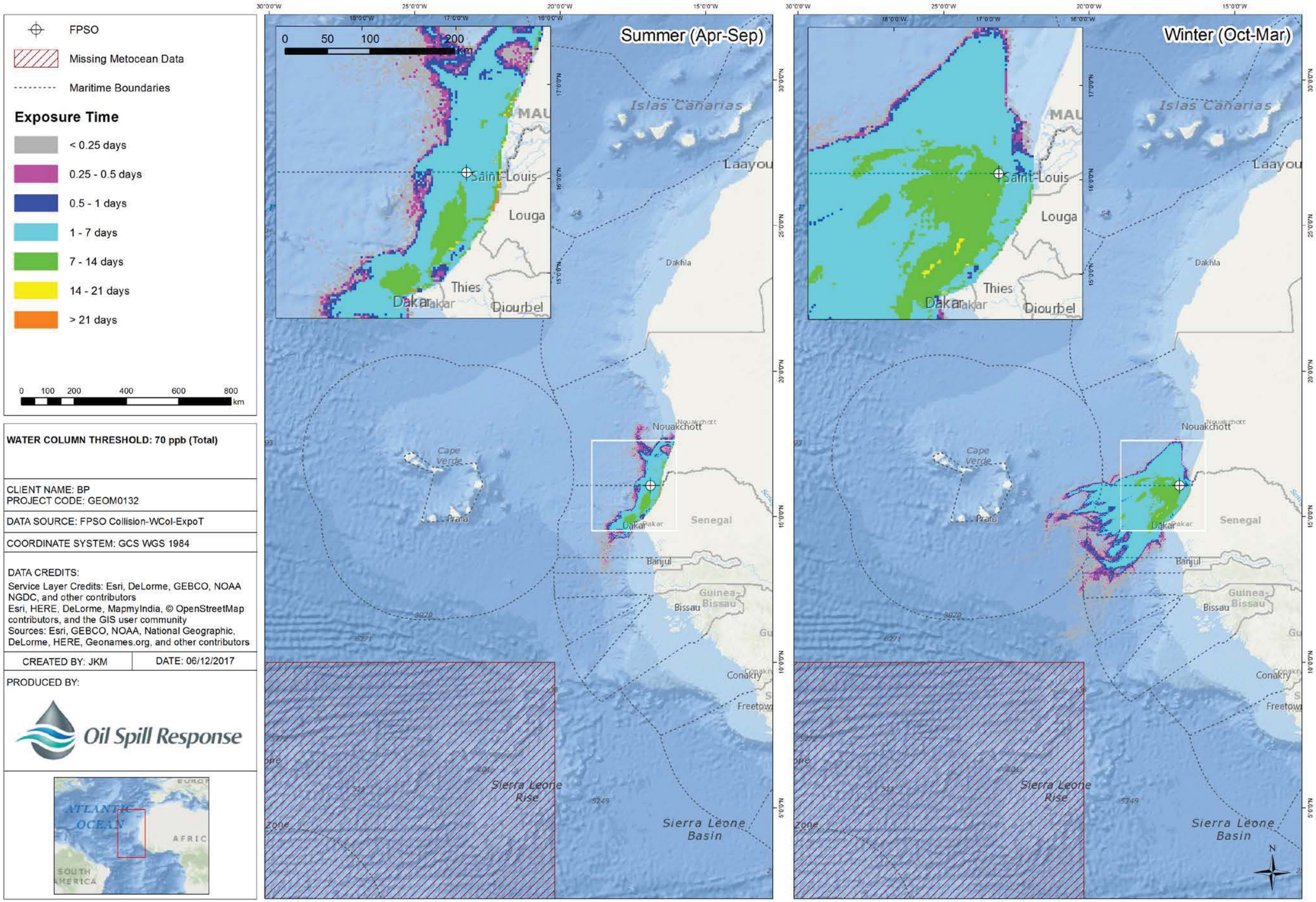


Figure 19: FPSO storage tank and diesel tank failure – Water Column (Total) Maximum Exposure Time – Summer (left) & Winter (right)

2.2 Comparison between Winter and Summer

Table 9 summarises the results of the stochastic simulations run for each scenario offshore Senegal. For more information on the thresholds used when post-processing the data see Section 1.4.

Table 10: Summary of stochastic results

Oil Spill Modelling Summary		
Spill Scenario/Description	FPSO storage tank and diesel tank failure - Summer	FPSO storage tank and diesel tank failure - Winter
Crosses a Maritime Boundary		
Cape Verde	< 1 % 35 days, 9 hours	71 % 15 days, 3 hours
Guinea-Bissau	6 % 27 days, 9 hours	8 % 33 days, 15 hours
Mauritania	85 % < 1 hour	88 % < 1 hour
Senegal	100 % < 1 hour	100 % < 1 hour
The Gambia	12 % 12 days, 21 hours	60 % 9 days, 6 hours
Shoreline Impact		
Mauritania	57 % 1 day, 18 hours	2 % 2 days, 12 hours
Senegal	100 % 1 day, 14 hours	82 % 2 days, 4 hours
Worst-Case Shoreline Impact		
Mass of oil onshore	20,121 MT	21,536 MT
Volume of oil onshore	25,502 m^3	27,295 m^3
Water content	0 %	0 %
Volume of emulsion onshore	25,502 m^3	27,295 m^3

Oil Spill Modelling Summary		
Spill Scenario/Description	FPSO storage tank and diesel tank failure - Summer	FPSO storage tank and diesel tank failure - Winter
Areas of Conservation Interest		
Cayar Canyon	34 % 2 days, 21 hours	98 % 2 days, 12 hours
Cayar MPA	33 % 2 days, 21 hours	76 % 3 days
Cayar Seamount Complex	9 % 10 days	79 % 3 days, 3 hours
Chatt Tboul Nature Reserve	14 % 4 days, 6 hours	- -
Coastal Habitats Neritic Zone MRT Extreme North	70 % 1 day, 9 hours	5 % 2 days, 0 hours
Cold Water Reefs	12 % 2 days, 9 hours	7 % 10 days, 3 hours
Conv Zone Canary Guinea EBSA	15 % 6 days, 3 hours	65 % 5 days, 6 hours
N Senegal Shelf Break IBA	100 % 3 hours	100 % 3 hours
Saint Louis MPA	88 % 12 hours	33 % 18 hours
Timris Canyon System	- -	<1 % 35 days, 12 hours

2.3 Worst-Case Oil Spill Scenario

Trajectory results are generated by simulating a single spill scenario under specific conditions on a particular date. One 'worst case' trajectory was selected, from each pool of trajectories that make up the stochastics, to investigate the fate and behaviour of oil during the simulation in more detail.

In this report, the 'worst-case' trajectories are defined as:

- The trajectory that results in the **most oil to reach the shore**

Table 11: Key results from Scenario 1

		TrajSim(108) Summer	TrajSim(32) Winter
Model Setup	**Release Location**	Tortue Phase-1 FPSO	
	Total Mass Spilled	136,522.4 MT	
First Shoreline Impact		3 day, 6 hours	2 day, 12 hours
Maximum Mass of Oil Onshore		20,121 MT	21,536 MT
Time when Maximum Mass of Oil Onshore Occurs		28 days	31 days, 9 hours

The following figures are presented:

Most oil ashore trajectory

Figure 20: Mass balance plot for a FPSO storage tank and diesel tank failure during Summer

Figure 21: Mass balance plot for a FPSO storage tank and diesel tank failure during Winter

Figure 22: Overall area impacted for a FPSO storage tank and diesel tank failure – Summer (left) & Winter (right)

Figure 23: Overall maximum dissolved concentration – Summer (left) & Winter (right)

Figure 24: Overall maximum total concentration – Summer (left) & Winter (right)

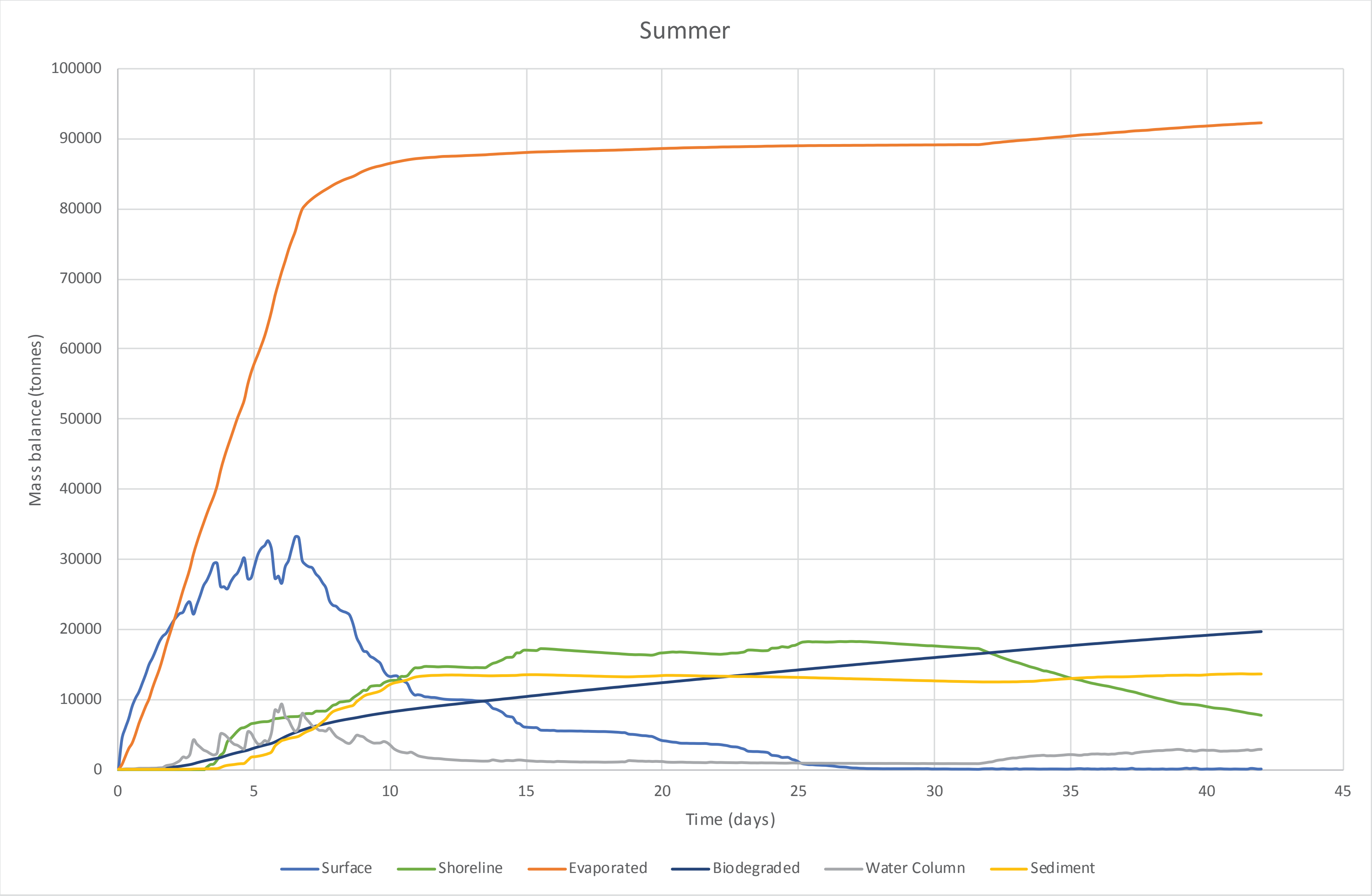


Figure 20: Mass balance plot for a FPSO storage tank and diesel tank failure during Summer

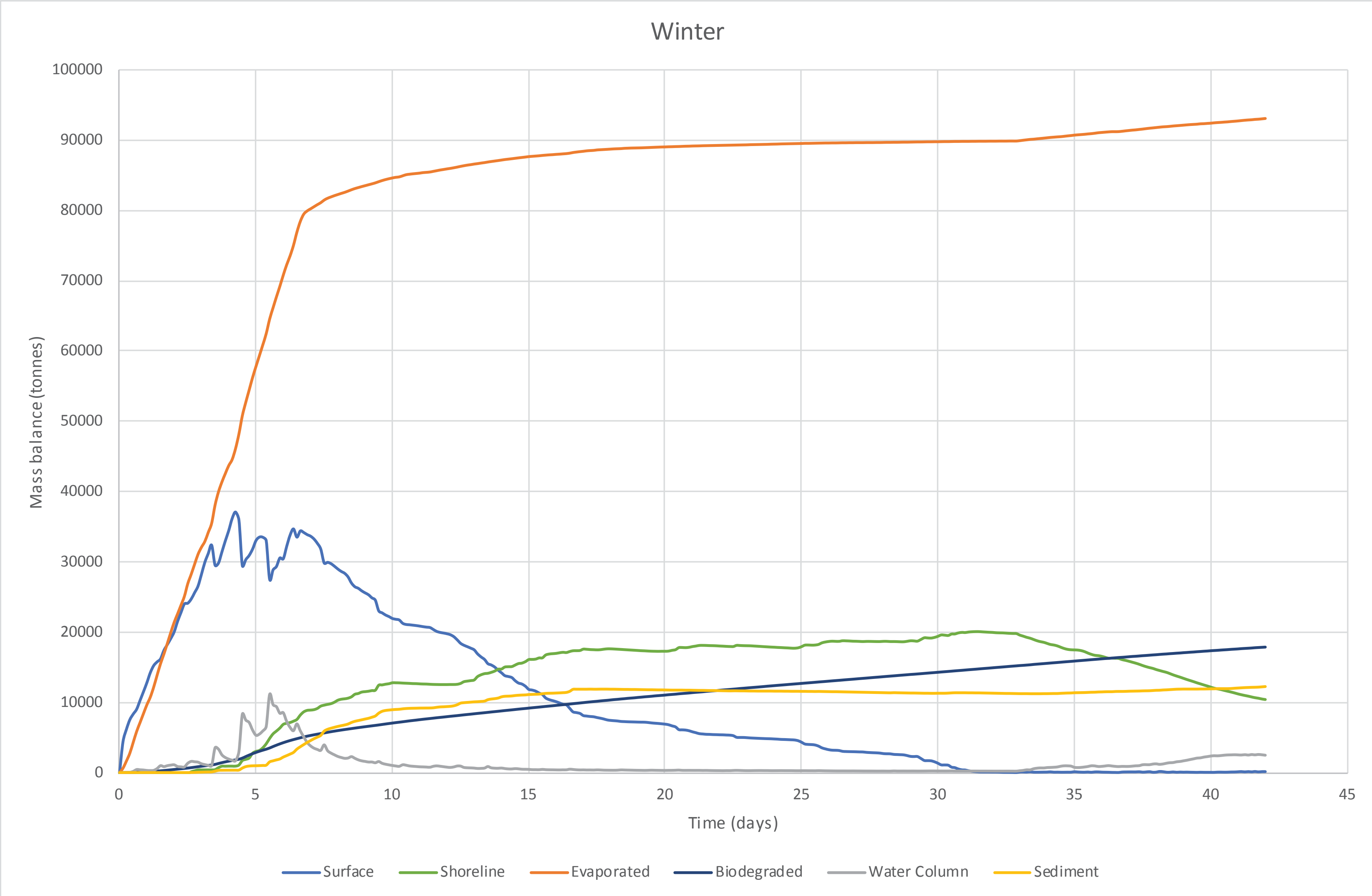


Figure 21: Mass balance plot for a FPSO storage tank and diesel tank failure during Winter

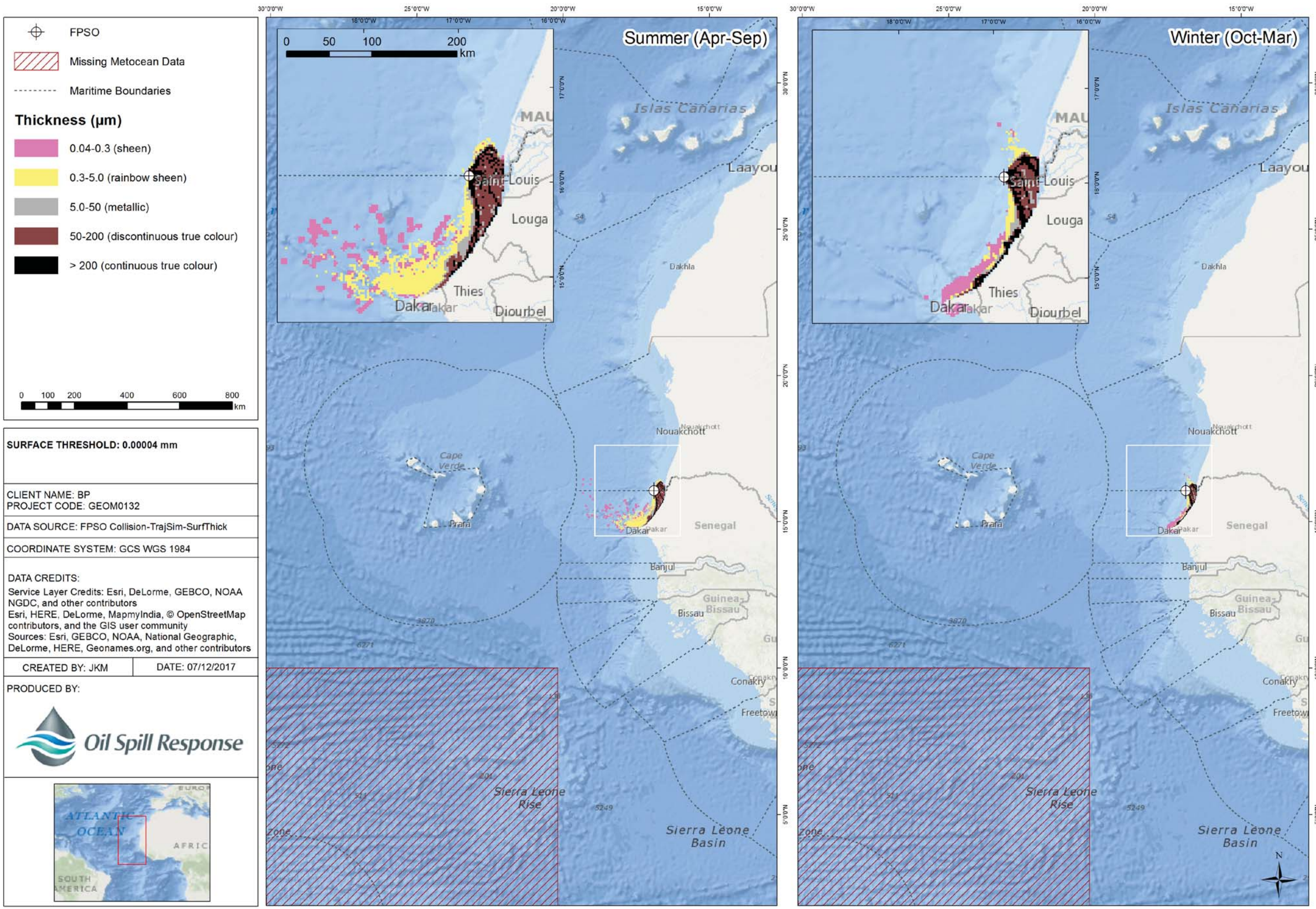


Figure 22: Overall area impacted for a FPSO storage tank and diesel tank failure – Summer (left) & Winter (right)

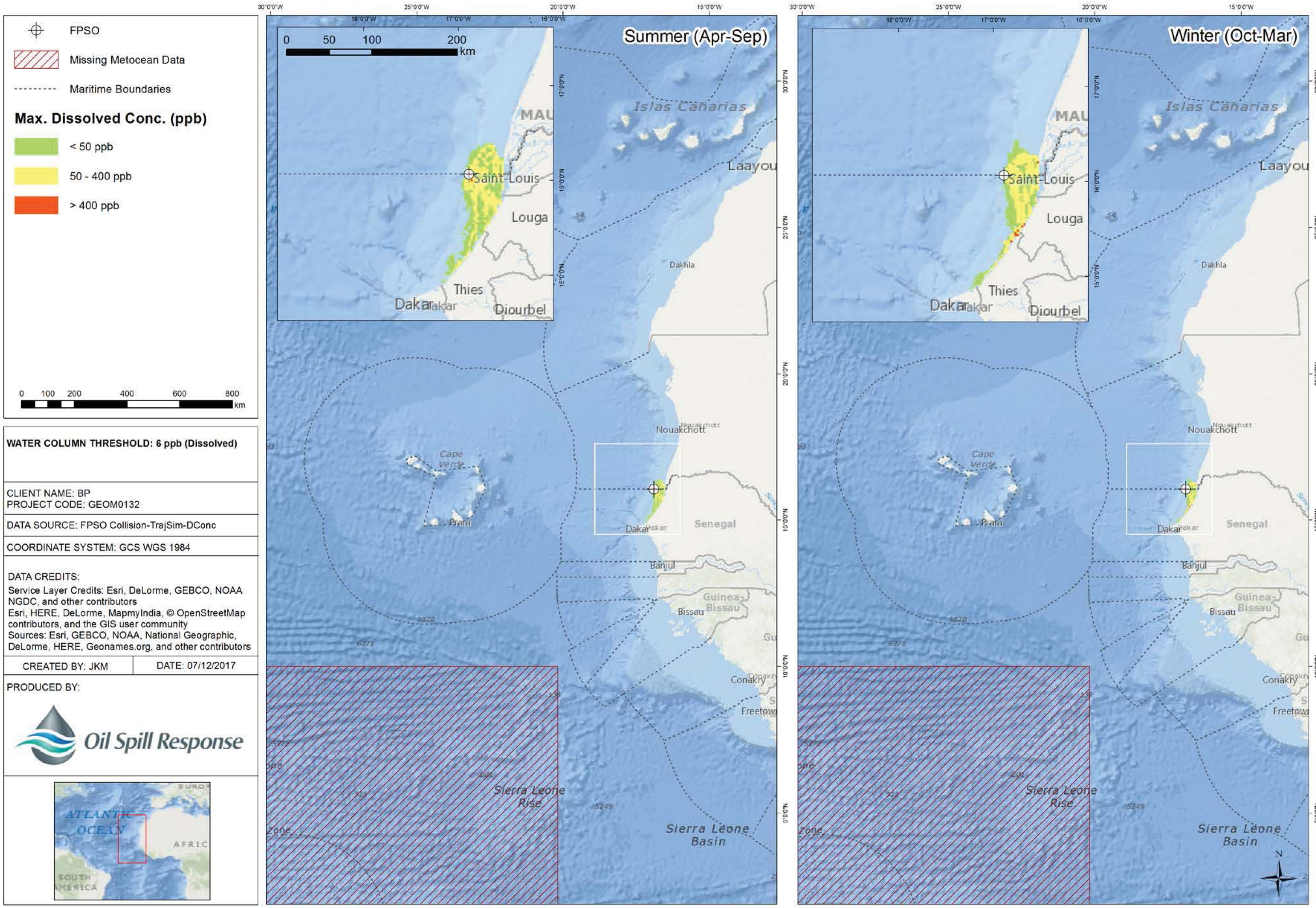


Figure 23: Overall maximum dissolved concentration – Summer (left) & Winter (right)

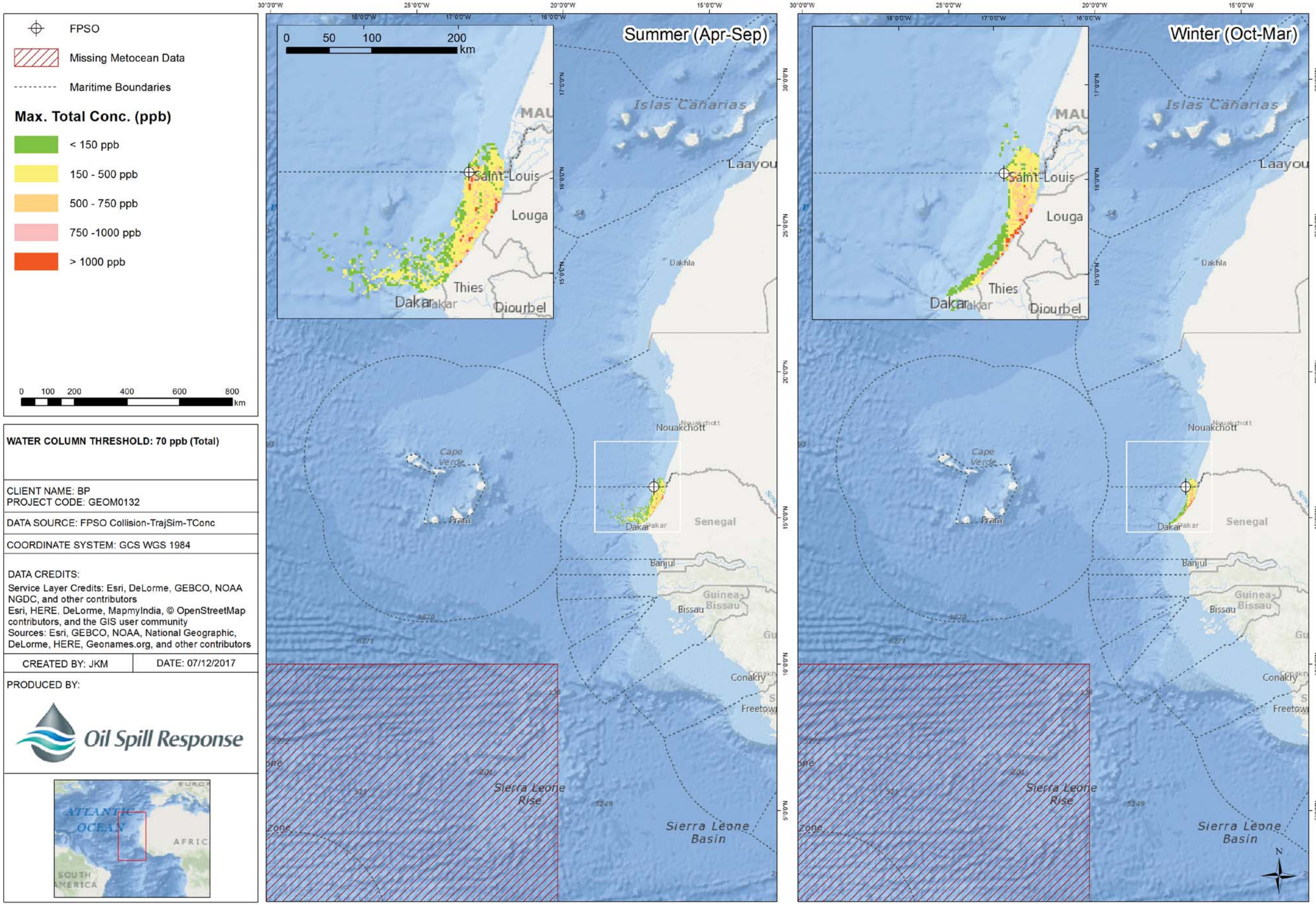


Figure 24: Overall maximum total concentration – Summer (left) & Winter (right)

3 Conclusion

One scenario was modelled for the Tortue Phase 1a Well offshore Senegal and Mauritania. This involved the release of 160,000 m^3 of condensate over 160 hours and 3,200 m^3 of diesel over 3.2 hours, due to an FPSO storage tank and diesel tank failure, resulting from a ship collision.

3.1 Shoreline Impact

A spill at this location, approximately 40 km from the shore, has a 100% chance of making a considerable shoreline impact (light oiling or higher) if the spill happens in Summer and an 82% chance of shoreline impact if it occurs in Winter. Mauritania and Senegal are the only two countries at risk of shoreline impact, but Senegal is most likely to be more severely impacted.

Summer

Summer has a higher risk to the shoreline of the two seasons.

In the worst-case scenario, a spill in summer may impact the shore 1 day, 14 hours after the release. However, there is a 10% chance that condensate and diesel will not make landfall within 4 days and in the best-cast scenario will not reach the shore for 8 days.

Similarly, the severity of the shoreline impact in summer ranges from around 1,000 MT in the best-case scenario, to more than 20,000 MT in the worst-case. There is a 50% chance that more than 9,500 MT may wash ashore.

A shoreline impact in the summer months is expected to have at least moderate shoreline oil. Further, these is a 22% chance of “heavy” shoreline oiling. Spatially, only a few km is expected to have heavy shoreline oiling but up to 323 km could be impacted by moderate oiling.

Winter

Winter has a lower risk to the shoreline of the two seasons.

In the worst-case scenario, a spill in winter may impact the shore in a little more than 2 days after the release. However, the similarity between summer and winter ends there since there is a 50% chance that condensate and diesel will not make landfall within approximately 5 days and in the best-cast scenario will not reach the shore at all.

Similarly, the severity of the shoreline impact in winter ranges from negligible (18% chance) in the best-case scenario, to more than 21,000 MT in the worst-case.

There is a 69% chance of moderate shoreline oiling and 14 % chance of light oiling, no heavy shoreline oiling is expected. Spatially, around 25 km is expected to have moderate shoreline oiling but up to 363 km could be impacted by moderate oiling in the worst-case.

3.2 Surface Impact

Senegal Waters’ are more than likely to be impacted by this spill scenario but Mauritania may not due to a southerly flowing current occurring in some scenarios. The waters of Cape Verde, Guinea-Bissau and The Gambia are also at risk in both summer and winter scenarios.

The waters of Senegal and Mauritania could experience a spill with a surface thickness more than 5 µm making them candidates for containment and recovery techniques. The waters of other neighbouring countries may experience oil sheen on the surface waters but not at a thickness that is likely to be effective for containment and recovery.

APPENDIX A. MODEL INPUTS

	Scenario 1	Scenario 2
Description	FPSO storage tank and diesel tank failure - summer	FPSO storage tank and diesel tank failure - winter
Latitude	16° 04' 00.0732" N	16° 04' 00.0732" N
Longitude	016° 53' 09.2260" W	016° 53' 09.2260" W
Time of Year	Apr-Sep	Oct-Mar
Release Depth	Surface (0 m)	
Release Rate	1,000 m^3/hr	
Release Duration	3.2 hours - Diesel 160 hours - Condensate	
Duration After Cessation	35 days	
Total Model Duration	42 days	
Oil Type	Diesel	Condensate
API Gravity	36.4	47.8
Specific Gravity	0.843	0.789
Viscosity (cP)	3.9	2.0
Pour Point (°c)	-36.0	-6.0
Wax (%)	-	6.00
Asphaltenes (%)	-	-
Diameter of Release Hole (m)	n/a	
Gas to Oil Ratio (GOR, Sm^3/m^3)	n/a	
Gas Density (kg/Sm^3)	n/a	

APPENDIX B. METOCEAN DATA

Table 12: Current data – general description

Name	G0132-Curr01		
Description	Sourced from BMT ARGOSS. The dataset consists of an amalgamation of the HYCOM global dataset with the BMT ARGOSS tidal model superimposed		
Start Time	Jan 2009	**Spatial Resolution**	~9 km
End Time	Dec 2011	**Temporal Resolution**	1 hour
Depth Levels [m]	0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1750, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500		

The hydrodynamic database is constructed from 3D current velocity fields, suitable for use in oil model simulations. This comprises of ocean currents (non-tidal residual) from a global ocean circulation model, combined with tidal current velocities.

Tidal current information is obtained from BMT ARGOSS from the integration of approximately 5,000 tidal stations and 15 years of satellite radar altimeter into depth averaged global and regional tidal models (2DH model). The tidal model provides tidal currents (u, v components) as well as surface elevation. The spatial resolution of the tidal model varies from 1/60 to 1/12 degrees globally.

The vertical structure of the tidal current component is established using a logarithmic profile which provides a reliable representation of tidal currents at different depths in shelf seas. The tidal model provides data at a spatial resolution of 4 minutes in the area of interest and can be provided in time steps as required by the client.

Ocean currents are obtained from a global ocean current model (HYCOM), which has the following characteristics:

Spatial resolution: 1/12 degree (can not be refined further)

Temporal resolution: Daily (cannot be refined further, other than by interpolation)

Data type: 3D current speed and direction

Depth: 3D datasets consist of up 33 depth layers from surface to seabed and spread across the water column. Individual layers and their distribution over the water column vary and depend on the local depth.

Availability: 2009 – 2012

The resultant data, representative of total current velocity, is provided as hourly current vectors, at selected depth levels, at 1/12 degree spatial resolution across the area of interest. It should be noted that in deep water, beyond the continental slope, tidal current velocity would be negligible.

Temporal resolutions of one hour are considered to be an optimal resolution, as coarser temporal resolutions would not adequately capture the data variability in areas where tidal currents form a key component of the total current

Table 13: Wind data – general description

Name	G0132-Wind01		
Description	Sourced from BMT ARGOSS. The dataset consists of the NCEP CFRS global dataset, calibrated by BMT ARGOSS against satellite altimeter and scatterometer measurements.		
Start Time	Jan 2009	**Spatial Resolution**	~35 km
End Time	Dec 2011	**Temporal Resolution**	3 hours
Altitude Level	The dataset includes hourly mean values of wind velocity at 10 m above sea level.		

Winds are provided as hourly mean values of north and east velocity components at 10m above sea level. Data is from the NCEP global dataset, calibrated by BMT ARGOSS against satellite altimeter and scatterometer measurements. The source data are available at spatial resolution of 0.5°x 0.5°, and at 3 hourly time steps.

APPENDIX C. HABITAT GRID

Table 14: Habitat domain details

<table>
<tr><th>Name</th><th colspan="4">Domain Extent</th></tr>
<tr><td rowspan="9">G0132-Hab02</td><th>Bottom</th><th>Top</th><th>Left</th><th>Right</th></tr>
<tr><td>05° 00' 00'' N</td><td>25° 00' 00'' N</td><td>030° 00' 00'' W</td><td>010° 00' 00'' W</td></tr>
<tr><th colspan="2">Number of Cells</th><th colspan="2">Cell Resolution</th></tr>
<tr><th>East to West</th><th>North to South</th><th>East to West</th><th>North to South</th></tr>
<tr><td>858</td><td>888</td><td>2,500 km</td><td>2,500 km</td></tr>
<tr><th colspan="4">Domain Size</th></tr>
<tr><th colspan="2">East to West</th><th colspan="2">North to South</th></tr>
<tr><td colspan="2">2,145 km</td><td colspan="2">2,220 km</td></tr>
</table>

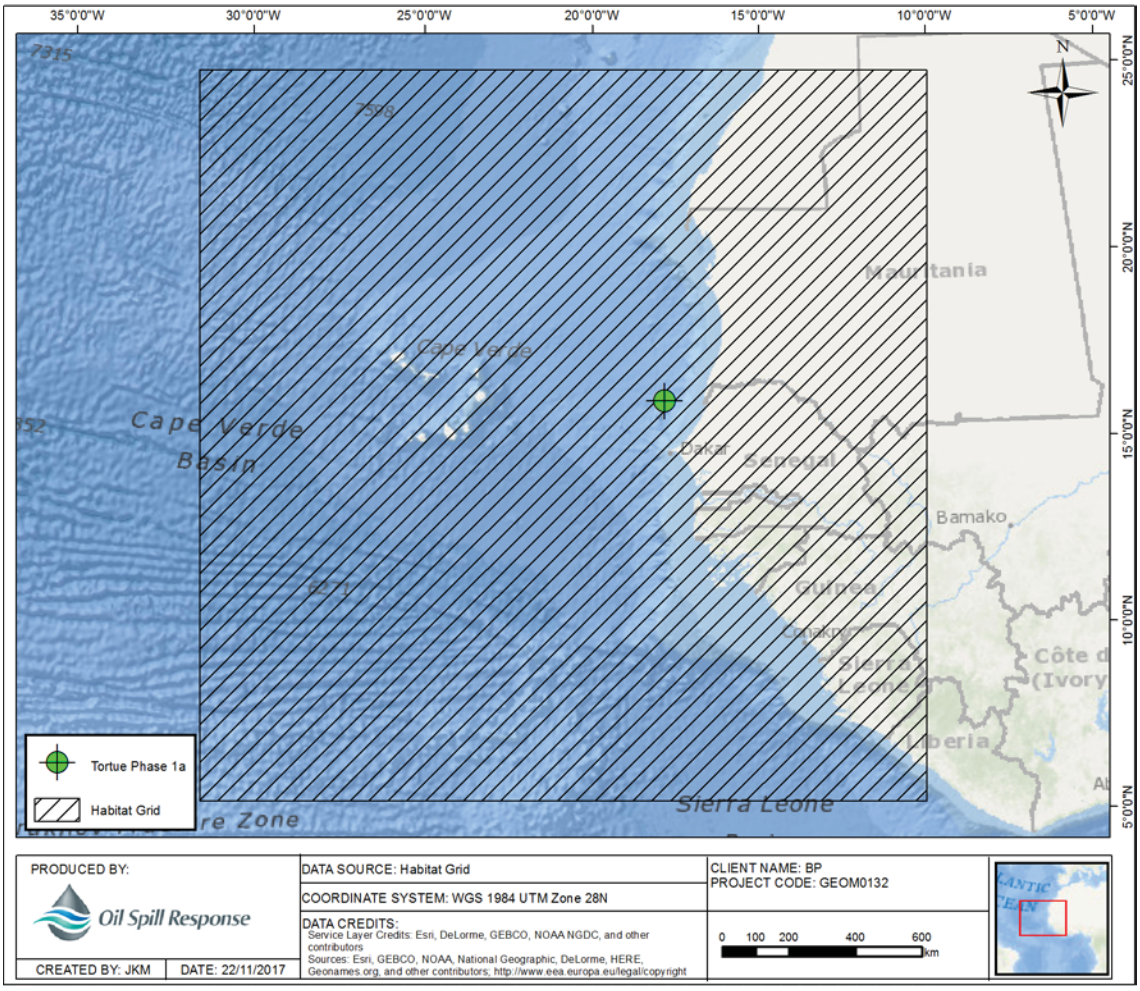


Figure 25:Extent of habitat grid used in this study

APPENDIX D. OIL CHARACTERISTICS AND BEHAVIOUR

The components found in oil are classified into two main groups: hydrocarbons and non-hydrocarbons (see Figure 29). If oil is rich in C1-12 alkanes, it is particularly light, as these are lighter components than the C25+ alkanes. Conversely, if oil contains high quantities of C25+ alkanes, resins and asphaltenes, it is heavy.

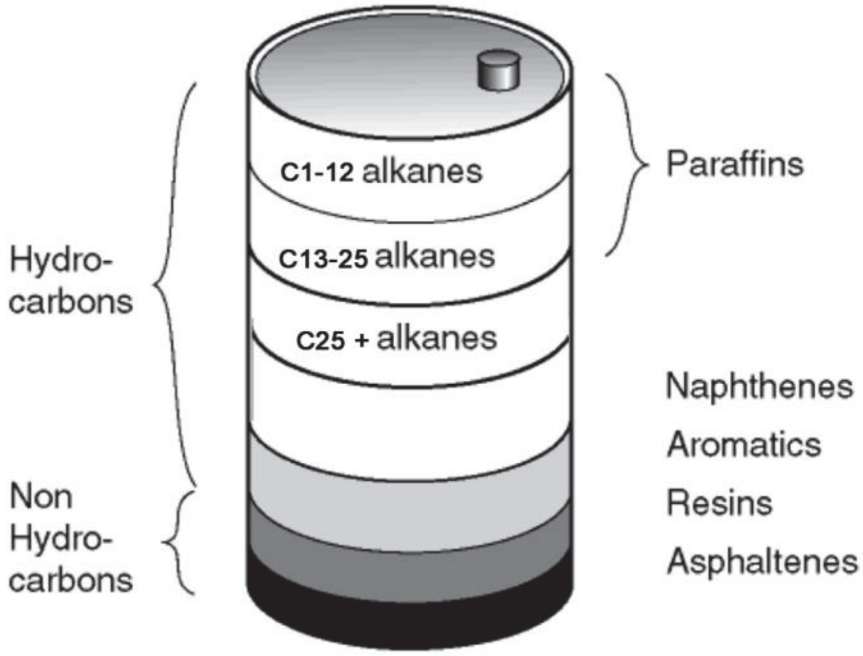


Figure 26:The chemical composition of crude oil

The chemical composition of oil is important when predicting how it will break down or weather. For example, oil containing mostly light components is likely to lose a greater volume to evaporation than heavy oil. Oils with carbon chains exceeding 15 (C15+) cannot evaporate, even during large storms. Long chains (for example, C25+ alkanes) take a long time to degrade in the water column. Asphaltenes can increase the stability of oil, allowing it to take up water but preventing the oil and water emulsion from breaking down.

As oil is a complicated mixture of organic compounds, its components must be analysed to characterise it successfully (LECO Corporation, 2012). The components of oil can be 'identified' and plotted using gas chromatography instruments which are coupled with mass spectrometers (see Bacher, 2014, for further information). The results of gas chromatography and mass spectrometry are converted into a list of 25 sub-components, as broken down in the OSCAR oil database. Each of the 25 sub-components is characterised by molecular weight, density, viscosity, boiling point, solubility in water, vapour pressure, and partition coefficient between oil and water.

The OSCAR Oil Database

A strength of the OSCAR model is its foundation on an observational database of oil weathering properties (maximum water content, viscosity, droplet size distribution, evaporation, emulsification and dispersion, which are measured in a wide range of conditions). The oil database contains complete weathering information for 340 crude oils and petroleum products. It also contains crude assay data for approximately 170 other crude oils (derived from the HPI database - HPI, 1987). But these oils have

not been lab-tested so model estimates of the weathering process are used in place of observational data. This reduces the reliability of the model.

Oil Matching

Two lab tested oils were selected for this modelling study based on the information provided by BP.

The properties of the modelled oils are shown in Table 14 and Table 15. Figure 30 and Figure 31 list the sub-components of the modelled oils and their percentage fraction.

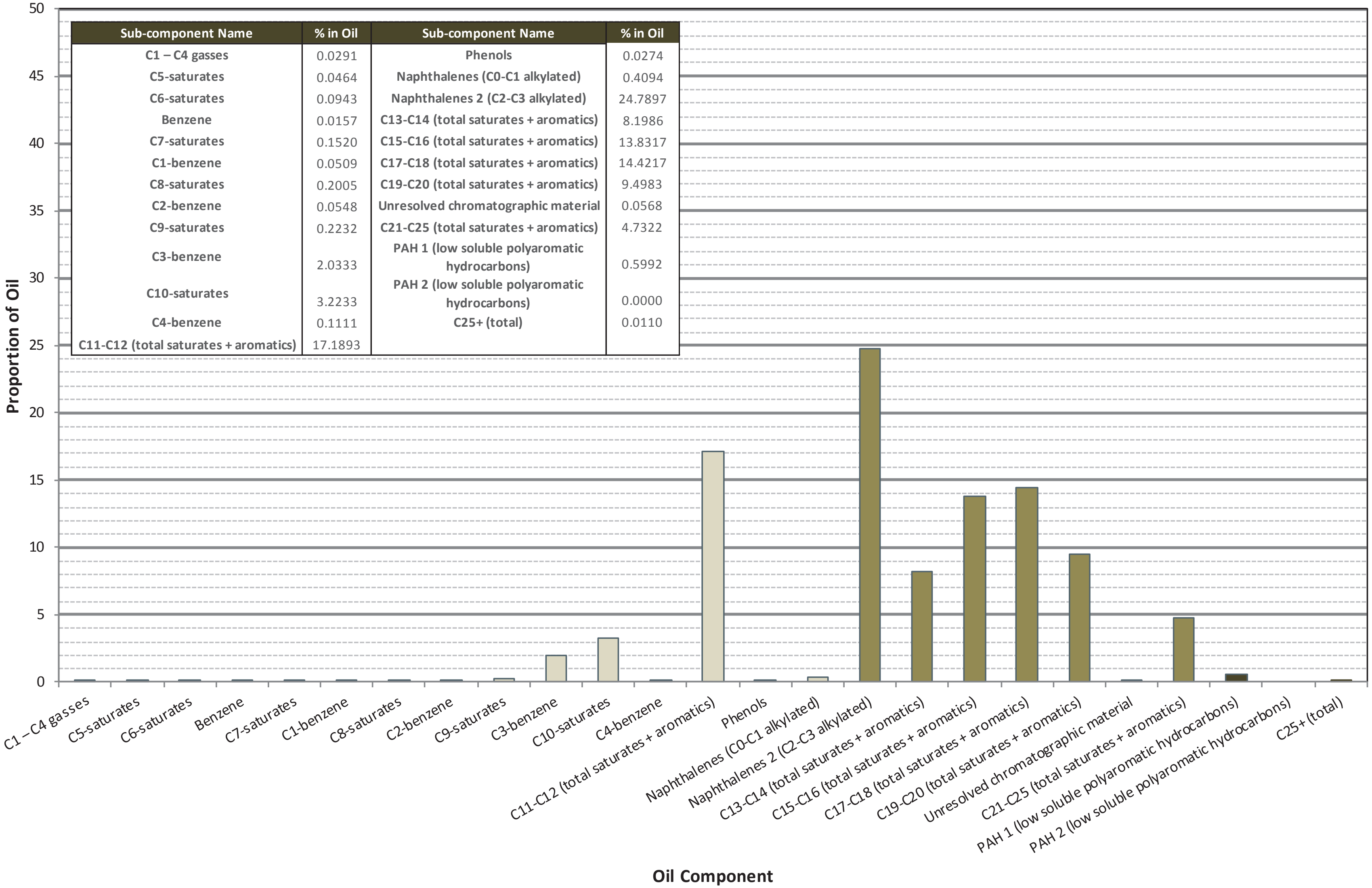
Table 15: Properties of the modelled diesel

Name	Specific Gravity	Viscosity (cP)	Pour Point[3]* (°C)	Wax Content (%)	Asphaltenes (%)
Client Diesel	0.843	3.9	-36.0	-	-
Modelled Diesel	0.843	3.9	-36.0	-	-

Table 16: Properties of the modelled condensate

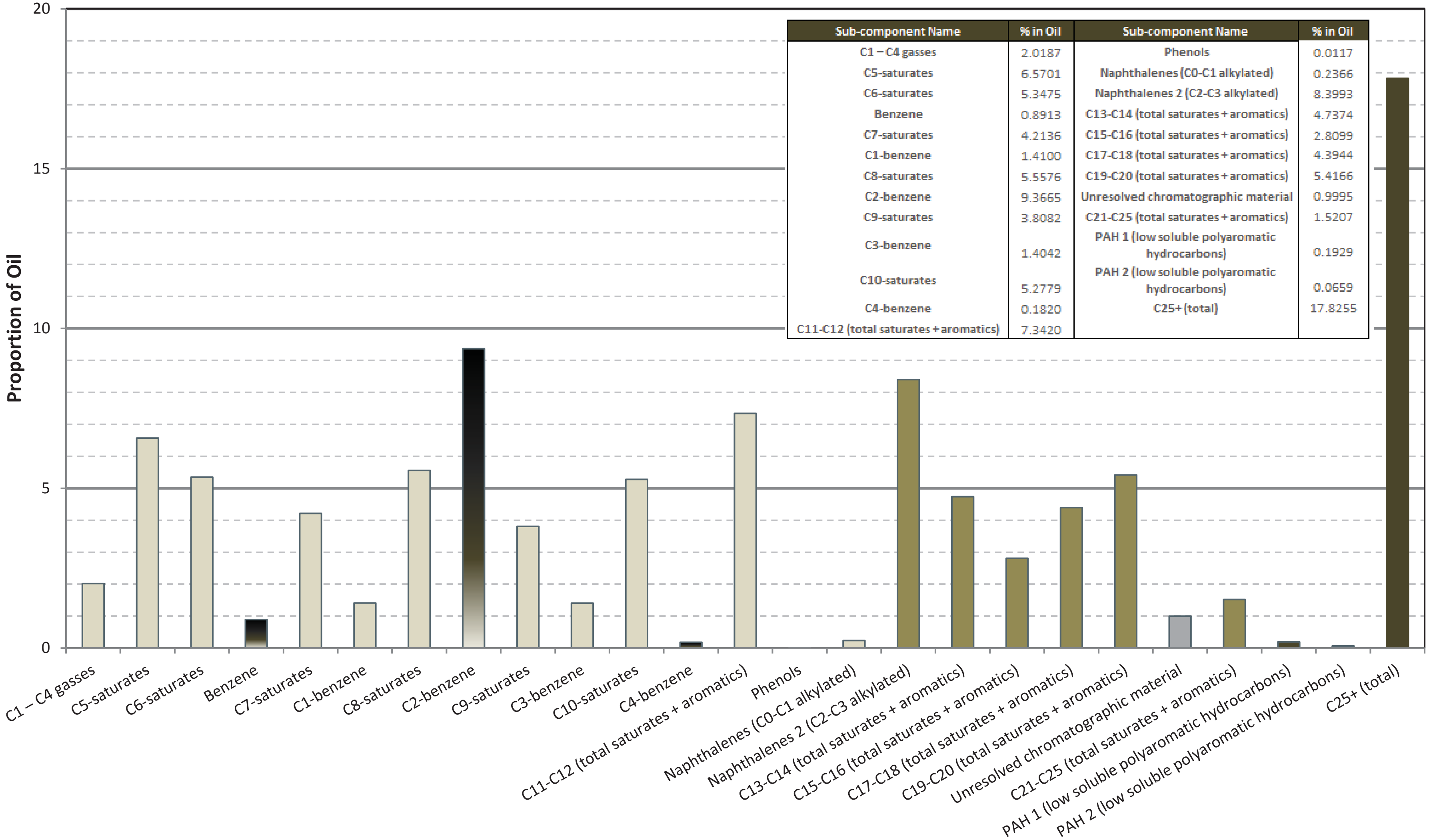
Name	Specific Gravity	Viscosity (cP)	Pour Point[3]* (°C)	Wax Content (%)	Asphaltenes (%)
Client Condensate	0.735	1.0	<-36.0	3.0 – 5.0	0
Modelled Condensate	0.789	2.0	-6.0	6.00	-

[3] Due to the algorithms in the model, Pour Point is of lesser importance when oil matching.



Sub-component Name	% in Oil	Sub-component Name	% in Oil
C1 – C4 gasses	0.0291	Phenols	0.0274
C5-saturates	0.0464	Naphthalenes (C0-C1 alkylated)	0.4094
C6-saturates	0.0943	Naphthalenes 2 (C2-C3 alkylated)	24.7897
Benzene	0.0157	C13-C14 (total saturates + aromatics)	8.1986
C7-saturates	0.1520	C15-C16 (total saturates + aromatics)	13.8317
C1-benzene	0.0509	C17-C18 (total saturates + aromatics)	14.4217
C8-saturates	0.2005	C19-C20 (total saturates + aromatics)	9.4983
C2-benzene	0.0548	Unresolved chromatographic material	0.0568
C9-saturates	0.2232	C21-C25 (total saturates + aromatics)	4.7322
C3-benzene	2.0333	PAH 1 (low soluble polyaromatic hydrocarbons)	0.5992
C10-saturates	3.2233	PAH 2 (low soluble polyaromatic hydrocarbons)	0.0000
C4-benzene	0.1111	C25+ (total)	0.0110
C11-C12 (total saturates + aromatics)	17.1893		

Figure 27:Chemical composition of the modelled diesel



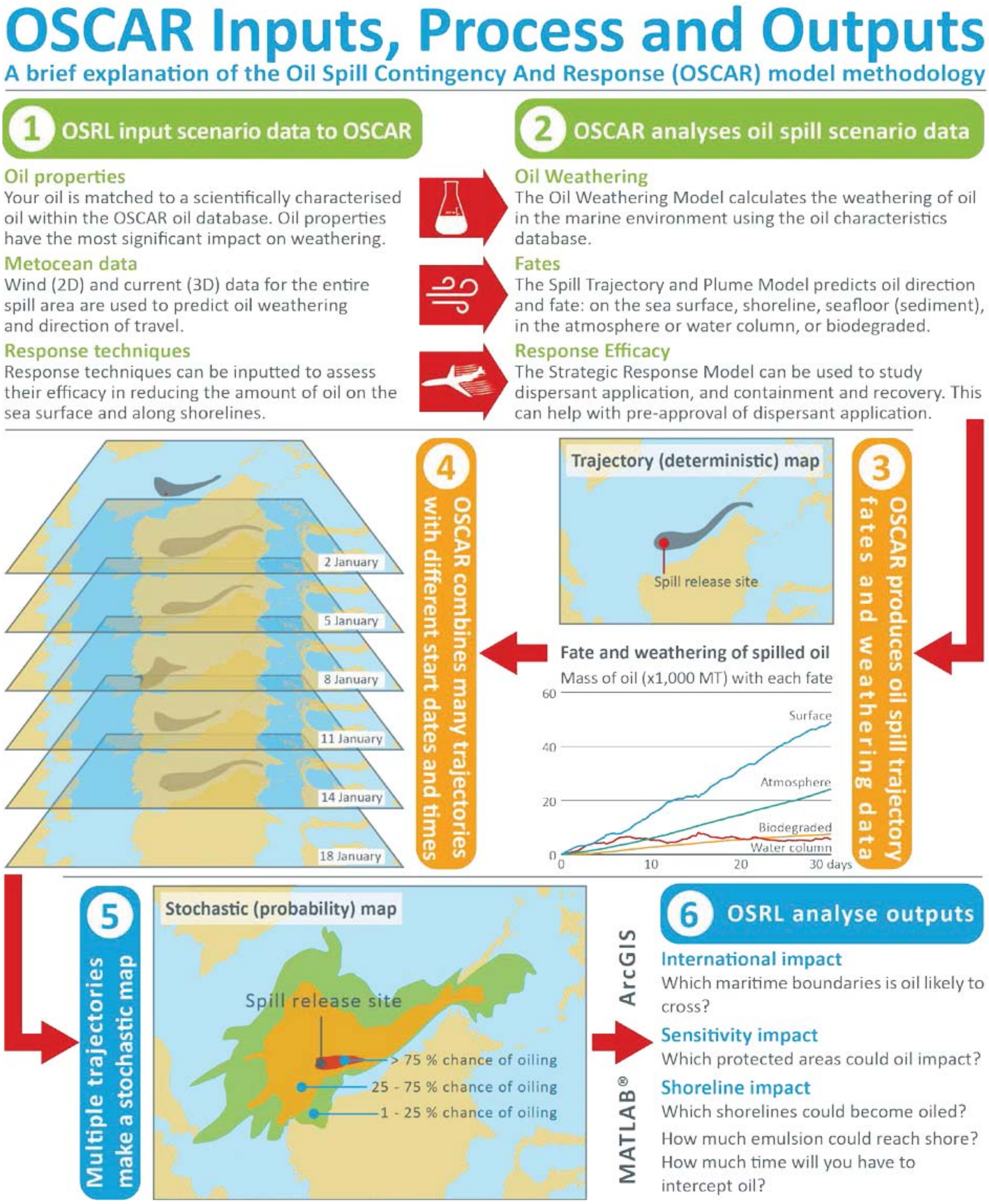
Sub-component Name	% in Oil	Sub-component Name	% in Oil
C1 – C4 gasses	2.0187	Phenols	0.0117
C5-saturates	6.5701	Naphthalenes (C0-C1 alkylated)	0.2366
C6-saturates	5.3475	Naphthalenes 2 (C2-C3 alkylated)	8.3993
Benzene	0.8913	C13-C14 (total saturates + aromatics)	4.7374
C7-saturates	4.2136	C15-C16 (total saturates + aromatics)	2.8099
C1-benzene	1.4100	C17-C18 (total saturates + aromatics)	4.3944
C8-saturates	5.5576	C19-C20 (total saturates + aromatics)	5.4166
C2-benzene	9.3665	Unresolved chromatographic material	0.9995
C9-saturates	3.8082	C21-C25 (total saturates + aromatics)	1.5207
C3-benzene	1.4042	PAH 1 (low soluble polyaromatic hydrocarbons)	0.1929
C10-saturates	5.2779	PAH 2 (low soluble polyaromatic hydrocarbons)	0.0659
C4-benzene	0.1820	C25+ (total)	17.8255
C11-C12 (total saturates + aromatics)	7.3420		

Figure 28:Chemical composition of the modelled condensate

APPENDIX E. OIL SPILL MODELLING SOFTWARE AND METHODOLOGY

This project was completed using the version of OSCAR contained within the Marine Environmental Modelling Workbench (MEMW) 8.0, a model that has been fully validated and calibrated using various field observations from several experimental oil spills (Reed et al., 1995, 1996).

OSCAR predicts the movement of oil at the water's surface and throughout the water column. OSCAR consists of several interlocking modules that are activated as required. The following infographic illustrates the OSCAR modelling process.



APPENDIX F. GLOSSARY OF TERMS, ACRONYMS AND ABBREVIATIONS

°C	Degrees Celsius (1.0°C = 33.8° Fahrenheit)
µm	Micrometre (1.0 µm = 10^{-6} m)
API	American Petroleum Institute
API Gravity	API Gravity, like specific gravity, is a ratio between the densities of oil and water. Unlike specific gravity, API gravity is only used to describe oil, which it characterises as: • Light - API > 31.1 • Medium - API between 22.3 and 31.1 • Heavy - API < 22.3 • Extra Heavy - API < 10.0 API Gravity is converted to Specific Gravity using the following formula: *API gravity = (141.5/Specific Gravity) – 131.5* An API of 10 is equivalent to water, so oils with an API above 10 will float on water while oils with an API below 10 will sink. See also: *Specific Gravity, API*
ArcGIS	A geographic Information System (GIS) used to present OSCAR outputs on maps.
Asphaltene Content	The asphaltenes present the crude oil components that are (1) insoluble in n-heptane at a dilution ratio of 40 parts alkane to 1 part crude oil and (2) re-dissolves in toluene. The asphaltenes include the crude oil material highest in molecular weight, polarity and aromaticity.
bbls	Barrels of oil (a unit of volume). (1.0 bbls = 0.15899 m³ and 1.0 m³ = 6.2898 bbls) The conversion between mass and volume requires knowledge of the oil density. See also: *MT, API Gravity, Specific Gravity*
bbls/day	Barrels of oil per day (rate).
BONN Agreement	The BONN Agreement is an international standard and agreement on how to characterise and respond to pollution. Although aimed at pollution in the North Sea (Europe) many of the characterisation standards are internationally recognised.
FPSO	Floating Production Diesel and Offloading - a floating vessel used for producing, processing and storing oil.
GOR	Gas to Oil Ratio - the ratio of volumetric flow of produced gas to the volumetric flow of oil. Although GOR is a ratio, the volume units must be known since gas and oil volumes are measured differently. GOR changes with temperature and pressure so the condition under which GOR is measured must be known.
ITOPF	The International Tanker Owners Pollution Federation Limited
km	Kilometres (1.0 km = 1,000 m) See also: *m*
m	Metres (1.0 km = 1,000 m) See also: *µm, km*
MATLAB	Matrix Laboratory - a multi-paradigm numerical computing environment and programming language used in this study for the manipulation of data outputs from OSCAR.

MEMW	Marine Environmental Modelling Workbench - the modelling software package developed by SINTEF. The MEMW consists of three models: • **DREAM (Dose, Risk and Effects Assessment Model)** • **OSCAR (Oil Spill Contingency and Response Model)** • **ParTrack Model** When combined, these three models quantify the environmental effect of most chemical pollution activities. See also: *OSCAR, SINTEF*
MT	Metric Tonnes - this is a unit of oil mass. (1.0 MT = 1,000 kg) The conversion between mass and volume requires knowledge of the oil's API or Specific Gravity as follows: *Barrels per metric ton = 1/[(141.5/(API + 131.5) x 0.159]* See also: *bbls, API Gravity, Specific Gravity*
NOAA	National Oceanic and Atmospheric Administration – an American scientific agency focussed on metocean conditions
OSCAR	Oil Spill Contingency And Response A state of the art 3D oil spill model and simulation tool for predicting the fates and effects of oil released into the marine environment. Developed by SINTEF, it sits within the larger MEMW application. See also: *SINTEF, MEMW*
OSRL	Oil Spill Response Limited
Pour Point	The pour point of a liquid is the lowest temperature at which it shows flow characteristics. If ambient temperature is less than the liquid's pour point it will begin to solidify.
SCAT	Shoreline Cleanup Assessment Technique
SINTEF	SINTEF is an independent research organisation in Norway which develops the OSCAR model used in this study.
Specific Gravity	Specific gravity is a ratio of the density of one substance to the density of a reference substance, usually water. Specific gravity of oil is a ratio of the density of oil to the density of water. See also: *API Gravity, bbls, MT*
Stochastic	Stochastic (or probabilistic) results show the probability or likelihood of an event occurring. They provide statistical data that can be used to assess risk and identify worst-case scenarios. Stochastic results are achieved by combining many different trajectory simulations. See also: *Trajectory*
Trajectory	Trajectory or deterministic results show the impact of a single spill event over time. Can be used to assess different response options such as booms, skimmers and dispersant. See also: *Stochastic*
UTC	Coordinated Universal Time
Wax Content	Represents the crude oil components that are soluble in higher molecular weight normal alkanes (n-heptane) but are insoluble in lower molecular weight alkanes (n-pentane).

APPENDIX G. REFERENCES

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APPENDIX N-1c : OIL SPILL MODELING REPORT – PIPELAYING VESSEL COLLISION

Oil Spill Modelling Report – Pipelaying Vessel Collision
Tortue Phase 1a

BP p.l.c.
Document Number: GEOM0132h R04
Issued: 21 May 2018

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EXECUTIVE SUMMARY

Oil spill modelling was completed by Oil Spill Response Ltd. (OSRL) on behalf of BP for the Tortue Phase 1a project, offshore Senegal and Mauritania (Figure 1). The results of this analysis will support the Oil Spill Contingency Plan and the Environmental Impact Assessment for the area. The modelled scenarios are summarised in Table 1.

Scenario 1. Pipelaying vessel collision resulting in the release of 2,980 m^3 of diesel over 3 hours, 3,370 m^3 of heavy fuel oil over 3.4 hours; and 92 m^3 of lubricating oil over 1 hour during summer (April-September)

Scenario 2. Pipelaying vessel collision resulting in the release of 2,980 m^3 of diesel over 3 hours, 3,370 m^3 of heavy fuel oil over 3.4 hours; and 92 m^3 of lubricating oil over 1 hour during winter (October-March)

The coastlines of Senegal and Mauritania are at risk due to a Pipelaying vessel collision. Summer is worse than winter with shoreline impact almost certainly occurring within 4.5 days and in the worst-case in less than 1 day. Whilst the worst-case shoreline impact for Summer and Winter is approximately the same at a little over 4,500 MT, Summer is the higher risk season. Summer has a 50% chance of 3,400 MT reaching the shore whereas Winter has only 2,900 MT for the same probability. Further, first shoreline impact in Summer ranges from less than a day to approximately 4.5 days in the best case. The Winter scenario has a much larger range, from less than a day to more than 50 days in the best case.

Senegal is expected to see more oiling than Mauritania. A Summer spill may also result in more "heavy" shoreline oiling (using ITOPF's recognition of shoreline oiling (See Thresholds)) than winter. However, the length of shoreline that could be impacted by heavy oiling is restricted to less than 4 km.

The trajectories undertaken shows that, whilst shoreline oiling may initially be considerable, the oil properties mean that it evaporates and biodegrades quickly.

The waters of Senegal and Mauritania could experience a spill with a surface thickness more than 5 µm making them candidates for containment and recovery techniques. The waters of other neighbouring countries are not expected to be impacted during summer, but are impacted by oil up to 3 µm during winter.

DOCUMENT HISTORY

Document Number	Revision	Document Type	Author	Technical Review	Format Review	Date of Issue
GEOM0132h	R01	Draft Modelling Report	JKM	LHM	SJB	08-Dec-17
GEOM0132h	R02	In response to comments	JKM	LHM	SJB	12-Jan-17
GEOM0132h	R03	In response to comments	LHM	LHM	LHM	19-Jan-17
GEOM0132h	R04	In response to comments	LHM	LHM	LHM	21-May-17

JKM – Jenny Kirsty Mitchell   LHM – Liam Harrington-Missin   SJB – Simon Blaen

DISCLAIMERS

- Modelling results are to be used for guidance purposes only and response strategies should not be based on these results alone.
- The resolution / quality of wind and current data vary between regions and models. As with any model, the quality and reliability of the results are dependent on the quality of the input data.

Considering the above, all advice, modelling, and other information provided is generic and illustrative only and not intended to be relied upon in any specific instance. The recipient of any advice, modelling or other information from, or on behalf of, OSRL acknowledges and agrees that any number of variables may impact on an oil spill and, as such, should be addressed on an individual basis. OSRL has no liability in relation to such advice, modelling or other information and the recipient of such information hereby fully indemnifies and holds harmless OSRL its officers, employees, shareholders, agents, contractors and sub-contractors against any costs, losses, claims or liabilities arising about such advice, modelling, training or other information.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Background

Oil spill modelling was completed by Oil Spill Response Ltd. (OSRL) on behalf of BP for the Tortue Phase 1a project, offshore Senegal and Mauritania (Figure 1). The results of this analysis will support the Oil Spill Contingency Plan and the Environmental Impact Assessment for the area. The modelled scenarios are summarised in Table 1.

Scenario 1. Pipelaying vessel collision resulting in the release of 2,980 m^3 of diesel over 3 hours, 3,370 m^3 of heavy fuel oil over 3.4 hours; and 92 m^3 of lubricating oil over 1 hour during summer (April-September)

Scenario 2. Pipelaying vessel collision resulting in the release of 2,980 m^3 of diesel over 3 hours, 3,370 m^3 of heavy fuel oil over 3.4 hours; and 92 m^3 of lubricating oil over 1 hour during winter (October-March)

The modelling was carried out using SINTEF's Oil Spill Contingency and Response (OSCAR) model. OSCAR is a 3D modelling tool used to predict the movement and fate of oil on the sea surface and throughout the water column (see APPENDIX F for further details).

1.2 Aims

The aim of this report is to present the risk to the sea surface and shoreline by creating spatial maps of:

1. Probability - to estimate how likely an area is to be impacted.
2. Arrival time - to estimate how quickly an area could be impacted.
3. Emulsion thickness - to estimate how severely an area could be impacted.

The data behind these maps allow us to answer the following questions:

1. How quickly could oil reach nearby shorelines and what mass?
2. Which countries are more likely to be affected by a spill from the pipelaying vessel?
3. Which environmental sensitivities could be affected by a spill from the pipelaying vessel?

Table 1: Scenario setup

Description	Pipelaying vessel collision - Summer	Pipelaying vessel collision - Winter
Season	April-September	October-March
Latitude	16° 03' 41.31" N	
Longitude	016° 36' 23.652" W	
Total Volume Released	6,442 m^3	
Total Mass Released	5,852.7 MT	
Duration of Release	3.4 hours	
Depth of Release	Surface (0 m)	
Nearest Shoreline	~10 km, St Louis, Senegal	

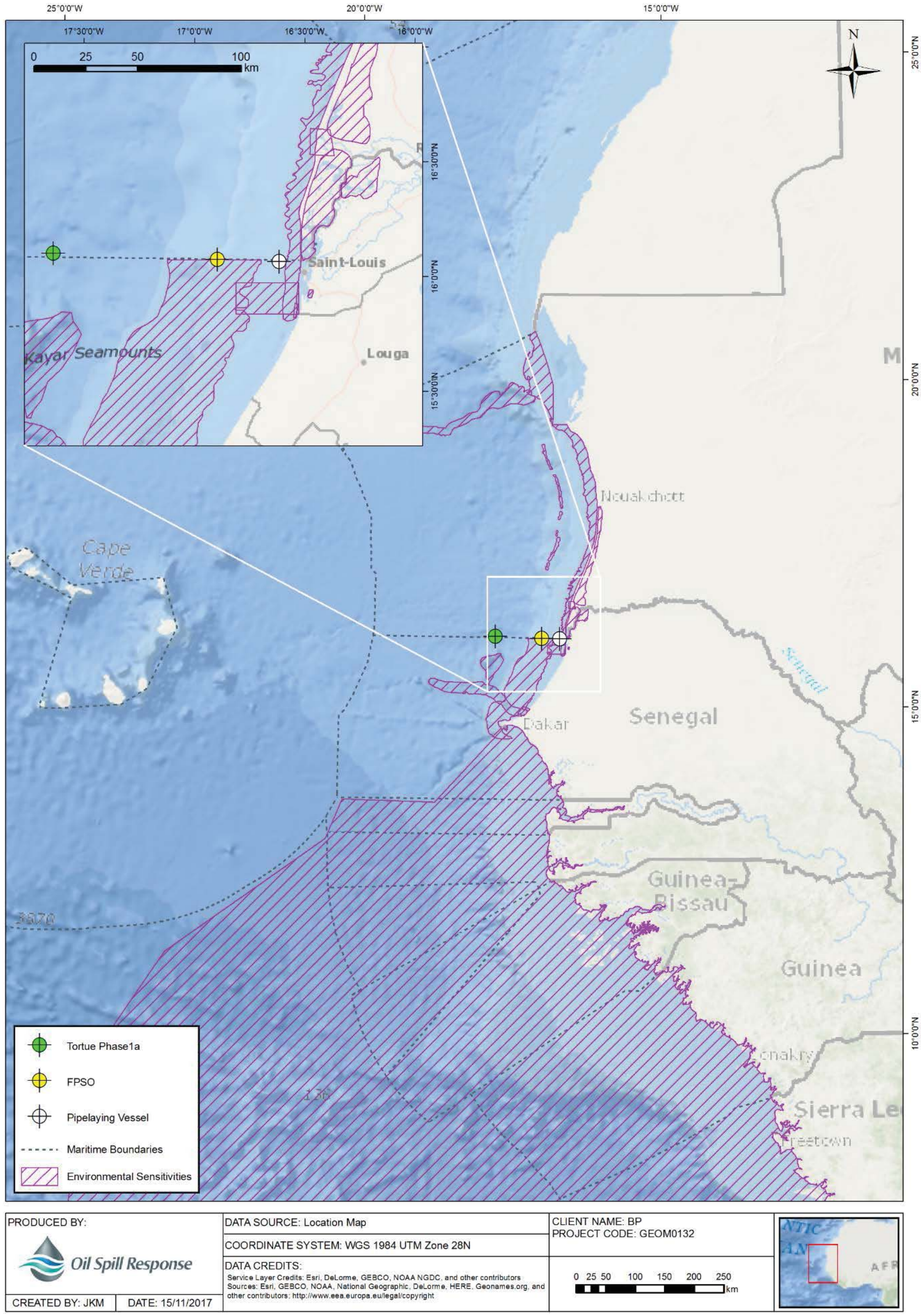


Figure 1: Map showing the release location

1.3 Modelling Setup

Two worst case stochastic simulations were run for the Pipelaying vessel collision (Table 2), with a total of 322 individual trajectories post-processed for the scenario to create the stochastic results. Each trajectory began on a different start date, so that each oil spill was simulated using a range of wind and current conditions.

Three years of hydrodynamic data (sourced from Copernicus and NOAA) were used as model inputs. See APPENDIX A to APPENDIX E for more information on the model setup.

Table 2: Summary of stochastic setup for spill scenarios

Description	Pipelaying vessel collision in Summer	Pipelaying vessel collision in Winter
Location	16° 03’ 41.31" N 016° 36’ 23.652" W	
Time of Year	April-September	October-March
Release Period	3 hours – Diesel 3.4 hours – Heavy Fuel Oil 1 hour – Lubricating Oil	
Release Rate	993.3 m^3/hour - Diesel 991.2 m^3/hour – Heavy Fuel Oil 92 m^3/hour – Lubricating Oil	
Total Release (Volume)	6,442 m^3	
Total Run Duration	60 days	
Total Number of Trajectories	165	157
Time Between Trajectories	3 days, 9 hours	3 days, 5 hours

Please note that a realistic worst-case release rate for a vessel collision is 1,000 m3/hr.

The total inventory of diesel is 2,980 m^3 meaning the total release duration will be 3 hrs leading to the release rate stated.

The total inventory of Heavy Fuel Oil is 3,370 m3 leading to the release duration and rate stated.

Finally, the volume of lubricant oil is 92m^3, since the lowest increment of time that we have set is 1 hour, we release this over the course of 1 hour.

Whilst, there will be minor differences if these timings and rates are adjusted, it will not change the conclusions or findings presented in the pages in this report.

1.4 Thresholds

Thresholds define the point below which data are no longer informative. For example, when surface emulsion thickness is less than 0.04 µm, the oil is no longer visible to the naked eye so may be considered negligible to a response. The thresholds applied to this study are given in Table 3.

Table 3: Thresholds used in the post-processing stage of the modelling

Threshold	Value	Description
Surface	0.04 µm	The Bonn Agreement Oil Appearance Code defines five oil layer thicknesses based on their optic effects and true colours. 0.04 µm is the minimum thickness that can be seen with the naked eye.
Water column	6 ppb (Dissolved)	Low level, in-water dissolved HC exposure.
	70 ppb (Total)	Entrained HC exposure level, OSPAR predicted no effect concentration (PNEC).
Shoreline	0.1 litres/m^2	Lower threshold for light oiling from the ITOPF document "Recognition of oil on shorelines".

The thickness key used in the surface emulsion thickness maps throughout this document is derived from the Bonn Oil Appearance Code (Table 4).

Table 4: Key used for sea surface emulsion thickness outputs

Appearance	Layer Thickness Interval	Colour
Sheen	0.04 µm - 0.3 µm	
Rainbow	0.3 µm -5 µm	
Metallic	5 µm - 50 µm	
Discontinuous True Colour	50 µm - 200 µm	
Continuous True Colour	>200 µm	

The thickness key used in the shoreline maps throughout this document is derived from the ITOPF Technical Information Paper (TIP) No. 6 "Recognition of oil on shorelines" (ITOPF, 2011b; Table 7). Very light oiling is deemed negligible by ITOPF (ITOPF, 2011b); no practical response is required for a very lightly oiled shoreline, apart from monitoring the oil spill.

Table 5: Key used for water column dissolved concentrations

Water Column Classification	Concentration	Colour
Low	< 50 ppb	
Moderate	50 - 400 ppb	
High	> 400 ppb	

Table 6: Key used for water column total concentrations

Concentration	Colour
< 150 ppb	
150 – 500 ppb	
500 – 750 ppb	
750 - 1000 ppb	
> 1000 ppb	

Table 7: Key used for shoreline emulsion thickness outputs

Shoreline Oiling Classification	Concentration	Thickness	Colour
Light Oiling	0.1 – 1 litres/m^2	0.1 mm – 1.0 mm	
Moderate Oiling	1 – 10 litres/m^2	1 mm – 10 mm	
Heavy Oiling	> 10 litres/m^2	> 10 mm	

2 RESULTS

2.1 Stochastic Results

The stochastic results for Scenario 1 were calculated from 322 trajectories. The scenario involves the release of 2,980 m^3 of diesel over 3 hours, 3,370 m3 of heavy fuel oil over 3.4 hours; and 92 m^3 of lubricating oil over 1 hour during the summer (April to September) and during winter (Oct to March). The release is tracked for a total of 60 days.

The following results are presented:

Sea Surface

Figure 2: Pipelaying vessel collision – Surface Probability of Cell Impact– Summer (left) & Winter (right)
Figure 3: Pipelaying vessel collision – Surface Minimum Arrival Time – Summer (left) & Winter (right)
Figure 4: Pipelaying vessel collision – Surface Maximum Emulsion Thickness – Summer (left) & Winter (right)
Figure 5: Pipelaying vessel collision – Surface Average Emulsion Thickness – Summer (left) & Winter (right)
Figure 6: Pipelaying vessel collision – Surface Maximum Exposure Time – Summer (left) & Winter (right)

Shoreline

Figure 7: Pipelaying vessel collision – Shoreline Probability of Cell Impact – Summer (left) & Winter (right)
Figure 8: Pipelaying vessel collision – Shoreline Minimum Arrival Time – Summer (left) & Winter (right)
Figure 9: Pipelaying vessel collision – Shoreline Impact – Summer (left) & Winter (right)

Figure 10: Pipelaying vessel collision – Shoreline Impact – Shoreline Arrival Time Probability - Summer (left) & Winter (right)

Figure 11: Pipelaying vessel collision – Shoreline Impact –Probability Shoreline Mass - Summer (left) & Winter (right)

Water Column (Dissolved Hydrocarbon)

Figure 12: Pipelaying vessel collision – Water Column (Dissolved) Probability of Cell Impact – Summer (left) & Winter (right)
Figure 13: Pipelaying vessel collision – Water Column (Dissolved) Minimum Arrival Time – Summer (left) & Winter (right)
Figure 14: Pipelaying vessel collision – Water Column (Dissolved) Concentrations – Summer (left) & Winter (right)
Figure 15: Pipelaying vessel collision – Water Column (Dissolved) Maximum Exposure Time– Summer (left) & Winter (right)

Water Column (Total Hydrocarbon)

Pipelaying vessel collision **Surface**

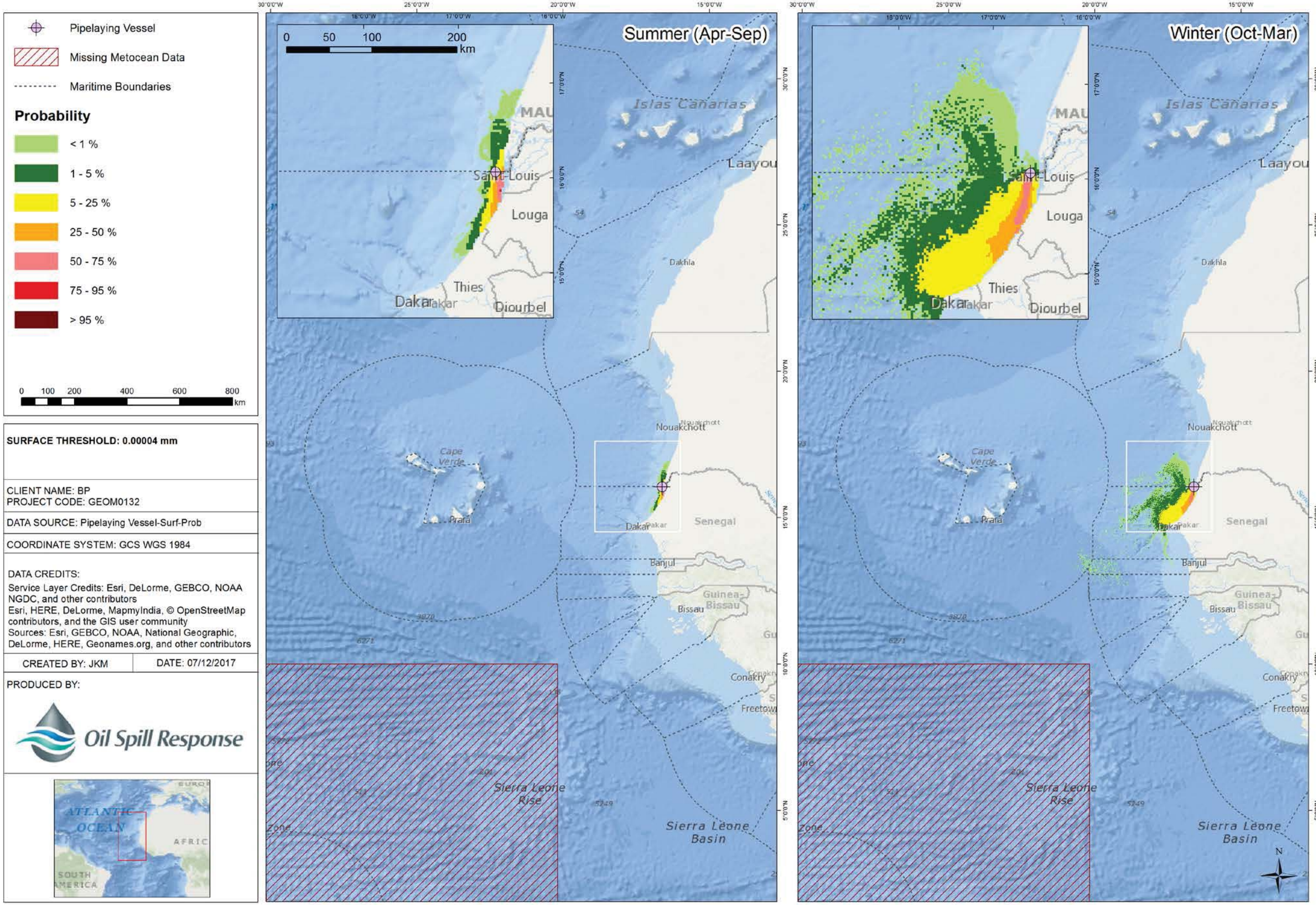


Figure 2: Pipelaying vessel collision – Surface Probability of Cell Impact– Summer (left) & Winter (right)

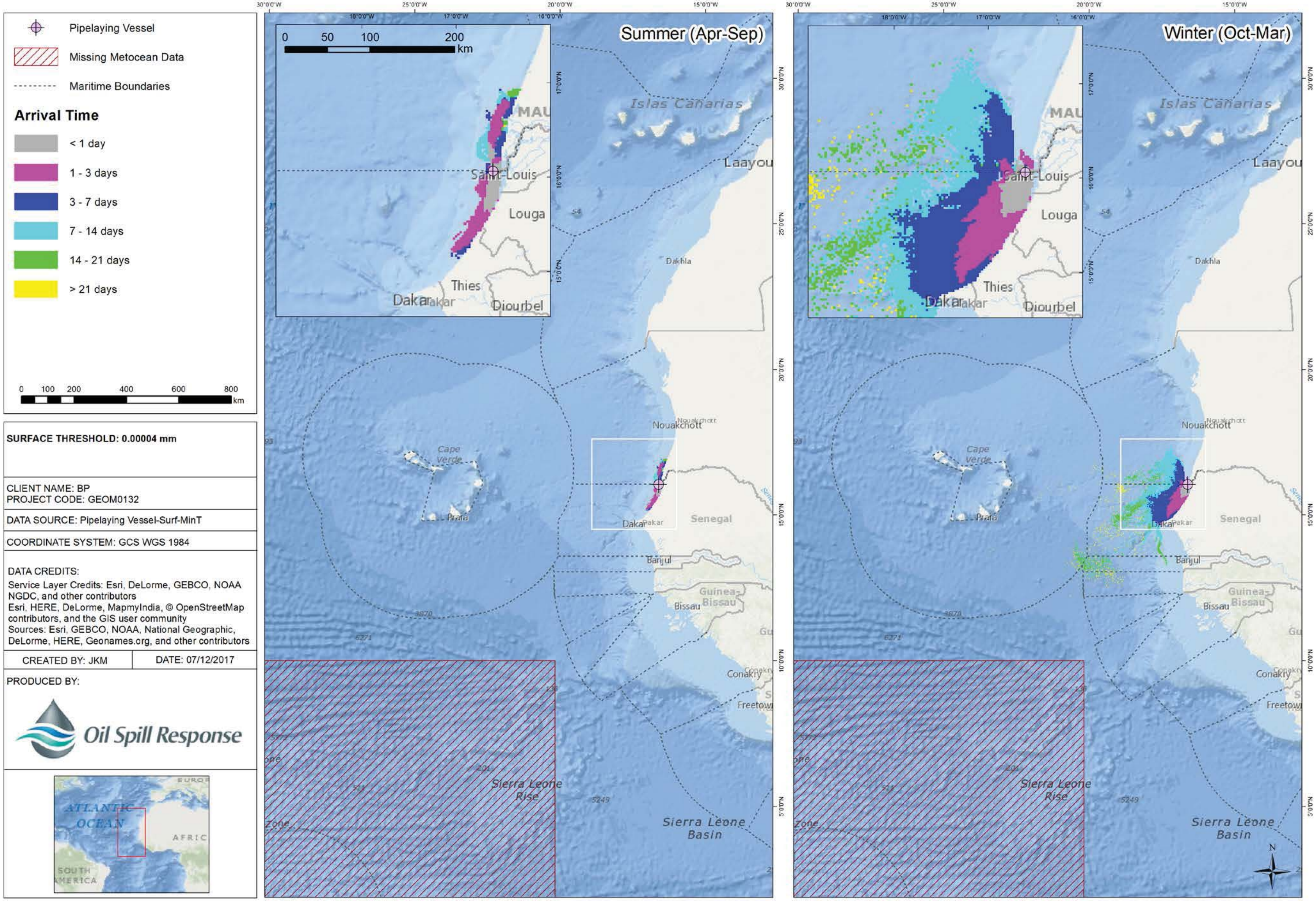


Figure 3: Pipelaying vessel collision – Surface Minimum Arrival Time – Summer (left) & Winter (right)

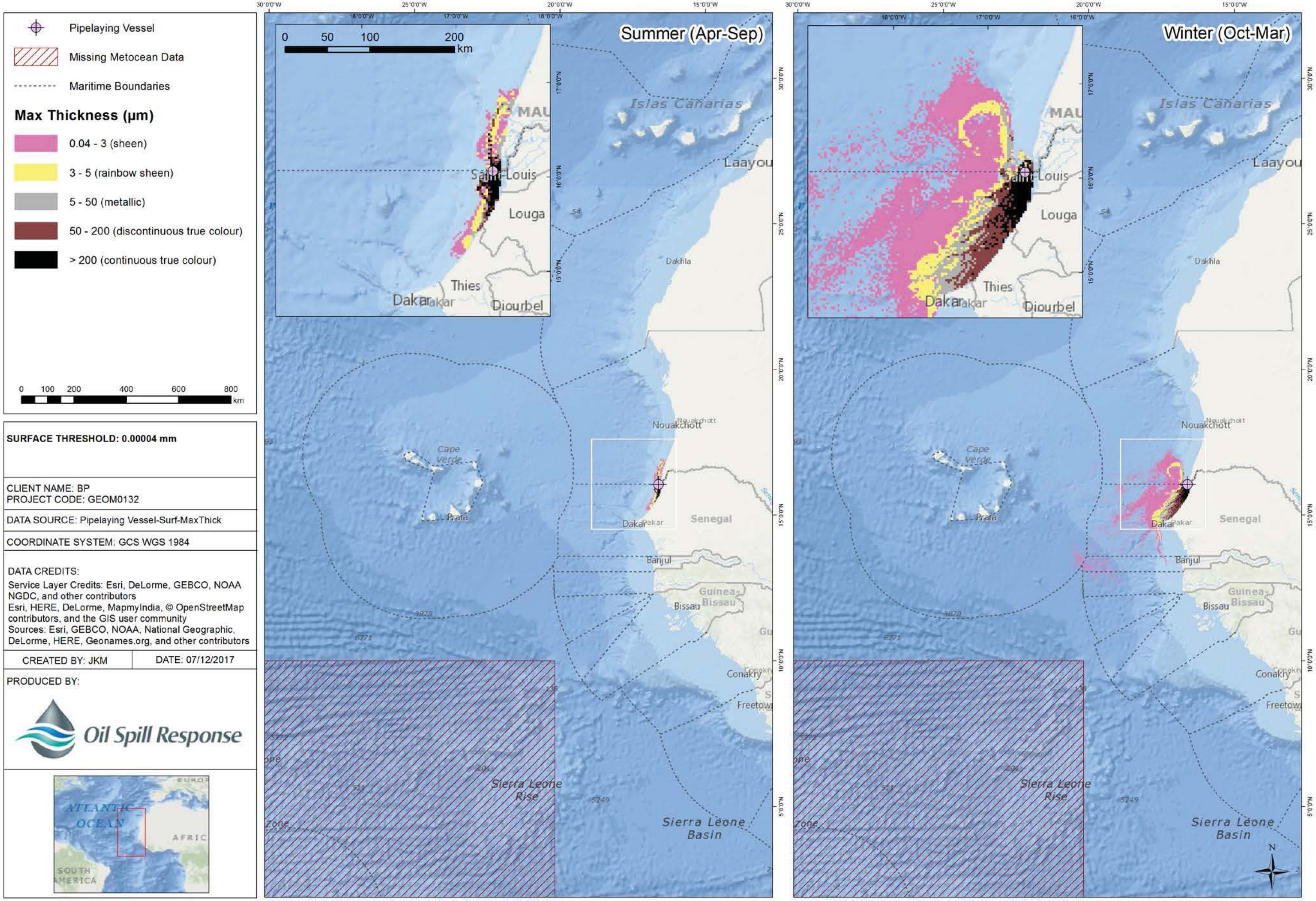


Figure 4: Pipelaying vessel collision – Surface Maximum Emulsion Thickness – Summer (left) & Winter (right)

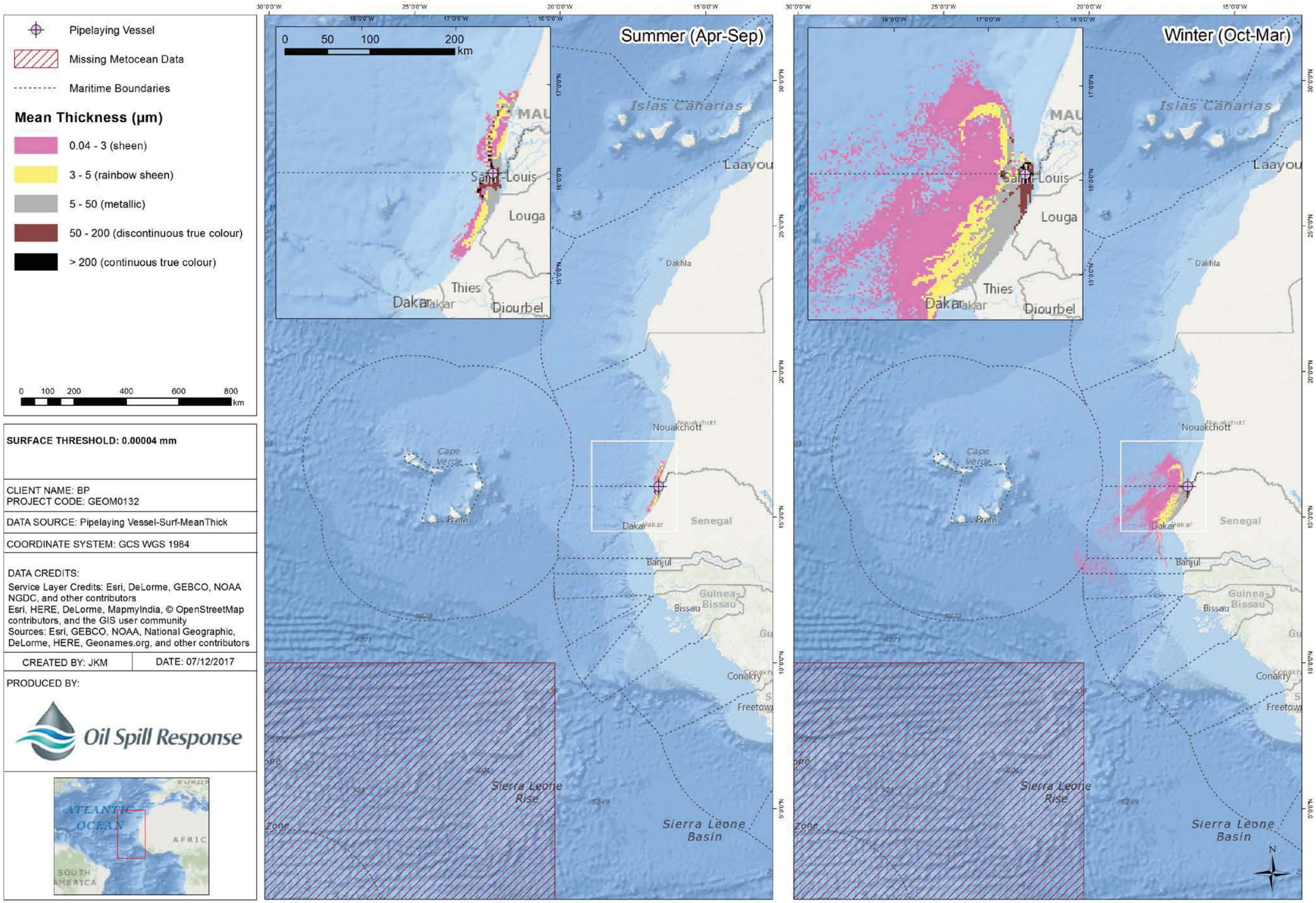


Figure 5: Pipelaying vessel collision – Surface Average Emulsion Thickness – Summer (left) & Winter (right)

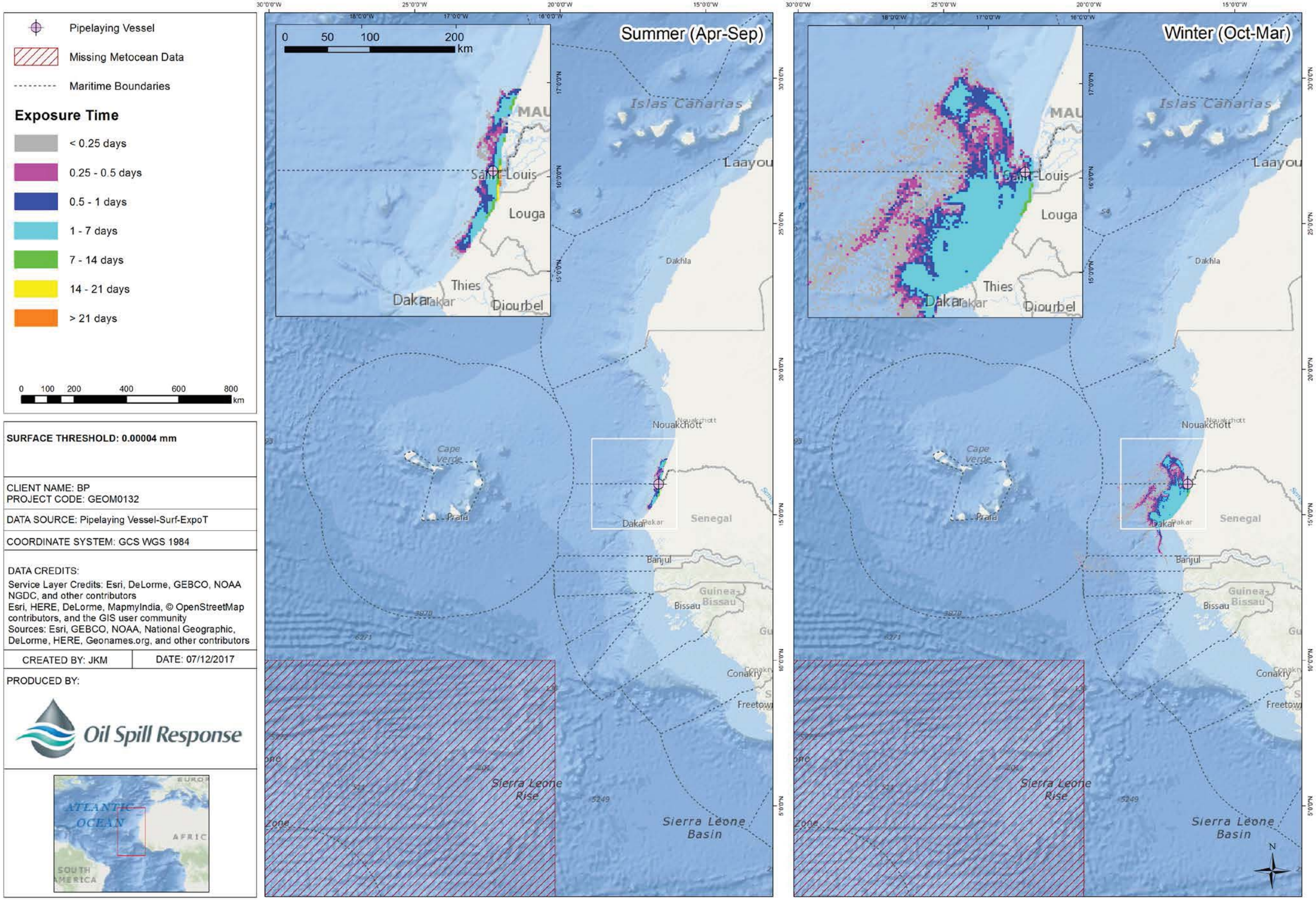


Figure 6: Pipelaying vessel collision – Surface Maximum Exposure Time – Summer (left) & Winter (right)

Pipelaying vessel collision
Shoreline

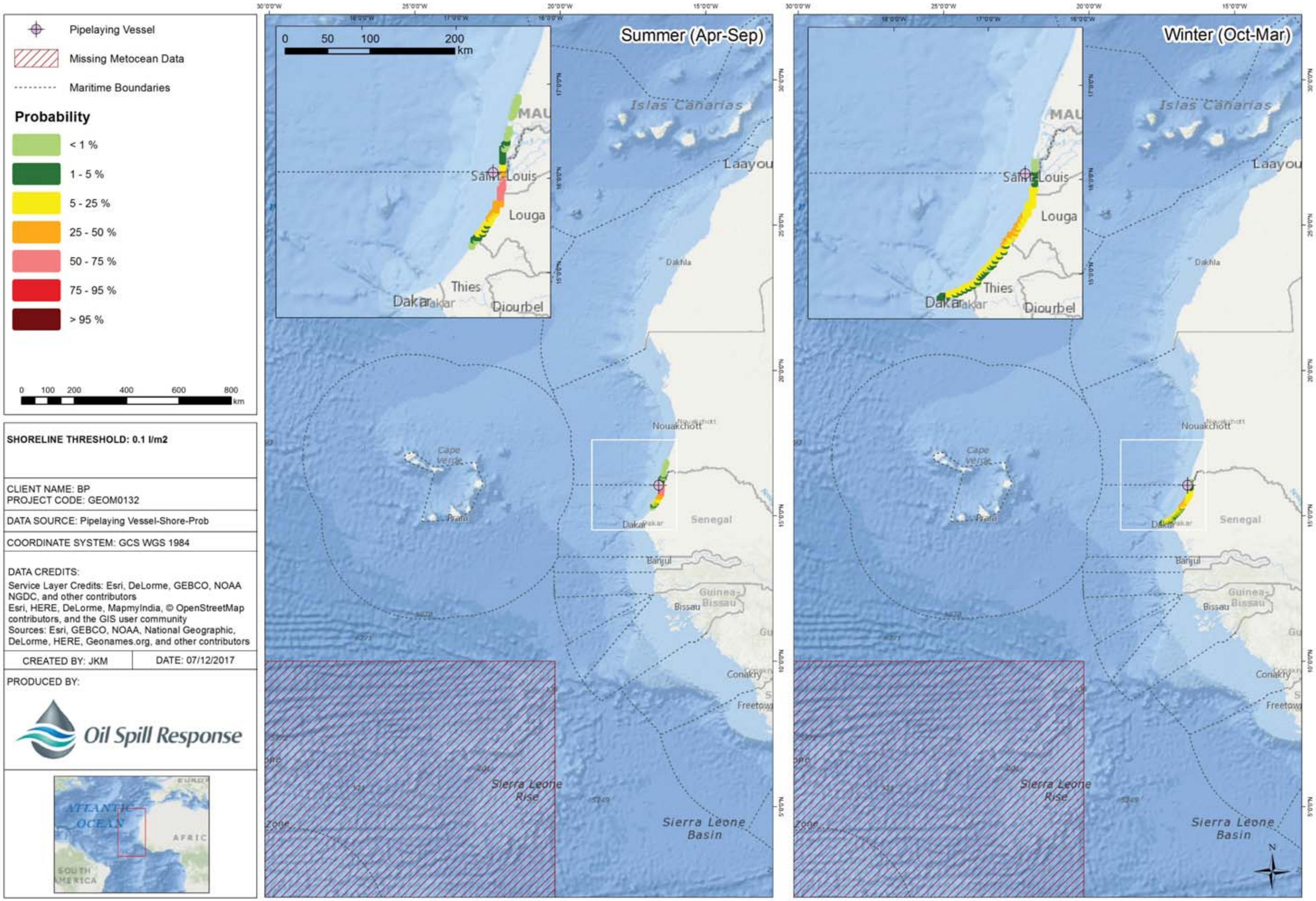


Figure 7: Pipelaying vessel collision – Shoreline Probability of Cell Impact – Summer (left) & Winter (right)

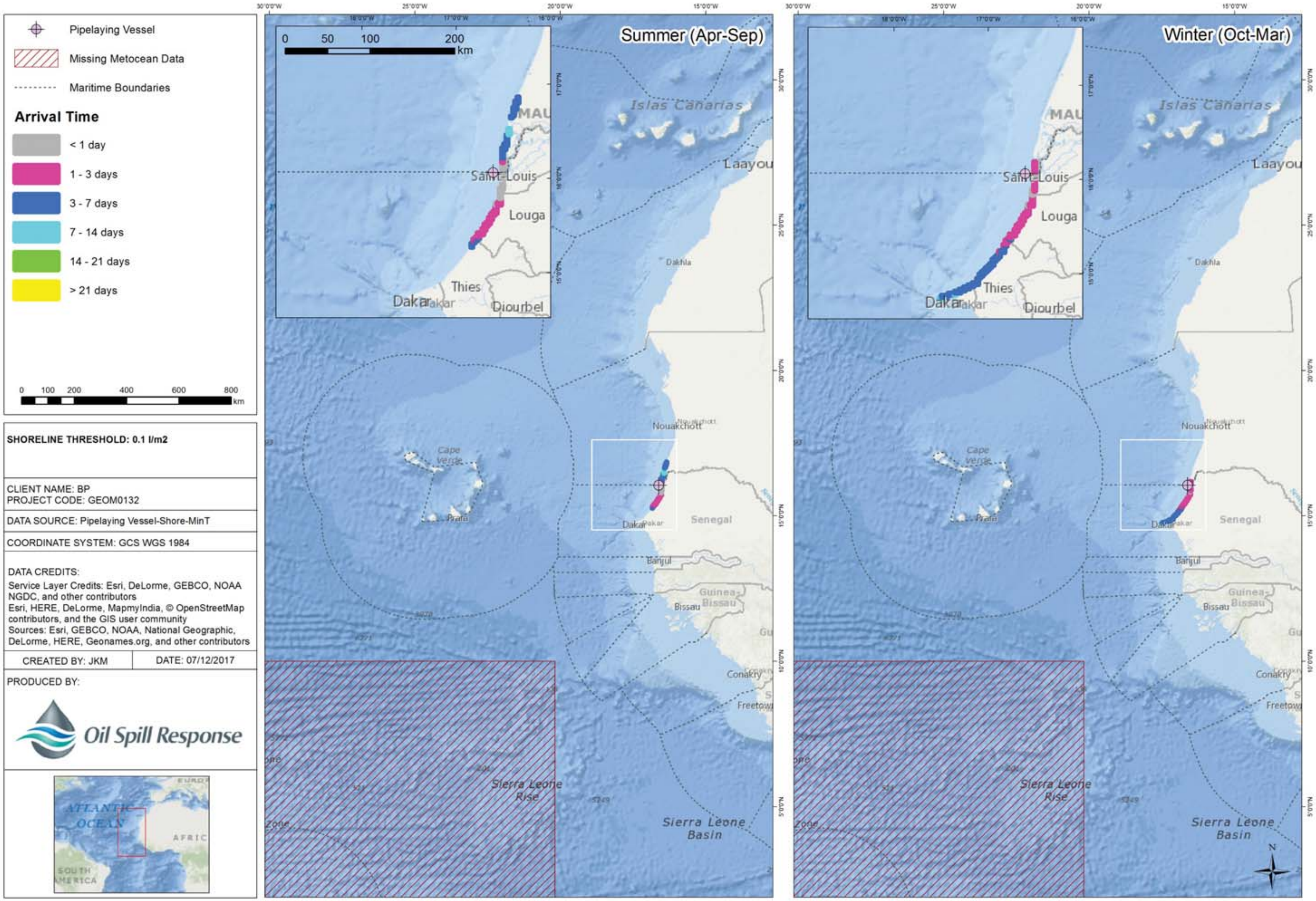


Figure 8: Pipelaying vessel collision – Shoreline Minimum Arrival Time – Summer (left) & Winter (right)

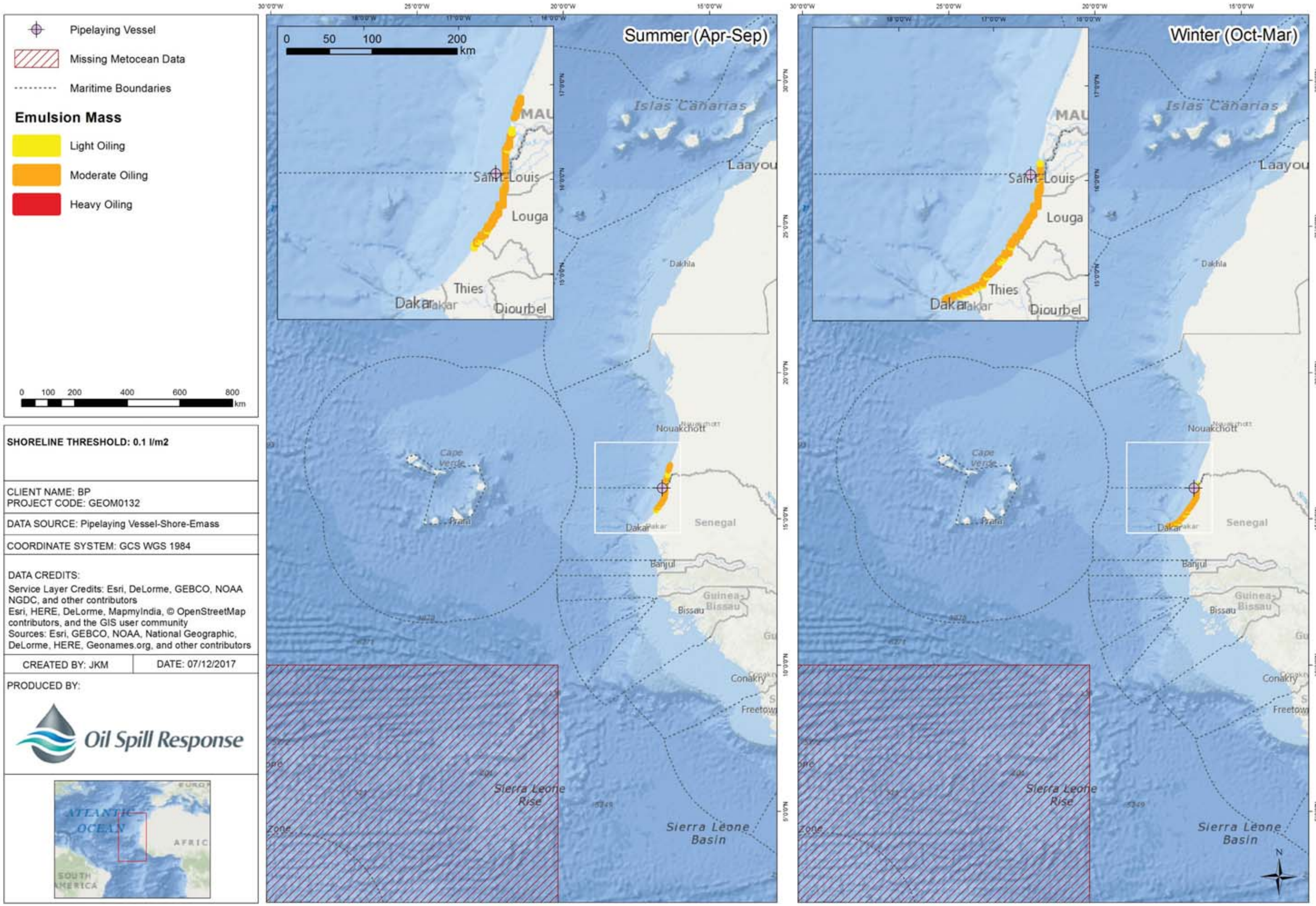


Figure 9: Pipelaying vessel collision – Shoreline Impact – Summer (left) & Winter (right)

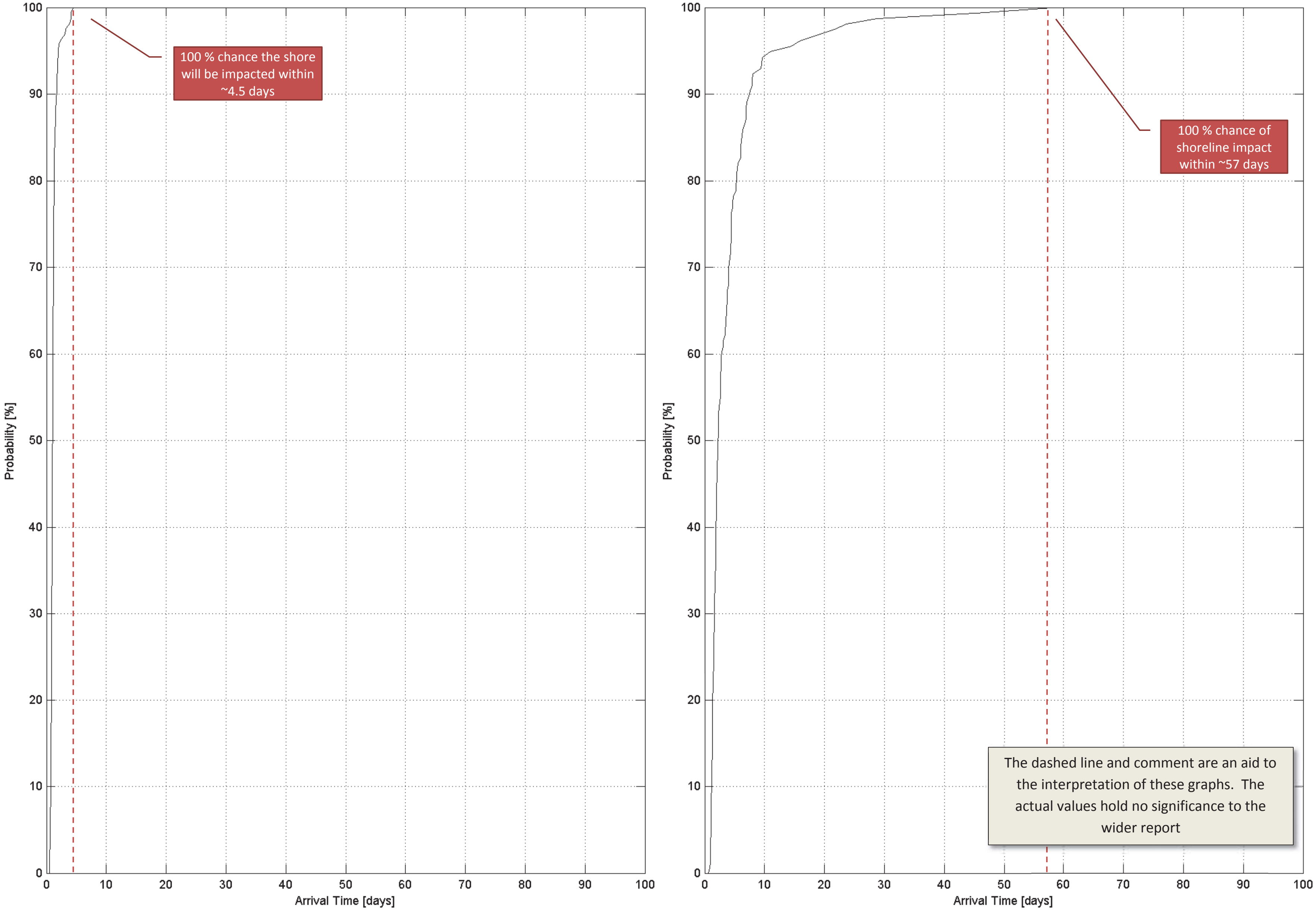


Figure 10: Pipelaying vessel collision – Shoreline Impact – Shoreline Arrival Time Probability - Summer (left) & Winter (right)

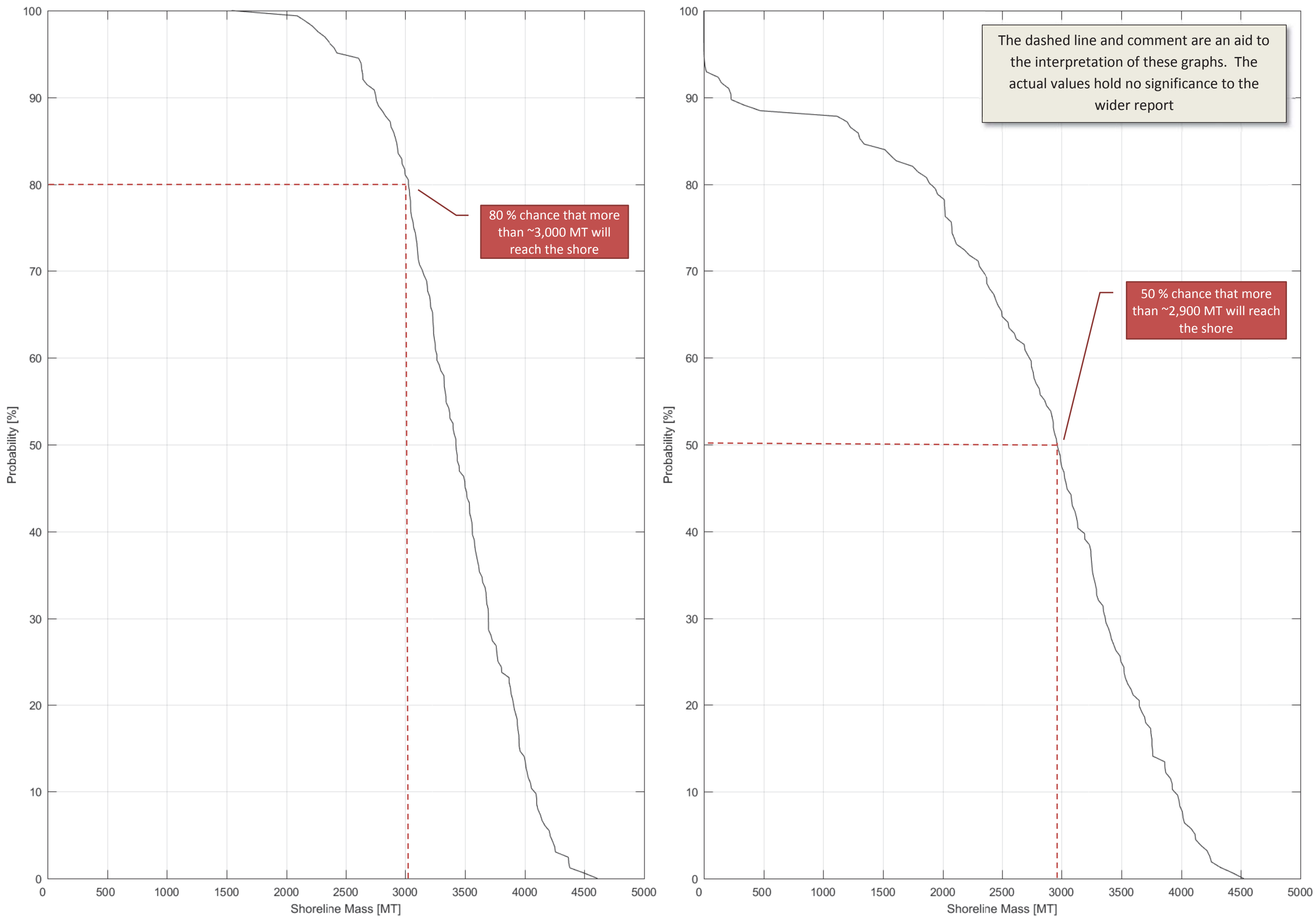


Figure 11: Pipelaying vessel collision – Shoreline Impact –Probability Shoreline Mass - Summer (left) & Winter (right)

Table 8 shows how many of the simulations result in different levels of shoreline impact based on ITOPF's Technical Information Paper (TIP) no. 6, "Recognition of Oil on Shorelines" and the length of shoreline impacted. For further information see Thresholds in Section 1.4.

Table 8: Severity of shoreline oiling following a pipelaying vessel collision from the Tortue Phase 1a Well

ITOPF Reference	Light, Moderate & Heavy Oiling		Light & Moderate Oiling		Light Oiling		No Significant Impact	
OSRL's SCAT Reference	Thick		Cover		Coat			
Season	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Number of Simulations	16 of 165	2 of 157	150 of 165	143 of 157	0 of 165	1 of 157	0 of 165	0 of 165
Probability	9%	1%	91%	91%	0%	1%	0%	0%

Each of the 165 trajectories is put into a single category based on its most severe shoreline oiling. For example, a trajectory that has at least one cell classified as *Heavy Oiling* will be placed in the heavy oiling category regardless of how many of the other cells have *Moderate* or *Light* oiling.

			Best case	Average (50th Percentile)	Worst case
Length of Shoreline Impacted	Heavy	Summer	0 km	0 km	4 km
		Winter	0 km	0 km	4 km
	Moderate	Summer	18 km	45 km	62 km
		Winter	0 km	35 km	58 km
	Light	Summer	0 km	8 km	25 km
		Winter	0 km	10 km	36 km

The data presented in these tables can be interpreted as follows

- In the best-case scenario;
  - Summer. There will only be 18 km of moderate oiling on the shoreline.
  - Winter. There is a chance (1%) that there will only be light oiling.
- In a "typical case" (50th percentile), there will be:
  - Summer = No heavy oiling, 45 km of moderate oiling, and 8 km of light oiling.
  - Winter = No heavy oiling, 35 km of moderate oiling and 10 km of light oiling.
- In a "worst-case" (maximum value[1]), there will be:
  - Summer = 4 km of heavy oiling, 62 km of moderate oiling, and 25 km of light oiling.
  - Winter = 4 km of heavy oiling, 58 km of moderate oiling and 36 km of light oiling.

[1] Note that this presents the maximum shoreline length in each category. It does not refer to 1 trajectory extracted from the stochastic.

Pipelaying vessel collision
Water Column Maps
Dissolved Concentrations

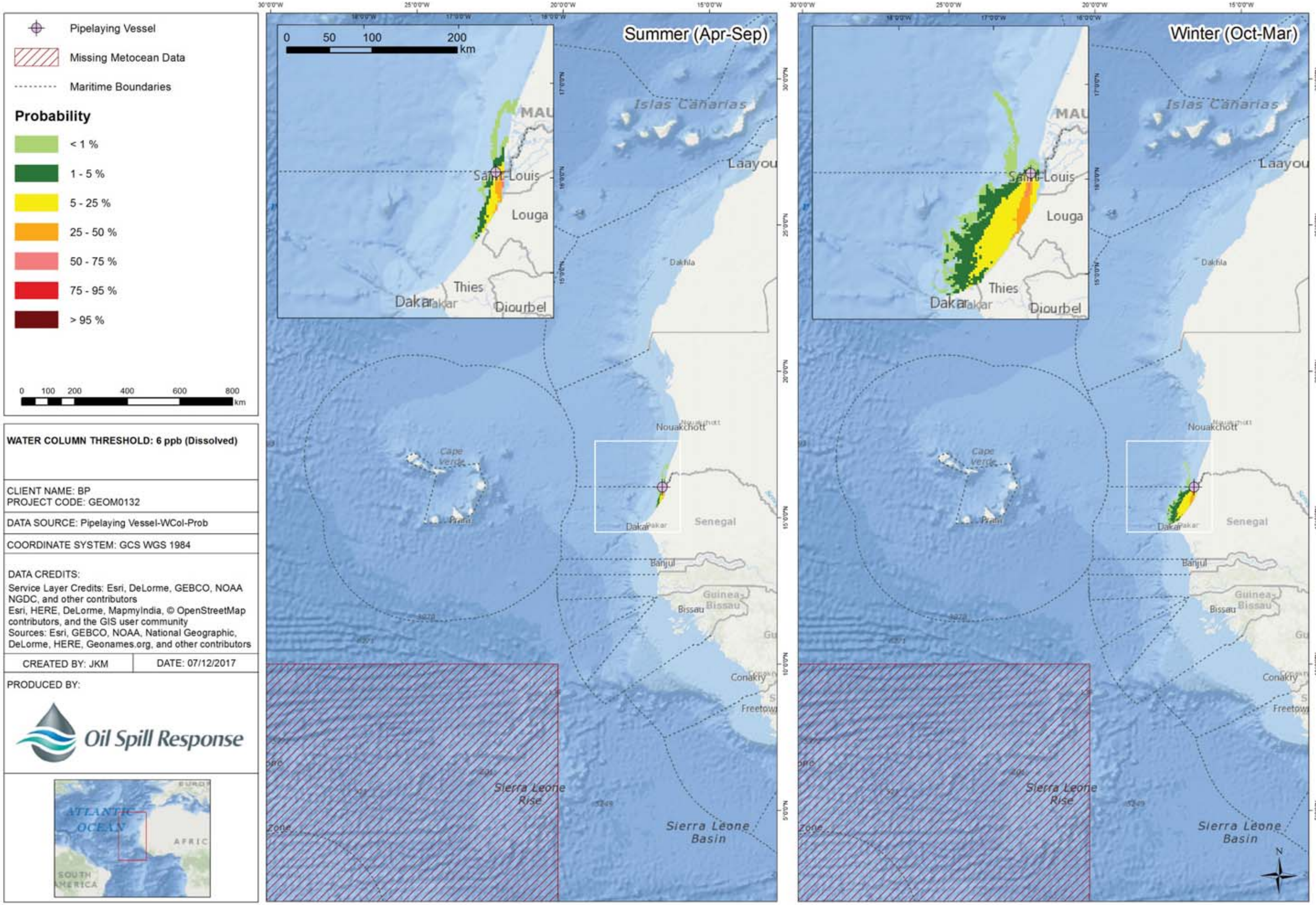


Figure 12: Pipelaying vessel collision – Water Column (Dissolved) Probability of Cell Impact – Summer (left) & Winter (right)

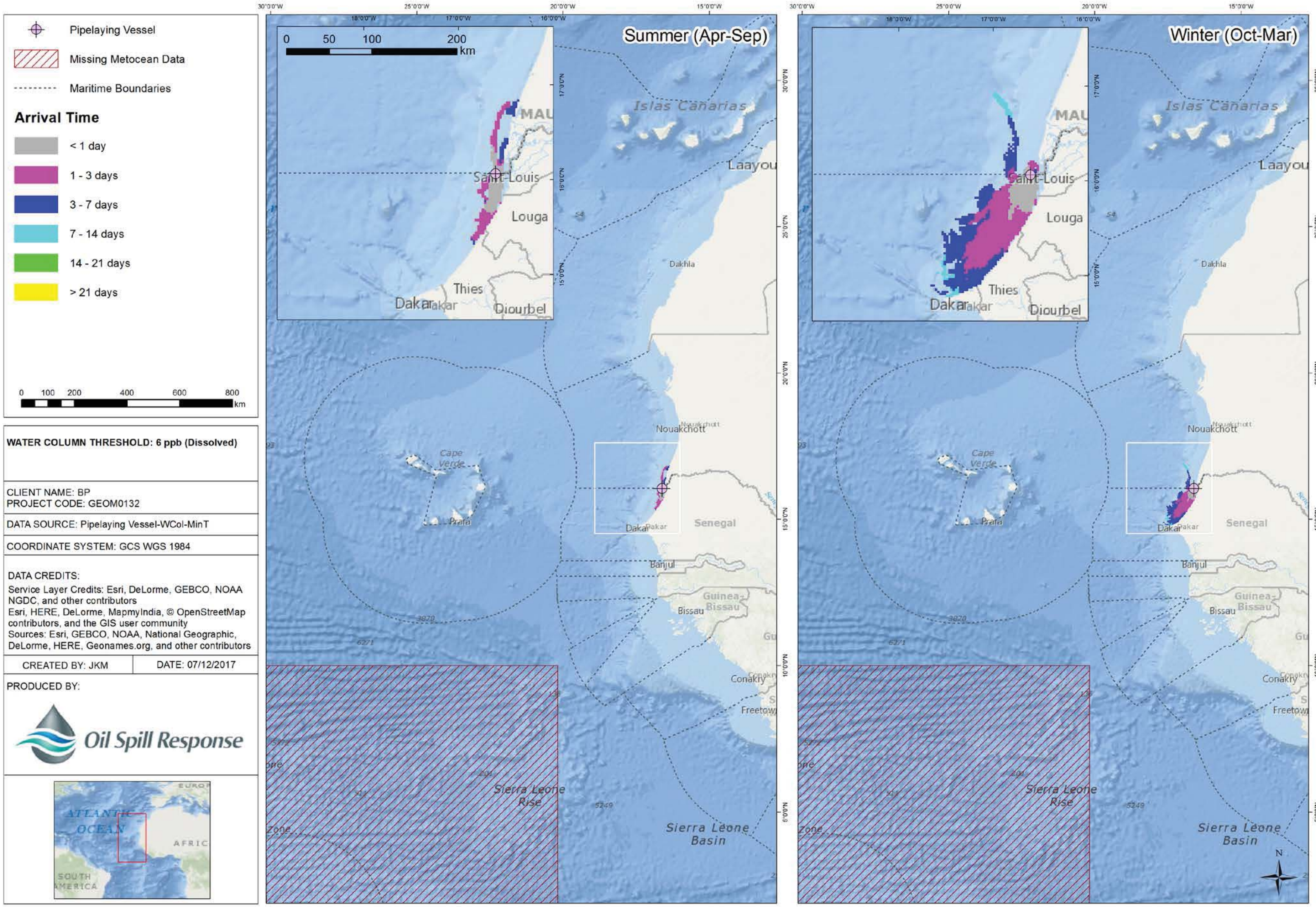


Figure 13: Pipelaying vessel collision – Water Column (Dissolved) Minimum Arrival Time – Summer (left) & Winter (right)

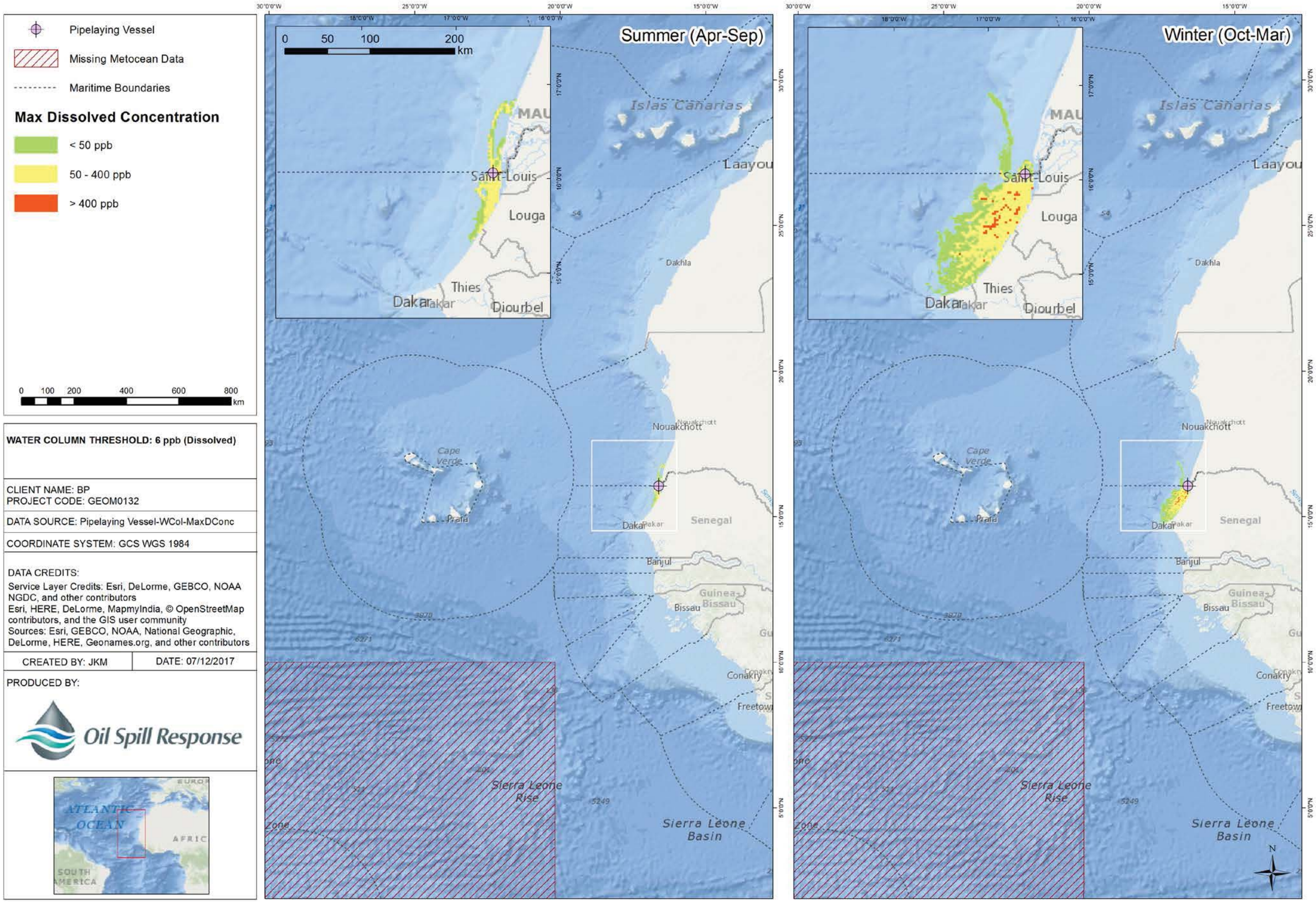


Figure 14: Pipelaying vessel collision – Water Column (Dissolved) Concentrations – Summer (left) & Winter (right)

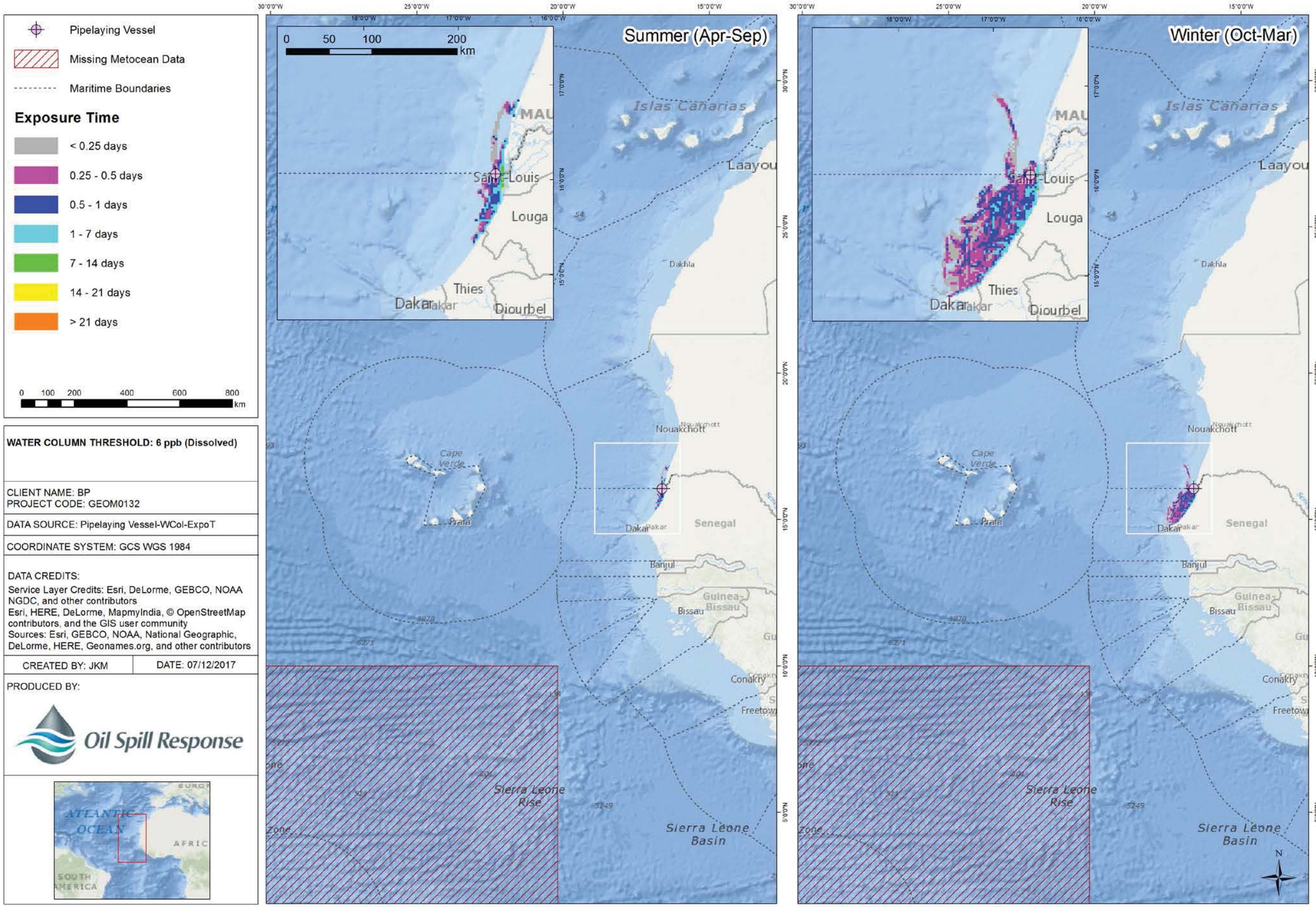


Figure 15: Pipelaying vessel collision – Water Column (Dissolved) Maximum Exposure Time– Summer (left) & Winter (right)

Pipelaying vessel
collision

Water Column Maps

Total Concentrations

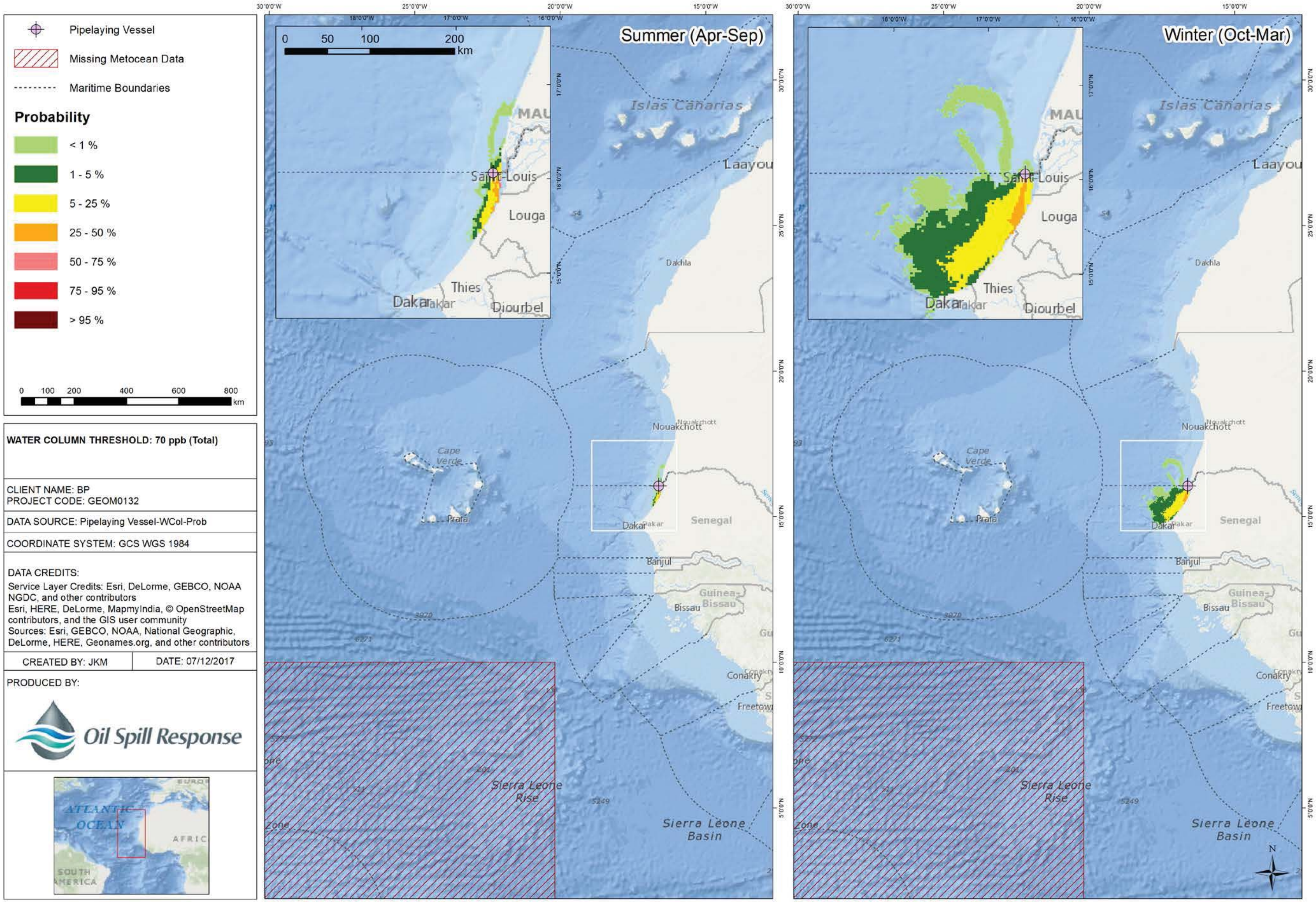


Figure 16: Pipelaying vessel collision – Water Column (Total) Probability of Cell Impact – Summer (left) & Winter (right)

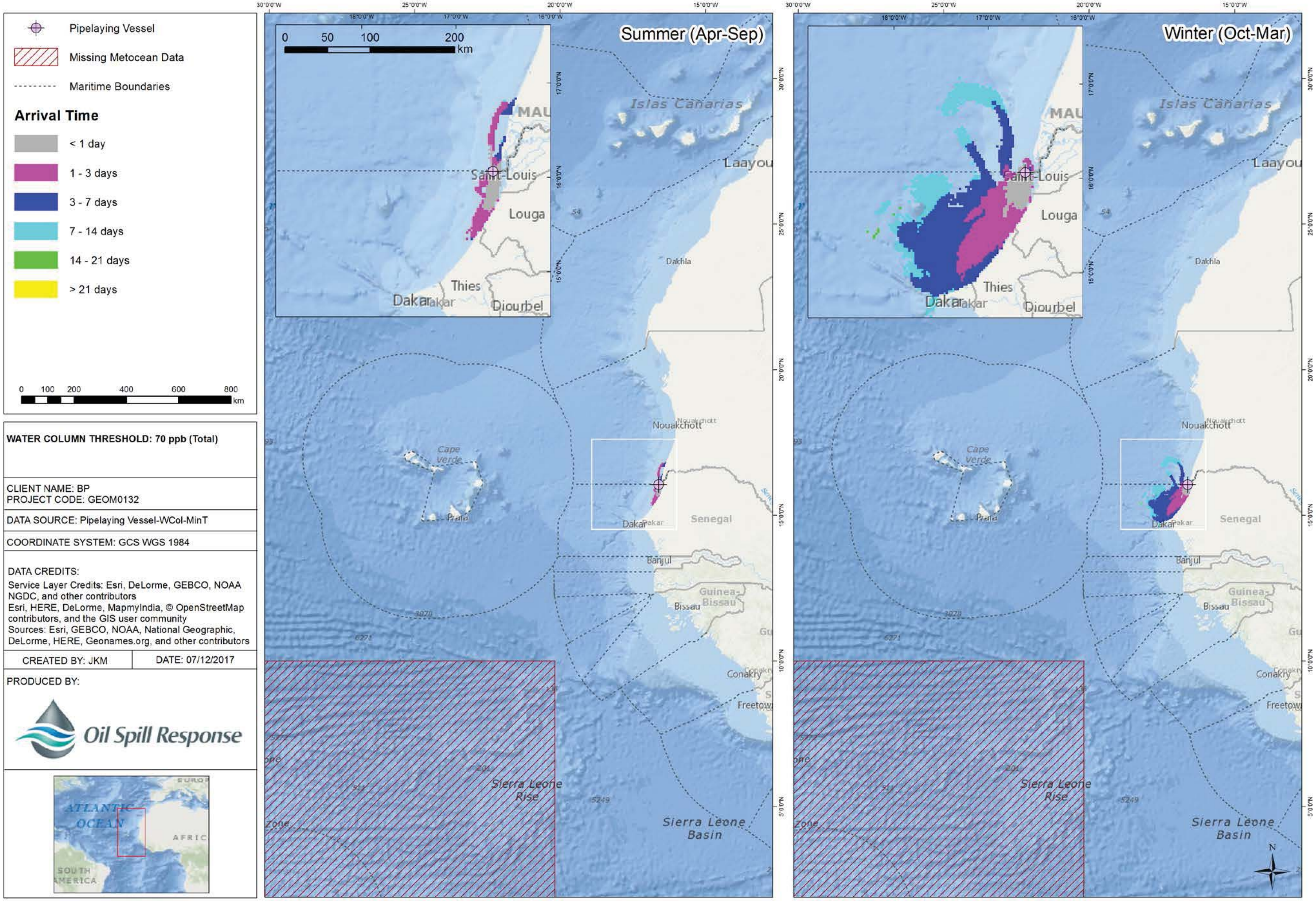


Figure 17: Pipelaying vessel collision – Water Column (Total) Minimum Arrival Time – Summer (left) & Winter (right)

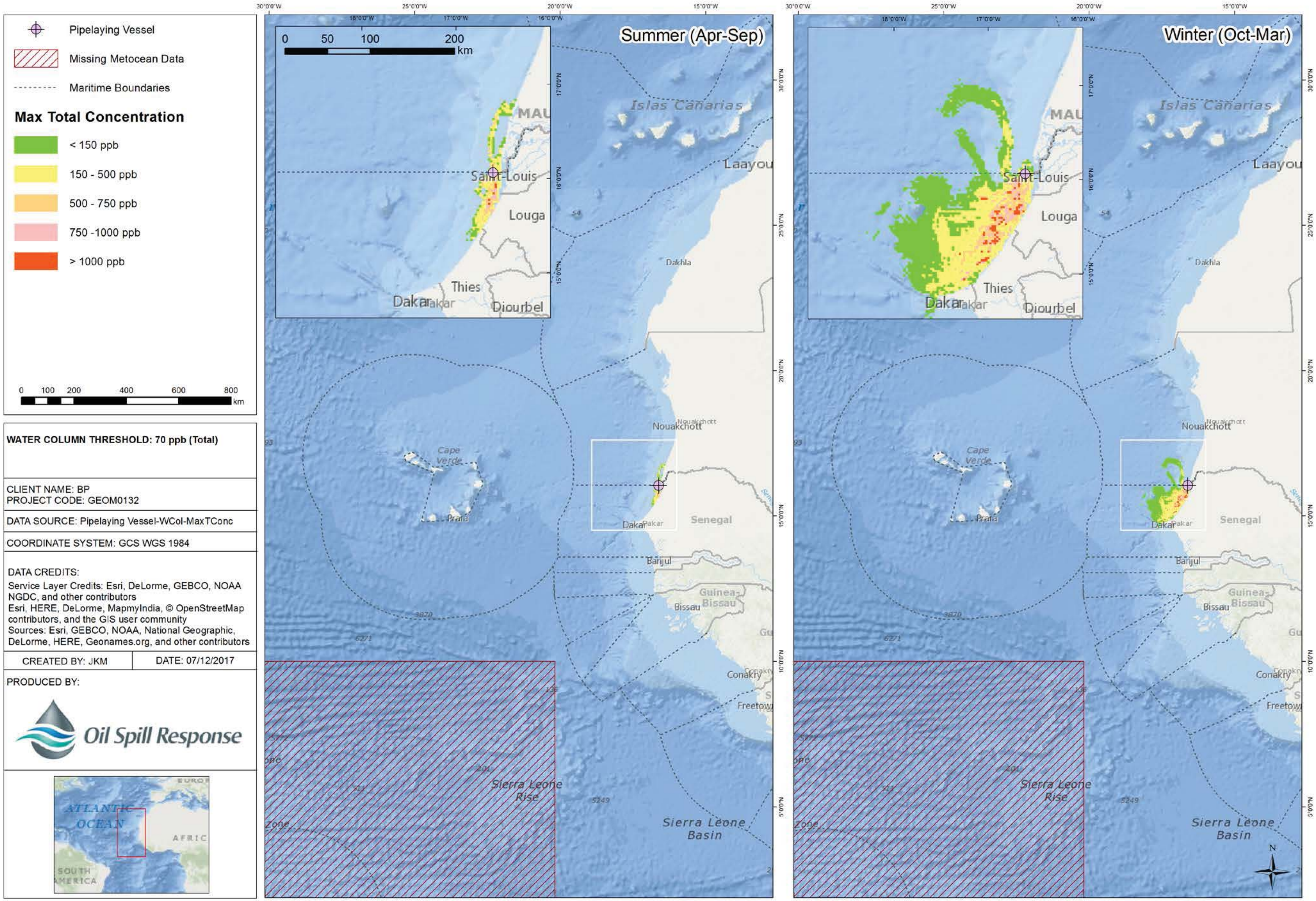


Figure 18: Pipelaying vessel collision – Water Column (Total) Concentrations – Summer (left) & Winter (right)

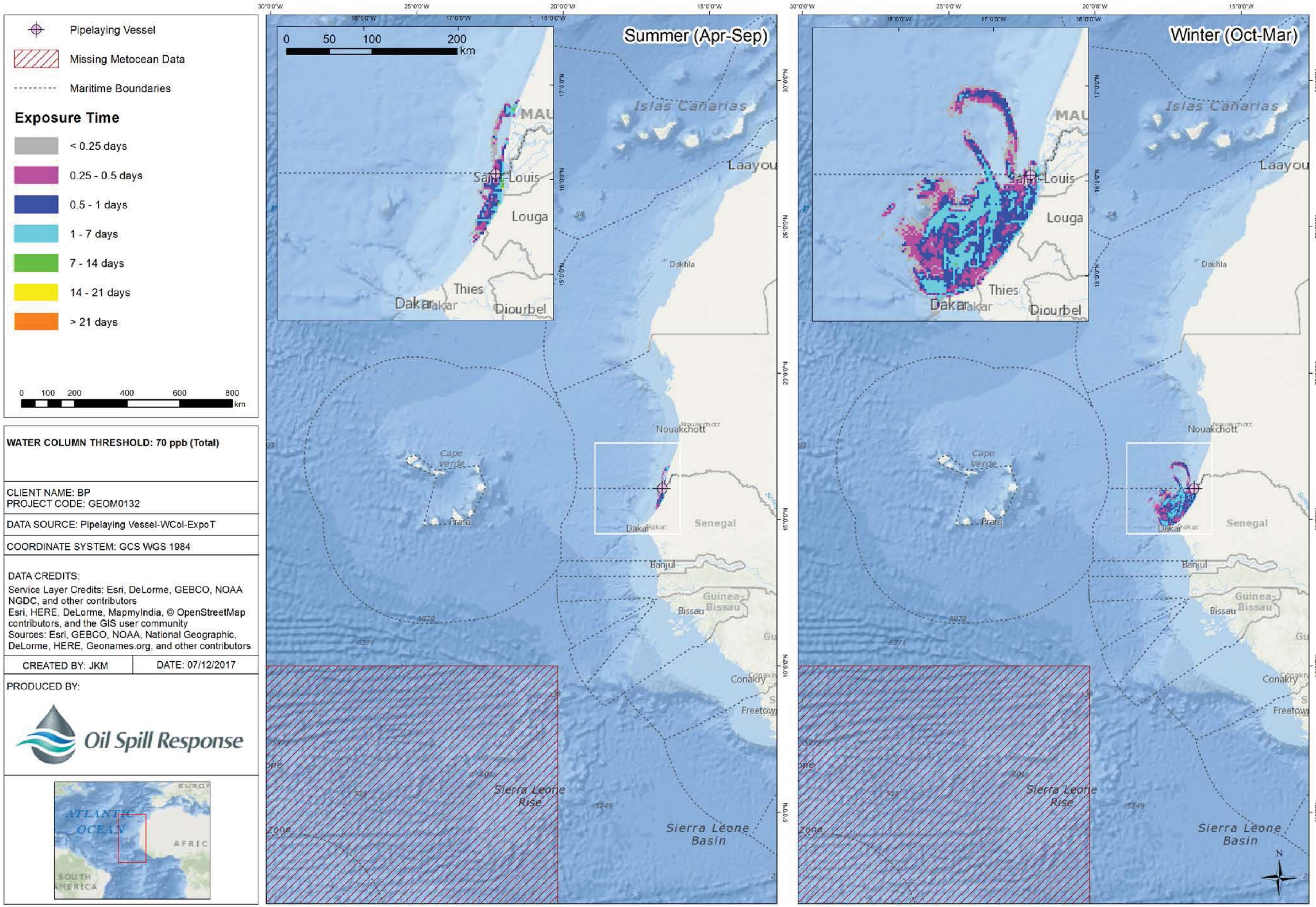


Figure 19: Pipelaying vessel collision – Water Column (Total) Maximum Exposure Time – Summer (left) & Winter (right)

2.2 Comparison between Winter and Summer

Table 9 summarises the results of the stochastic simulations run for each scenario offshore Senegal. For more information on the thresholds used when post-processing the data see Section 1.4.

Table 9: Summary of stochastic results

Oil Spill Modelling Summary		
Spill Scenario/Description	Pipelaying vessel collision - Summer	Pipelaying vessel collision - Winter
Crosses a Maritime Boundary		
Cape Verde	- -	11 % 17 days, 15 hours
Mauritania	43 % < 1 hour	13 % 3 hours
Senegal	100 % < 1 hour	100 < 1 hour
The Gambia	- -	6 % 14 days, 12 hours
Shoreline Impact		
Mauritania	31 % 14 hours	1 % 1 day, 1 hour
Senegal	99 % 11 hours	93 % 14 hours
Worst-Case Shoreline Impact		
Mass of oil onshore	4,610 MT	4,523 MT
Volume of oil onshore[2]	5,469 m^3	5,365 m^3
Water content	0 %	0 %
Volume of emulsion onshore	5,469 m^3	5,365 m^3

[2] This scenario combines different oils in one simulation. These oils have unique properties including their specific gravity. As such, it is impossible to accurately simulate how the volume of the spill will change over time and what the volume of the oil will be when the oil reaches the shore. The value presented shows the volume of the weathered oil IF the specific gravity is 0.843 kg/litre.

Oil Spill Modelling Summary		
Spill Scenario/Description	Pipelaying vessel collision - Summer	Pipelaying vessel collision - Winter
Areas of Conservation Interest		
Cayar Canyon	- -	42 % 2 days, 18 hours
Cayar MPA	- -	28 % 3 days, 6 hours
Cayar Seamount Complex	- -	11 % 4 days, 21 hours
Chatt Tboul Nature Reserve	< 1 % 4 days, 12 hours	- -
Coastal Habitats Neritic Zone MRT Extreme North	87 % 6 hours	20 % 6 hours
Conv Zone Canary Guinea EBSA	- -	8 % 8 days
N Senegal Shelf Break IBA	2% 1 day, 9 hours	58 % 3 hours
Saint Louis MPA	99 % 6 hours	100 % 6 hours

2.3 Worst-Case Oil Spill Scenario

Trajectory results are generated by simulating a single spill scenario under specific conditions on a particular date. One 'worst case' trajectory was selected, from each pool of trajectories that make up the stochastics, to investigate the fate and behaviour of oil during the simulation in more detail.

In this report, the 'worst-case' trajectories are defined as:

- The trajectory that results in the **most oil to reach the shore**

Table 10: Key results from Scenario 1

		TrajSim(107) Summer	TrajSim(150) Winter
Model Setup	**Release Location**	Tortue Phase-1 Pipelaying vessel	
	Total Mass Spilled	5,882.7 MT	
First Shoreline Impact		2 days	1 day, 9 hours
Maximum Mass of Oil Onshore		4,610 MT	4,523 MT
Time when Maximum Mass of Oil Onshore Occurs		4 days 12 hours	9 days, 12 hours

The following figures are presented:

Most oil ashore trajectory

Figure 20: Mass balance plot for a Pipelaying vessel collision during Summer

Figure 21: Mass balance plot for a Pipelaying vessel collision during Winter

Figure 22: Overall area impacted for a Pipelaying vessel collision – Summer (left) & Winter (right)

Figure 23: Overall maximum dissolved concentration – Summer (left) & Winter (right)

Figure 24: Overall maximum total concentration – Summer (left) & Winter (right)

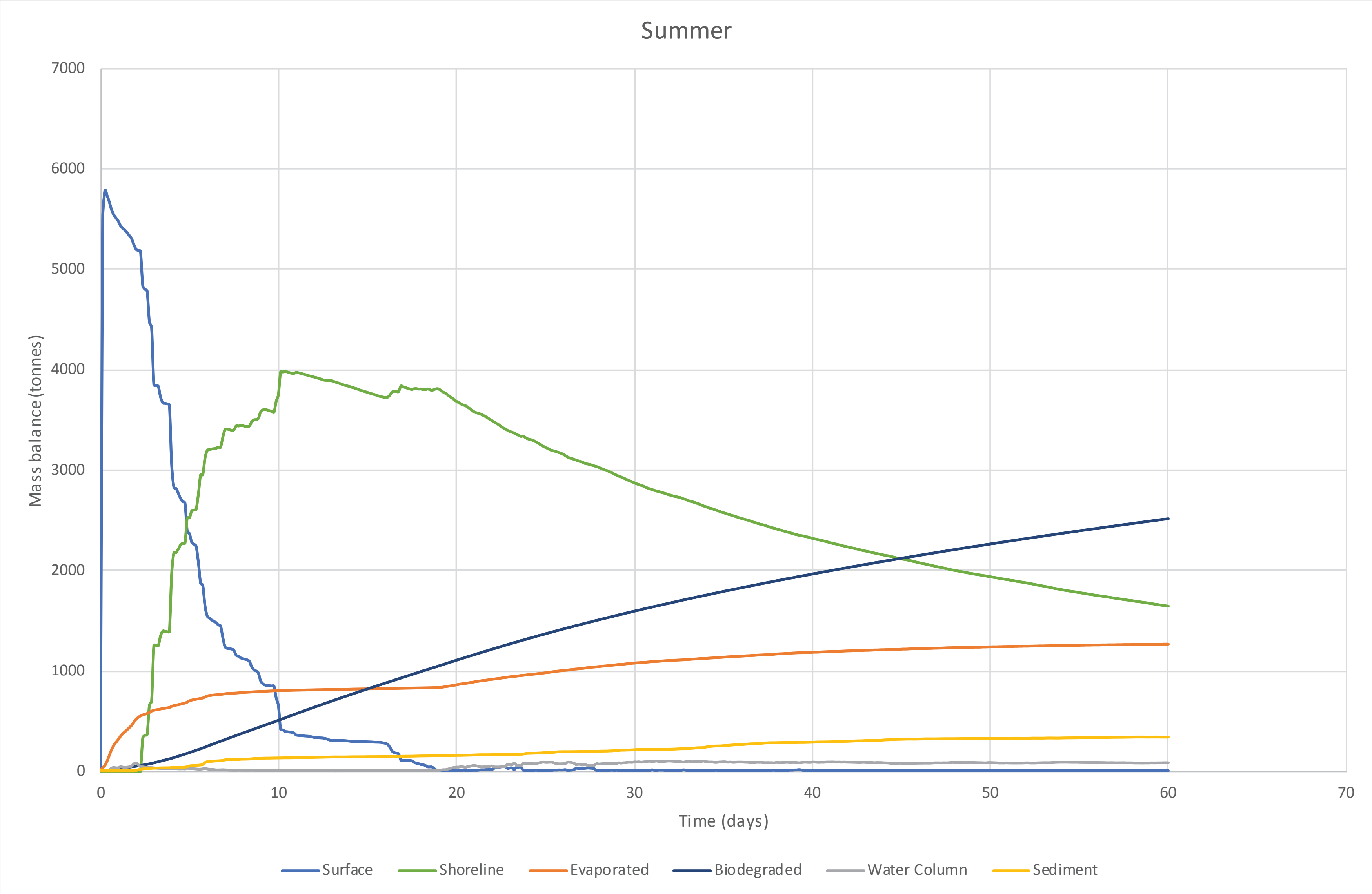


Figure 20: Mass balance plot for a Pipelaying vessel collision during Summer

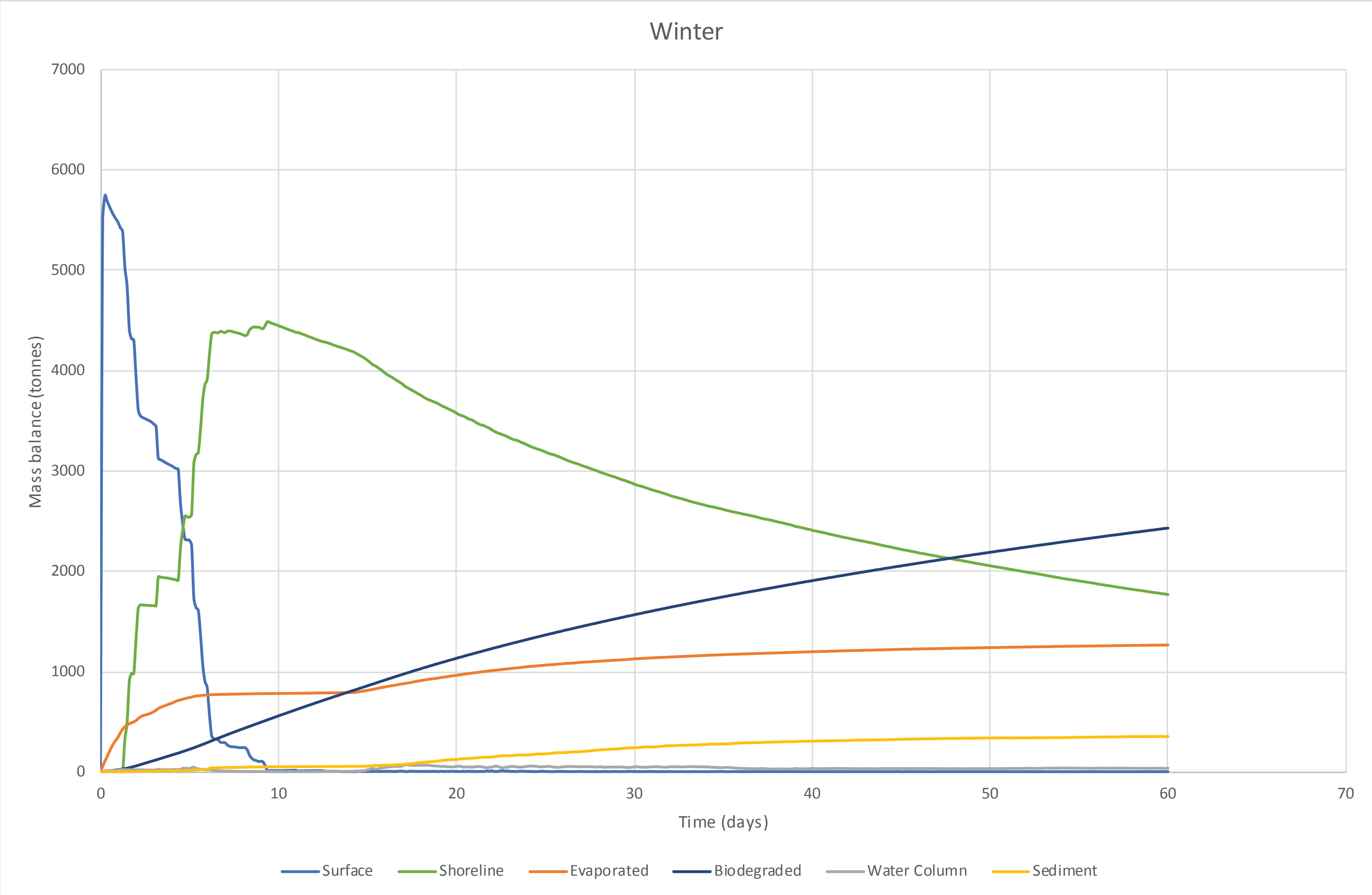


Figure 21: Mass balance plot for a Pipelaying vessel collision during Winter

Table 11: Mass balance comparison table for a pipelaying vessel collision during summer and winter

	FATES (tonnes)											
	Surface		Shoreline		Evaporated		Biodegraded		Water Column		Sediment	
Time Stamp	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
0.5 days	5,678	5,635	0	0	156.2	197.7	8.604	8.469	9.988	10.8	0	0
1 day	5,488	5,471	0	0	314.2	346.1	20.8	20.29	29.39	16.02	0	0
5 days	2,368	2,306	2,529	2,544	702.4	737.3	181.4	222.9	22.94	30.74	48.89	11.86
10 days	648.8	11.07	3,761	4,456	805	778.5	502.9	555.7	4.533	1.633	130.6	49.82
20 days	2.557	2.31	3,693	3,584	862.8	959	1,101	1,130	36.45	52.91	156.8	124.4
30 days	0.9352	2.555	2,879	2,874	1,081	1,123	1,590	1,564	87.47	47.67	213.7	242.1
40 days	1.939	0.7551	2,325	2,413	1,190	1,194	1,960	1,904	85.17	31.71	290.7	308.8
50 days	0.2529	0.3724	1,942	2,059	1,244	1,235	2,259	2,187	80.26	31.17	327.9	340.8
60 days	0.1432	0.6229	1,649	1,772	1,272	1,261	2,510	2,428	78.63	35.25	342.6	356

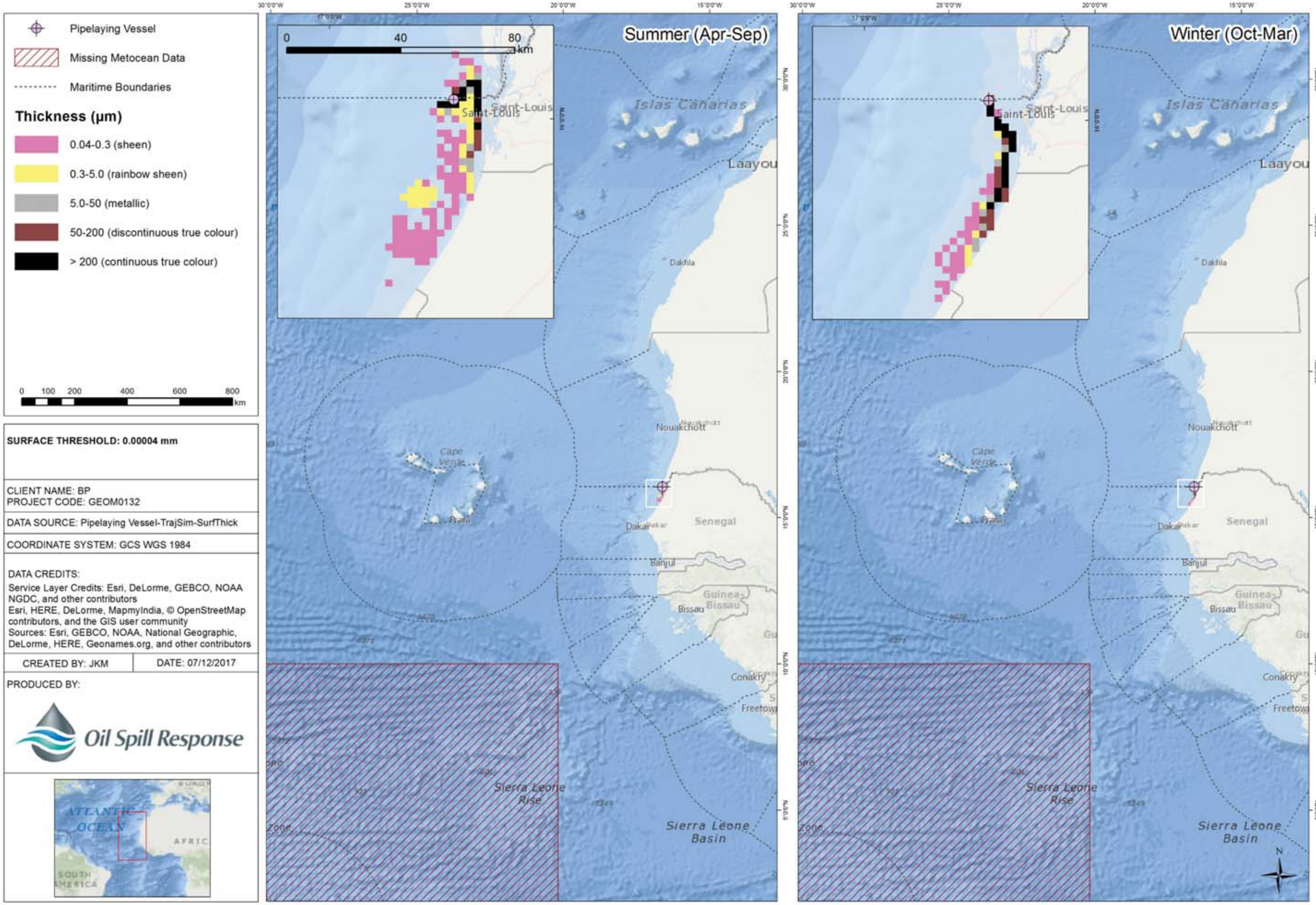


Figure 22: Overall area impacted for a Pipelaying vessel collision – Summer (left) & Winter (right)

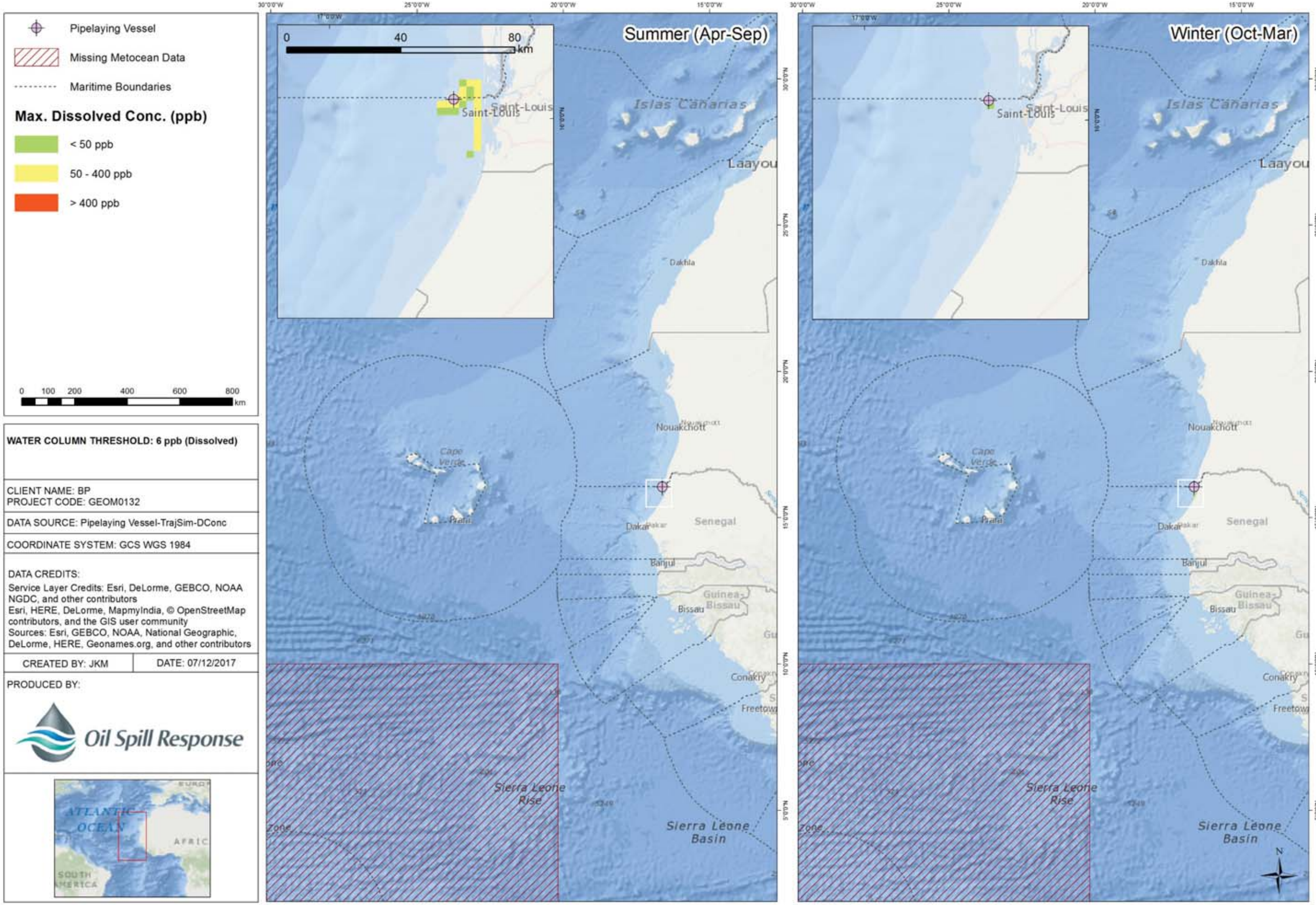


Figure 23: Overall maximum dissolved concentration – Summer (left) & Winter (right)

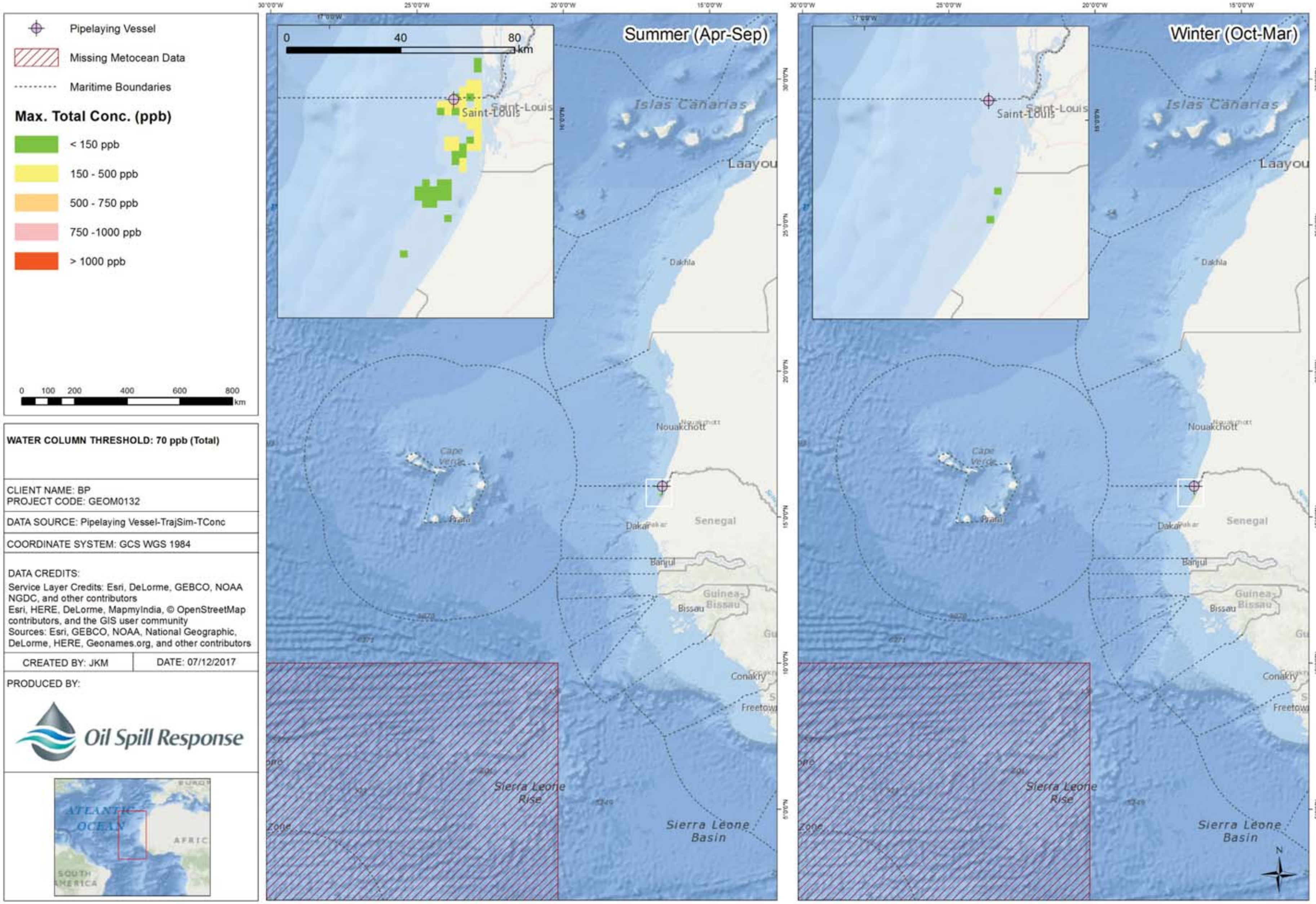


Figure 24: Overall maximum total concentration – Summer (left) & Winter (right)

3 CONCLUSION

One scenario was modelled for the Tortue Phase 1a Well offshore Senegal and Mauritania. This involved the release of 2,980 m^3 of diesel over 3 hours, 3,370 m3 of heavy fuel oil over 3.4 hours; and 92 m^3 of lubricating oil over 1 hour, due to a pipelaying vessel collision.

3.1 Shoreline Impact

A spill at this location, approximately 10 km from the shore, has a 100 % chance of making a considerable shoreline impact (light oiling or higher) whether the spill happens in Summer or Winter. Mauritania and Senegal are the only two countries at risk of shoreline impact, but Senegal is most likely to be more severely impacted.

Summer

Summer has a higher risk to the shoreline of the two seasons.

In the worst-case arrival time scenario, a spill in summer may impact the shore 2 days after the initial release.

The severity of the shoreline impact in summer ranges from 1,500 MT in the best-case scenario, to more than 4,500 MT in the worst-case. There is a 50% chance that more than 3400 MT of oil could impact the shore[3].

A shoreline impact in the summer months is expected to have at least moderate shoreline oiling. Further, there is a 9% chance of “heavy” shoreline oiling and an 91% chance of moderate shoreline oiling. Spatially, only a few km is expected to have heavy shoreline oiling but up to 62 km could be impacted by moderate oiling.

Winter

Winter has a lower risk to the shoreline of the two seasons.

In the worst-case scenario, a spill in winter may impact the shore in a little more than 1 day after the release.

Similarly, the severity of the shoreline impact in winter ranges from a few metric tonnes in the best-case scenario, to more than 4,500 MT in the worst-case. There is a 50% chance that more than 2,900 MT may wash ashore[3]. This is 500 MT less than the Summer scenario.

There is a 1% chance of “heavy” shoreline oiling, a 91% chance of moderate shoreline oiling and 1% chance of “light” shoreline oiling. Spatially, only a few km is expected to have heavy shoreline oiling but up to 58 km could be impacted by moderate oiling.

3.2 Surface Impact

Senegal Waters’ are more than likely to be impacted by this spill scenario, no matter what the season, but Mauritania may not due to a southerly flowing current occurring in some scenarios. Only two countries are at risk in the summer, however, four countries could be

[3] Calculated from Figure 11

impacted in the winter scenario although both Cape Verde and The Gambia have only an 11% and 6% chance of impact respectively.

The waters of Senegal and Mauritania could experience a spill with a surface thickness more than 5 µm making them candidates for containment and recovery techniques. The waters of other neighbouring countries may experience oil sheen on the surface waters during winter, but not during summer. During winter, the oil sheen on the surface waters are not at a thickness that is likely to be effective for containment and recovery.

APPENDIX A. MODEL INPUTS

	Scenario 1		Scenario 2
Description	Pipelaying vessel collision - summer		Pipelaying vessel collision - winter
Latitude	16° 03’ 41.31" N		16° 03’ 41.31" N
Longitude	016° 36’ 23.652" W		016° 36’ 23.652" W
Time of Year	Apr-Sep		Oct-Mar
Release Depth	Surface (0 m)		
Release Rate	993.3 m^3/hr - Diesel 991.2 m^3/hr – Heavy Fuel Oil 92 m^3/hr – Lubricating Oil		
Release Duration	3 hrs - Diesel 3.4 hrs – Heavy Fuel Oil 1 hr – Lubricating Oil		
Duration After Cessation	60 days		
Total Model Duration	60 days		
Oil Type	Diesel	HFO	Lubricating
API Gravity	36.4	15.1	33.8
Specific Gravity	0.843	0.965	0.856
Viscosity (cP)	3.9	10,000	17.0
Pour Point (°c)	-36.0	20.0	-39.0
Wax (%)	-	-	-
Asphaltenes (%)	-	-	0.10
Diameter of Release Hole (m)	n/a		
Gas to Oil Ratio (GOR, Sm^3/m^3)	n/a		
Gas Density (kg/Sm^3)	n/a		

APPENDIX B. METOCEAN DATA

Table 12: Current data – general description

Name	G0132-Curr01		
Description	Sourced from BMT ARGOSS. The dataset consists of an amalgamation of the HYCOM global dataset with the BMT ARGOSS tidal model superimposed		
Start Time	Jan 2009	**Spatial Resolution**	~9 km
End Time	Dec 2011	**Temporal Resolution**	1 hour
Depth Levels [m]	0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1750, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500		

The hydrodynamic database is constructed from 3D current velocity fields, suitable for use in oil model simulations. This comprises of ocean currents (non-tidal residual) from a global ocean circulation model, combined with tidal current velocities.

Tidal current information is obtained from BMT ARGOSS from the integration of approximately 5,000 tidal stations and 15 years of satellite radar altimeter into depth averaged global and regional tidal models (2DH model). The tidal model provides tidal currents (u, v components) as well as surface elevation. The spatial resolution of the tidal model varies from 1/60 to 1/12 degrees globally.

The vertical structure of the tidal current component is established using a logarithmic profile which provides a reliable representation of tidal currents at different depths in shelf seas. The tidal model provides data at a spatial resolution of 4 minutes in the area of interest and can be provided in time steps as required by the client.

Ocean currents are obtained from a global ocean current model (HYCOM), which has the following characteristics:

Spatial resolution: 1/12 degree (can not be refined further)

Temporal resolution: Daily (cannot be refined further, other than by interpolation)

Data type: 3D current speed and direction

Depth: 3D datasets consist of up to 33 depth layers from surface to seabed and spread across the water column. Individual layers and their distribution over the water column vary and depend on the local depth.

Availability: 2009 – 2012

The resultant data, representative of total current velocity, is provided as hourly current vectors, at selected depth levels, at 1/12 degree spatial resolution across the area of interest. It should be noted that in deep water, beyond the continental slope, tidal current velocity would be negligible.

Temporal resolutions of one hour are considered to be an optimal resolution, as coarser temporal resolutions would not adequately capture the data variability in areas where tidal currents form a key component of the total current

Table 13: Wind data – general description

Name	G0132-Wind01		
Description	Sourced from BMT ARGOSS. The dataset consists of the NCEP CFRS global dataset, calibrated by BMT ARGOSS against satellite altimeter and scatterometer measurements.		
Start Time	Jan 2009	**Spatial Resolution**	~35 km
End Time	Dec 2011	**Temporal Resolution**	3 hours
Altitude Level	The dataset includes hourly mean values of wind velocity at 10 m above sea level.		

Winds are provided as hourly mean values of north and east velocity components at 10m above sea level. Data is from the NCEP global dataset, calibrated by BMT ARGOSS against satellite altimeter and scatterometer measurements. The source data are available at spatial resolution of 0.5°x 0.5°, and at 3 hourly time steps.

APPENDIX C. HABITAT GRID

Table 14: Habitat domain details

Name	Domain Extent			
G0132-Hab02	Bottom	Top	Left	Right
	05° 00' 00'' N	25° 00' 00'' N	030° 00' 00'' W	010° 00' 00'' W
	Number of Cells		Cell Resolution	
	East to West	North to South	East to West	North to South
	858	888	2,500 km	2,500 km
	Domain Size			
	East to West		North to South	
	2,145 km		2,220 km	

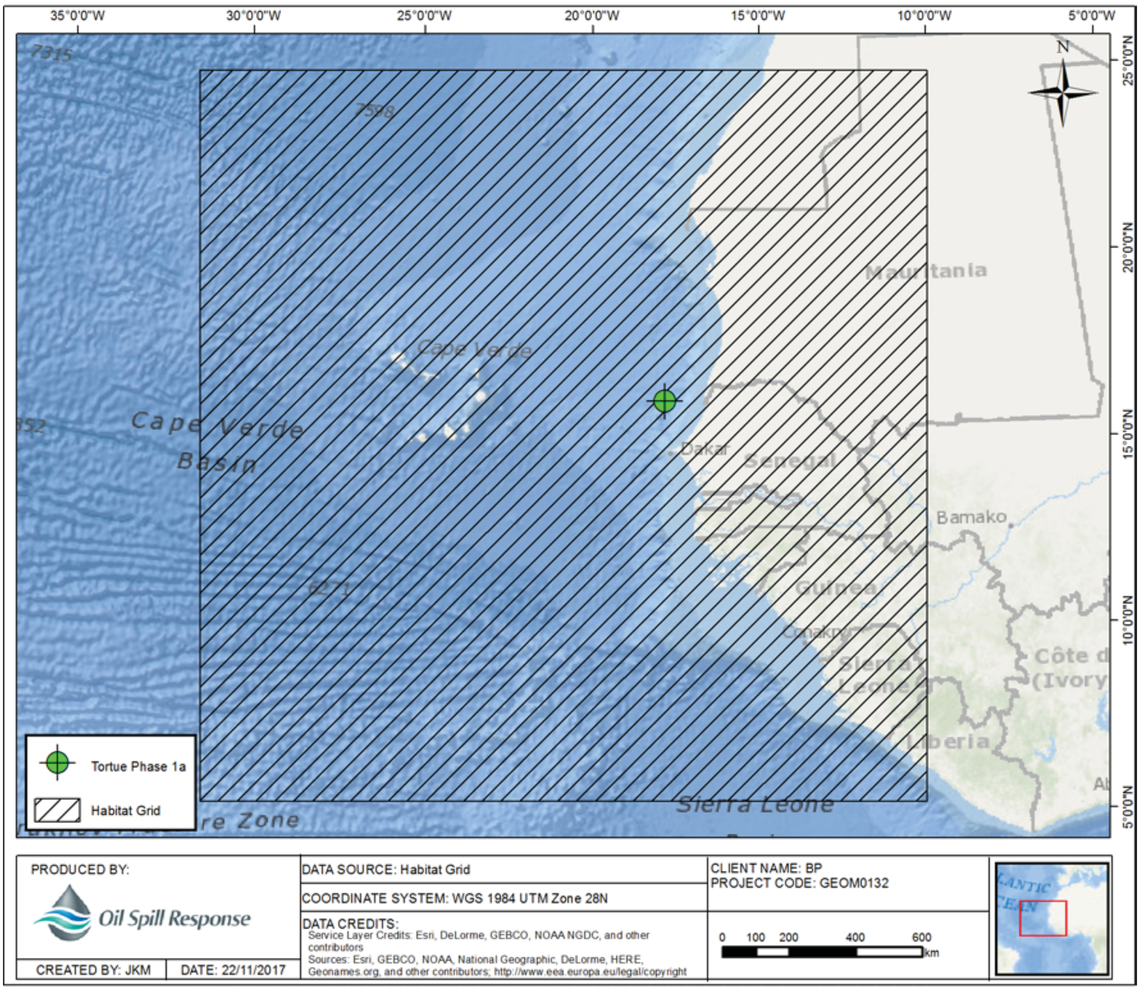


Figure 25:Extent of habitat grid used in this study

APPENDIX D. OIL CHARACTERISTICS AND BEHAVIOUR

The components found in oil are classified into two main groups: hydrocarbons and non-hydrocarbons (see Figure 29). If oil is rich in C1-12 alkanes, it is particularly light, as these are lighter components than the C25+ alkanes. Conversely, if oil contains high quantities of C25+ alkanes, resins and asphaltenes, it is heavy.

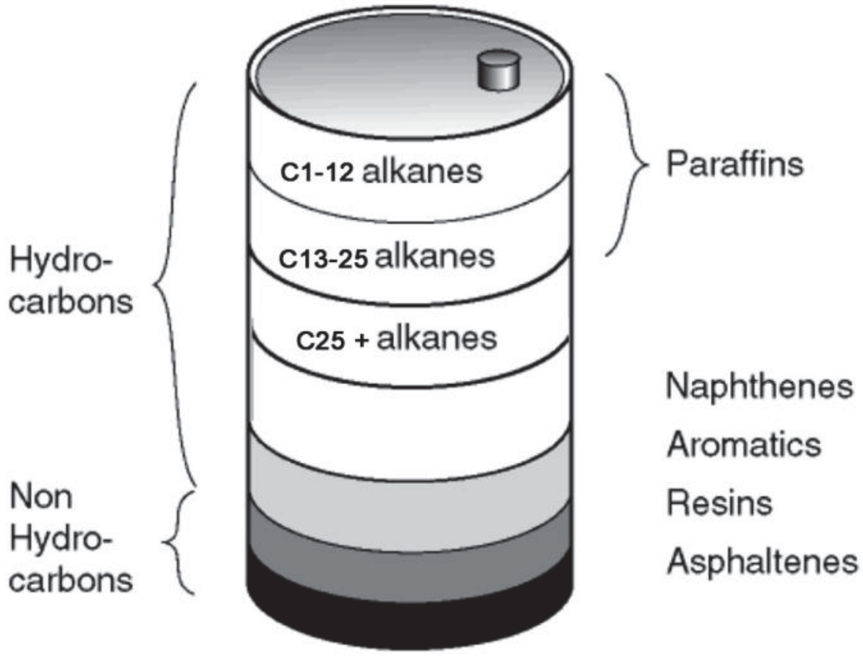


Figure 26:The chemical composition of crude oil

The chemical composition of oil is important when predicting how it will break down or weather. For example, oil containing mostly light components is likely to lose a greater volume to evaporation than heavy oil. Oils with carbon chains exceeding 15 (C15+) cannot evaporate, even during large storms. Long chains (for example, C25+ alkanes) take a long time to degrade in the water column. Asphaltenes can increase the stability of oil, allowing it to take up water but preventing the oil and water emulsion from breaking down.

As oil is a complicated mixture of organic compounds, its components must be analysed to characterise it successfully (LECO Corporation, 2012). The components of oil can be 'identified' and plotted using gas chromatography instruments which are coupled with mass spectrometers (see Bacher, 2014, for further information). The results of gas chromatography and mass spectrometry are converted into a list of 25 sub-components, as broken down in the OSCAR oil database. Each of the 25 sub-components is characterised by molecular weight, density, viscosity, boiling point, solubility in water, vapour pressure, and partition coefficient between oil and water.

The OSCAR Oil Database

A strength of the OSCAR model is its foundation on an observational database of oil weathering properties (maximum water content, viscosity, droplet size distribution, evaporation, emulsification and dispersion, which are measured in a wide range of conditions). The oil database contains complete weathering information for 340 crude oils and petroleum products. It also contains crude assay data for approximately 170 other crude oils (derived from the HPI database - HPI, 1987). But these oils have

not been lab-tested so model estimates of the weathering process are used in place of observational data. This reduces the reliability of the model.

Oil Matching

Three lab tested oils were selected for this modelling study based on the information provided by BP.

The properties of the modelled oils are shown in Table 14 , Table 15 and Table 16. Figure 30, Figure 31 and Figure 32 list the sub-components of the modelled oils and their percentage fraction.

Table 15: Properties of the modelled diesel

Name	Specific Gravity	Viscosity (cP)	Pour Point[4]* (°C)	Wax Content (%)	Asphaltenes (%)
Client Diesel	0.843	3.9	-36.0	-	-
Modelled Diesel	0.843	3.9	-36.0	-	-

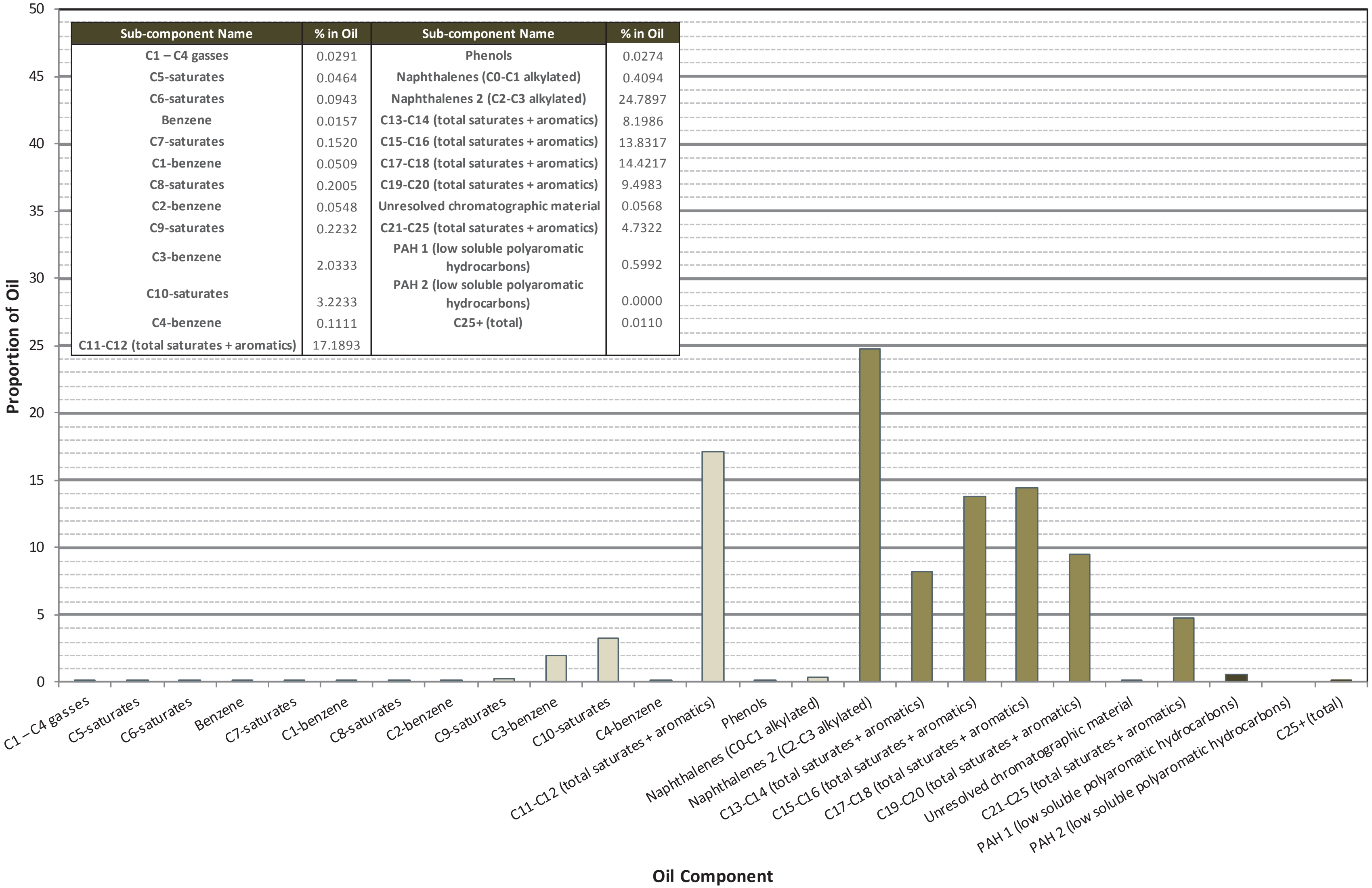
Table 16: Properties of the modelled heavy fuel oil

Name	Specific Gravity	Viscosity (cP)	Pour Point[4]* (°C)	Wax Content (%)	Asphaltenes (%)
Client HFO	0.965	10,000	20.0	-	-
Modelled HFO	0.965	10,000	20.0	-	-

Table 17: Properties of the modelled lubricating oil

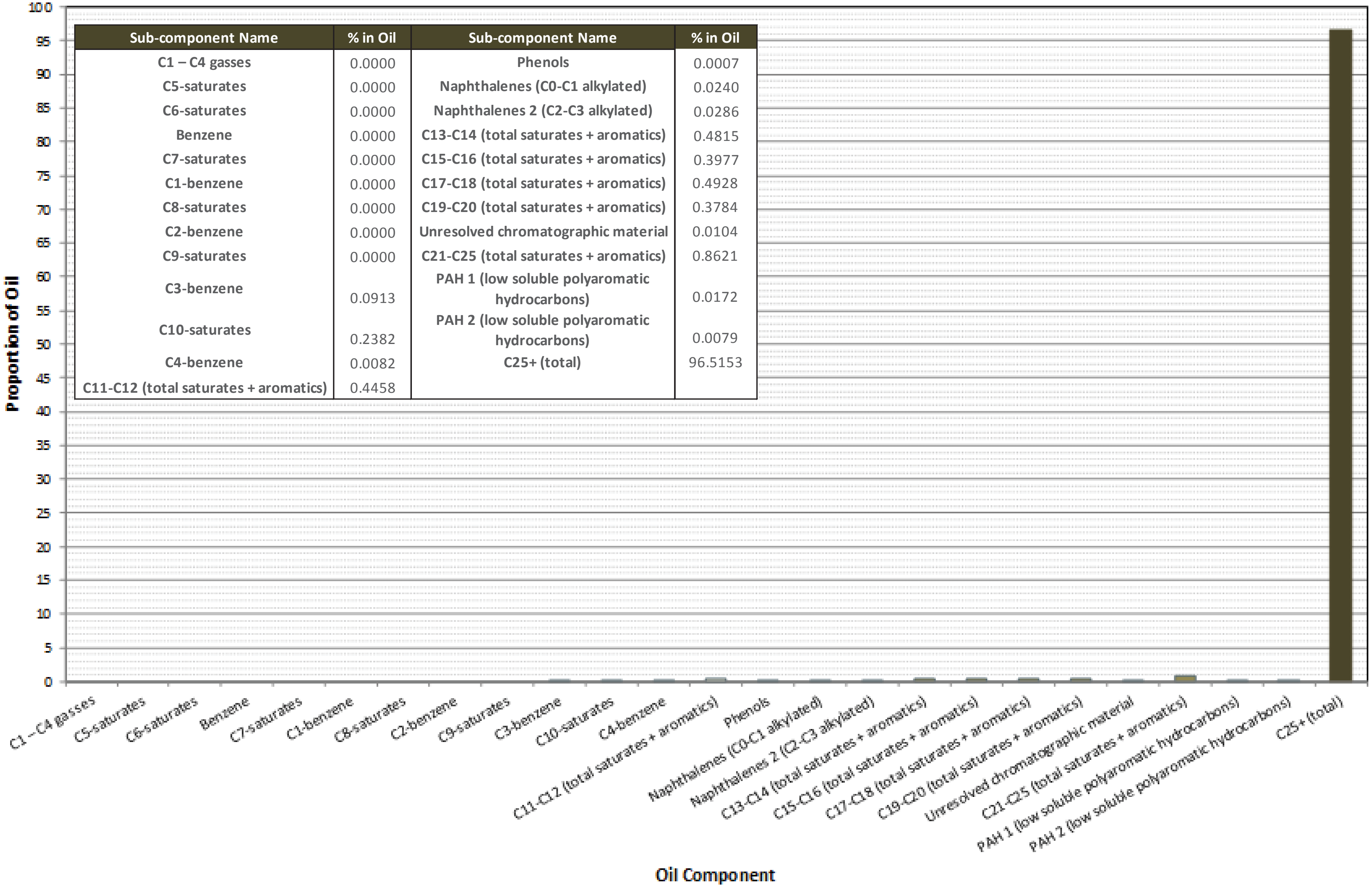
Name	Specific Gravity	Viscosity (cP)	Pour Point[4]* (°C)	Wax Content (%)	Asphaltenes (%)
Client Lubricating Oil	0.837	46	-54.0	-	-
Modelled Lubricating Oil	0.856	17.0	-39.0	-	0.10

[4] Due to the algorithms in the model, Pour Point is of lesser importance when oil matching.



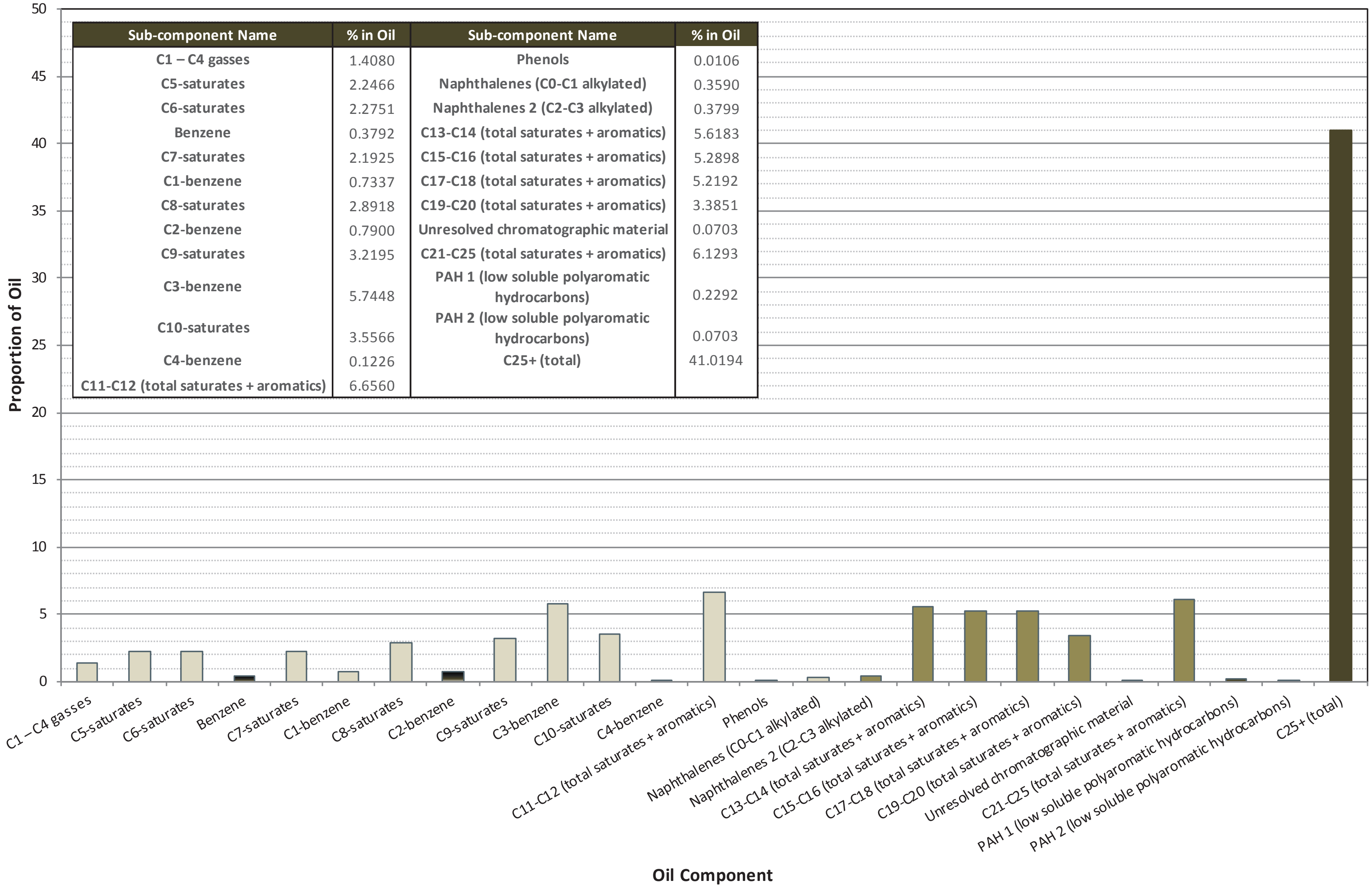
Sub-component Name	% in Oil	Sub-component Name	% in Oil
C1 – C4 gasses	0.0291	Phenols	0.0274
C5-saturates	0.0464	Naphthalenes (C0-C1 alkylated)	0.4094
C6-saturates	0.0943	Naphthalenes 2 (C2-C3 alkylated)	24.7897
Benzene	0.0157	C13-C14 (total saturates + aromatics)	8.1986
C7-saturates	0.1520	C15-C16 (total saturates + aromatics)	13.8317
C1-benzene	0.0509	C17-C18 (total saturates + aromatics)	14.4217
C8-saturates	0.2005	C19-C20 (total saturates + aromatics)	9.4983
C2-benzene	0.0548	Unresolved chromatographic material	0.0568
C9-saturates	0.2232	C21-C25 (total saturates + aromatics)	4.7322
C3-benzene	2.0333	PAH 1 (low soluble polyaromatic hydrocarbons)	0.5992
C10-saturates	3.2233	PAH 2 (low soluble polyaromatic hydrocarbons)	0.0000
C4-benzene	0.1111	C25+ (total)	0.0110
C11-C12 (total saturates + aromatics)	17.1893		

Figure 27:Chemical composition of the modelled diesel



Sub-component Name	% in Oil	Sub-component Name	% in Oil
C1 – C4 gasses	0.0000	Phenols	0.0007
C5-saturates	0.0000	Naphthalenes (C0-C1 alkylated)	0.0240
C6-saturates	0.0000	Naphthalenes 2 (C2-C3 alkylated)	0.0286
Benzene	0.0000	C13-C14 (total saturates + aromatics)	0.4815
C7-saturates	0.0000	C15-C16 (total saturates + aromatics)	0.3977
C1-benzene	0.0000	C17-C18 (total saturates + aromatics)	0.4928
C8-saturates	0.0000	C19-C20 (total saturates + aromatics)	0.3784
C2-benzene	0.0000	Unresolved chromatographic material	0.0104
C9-saturates	0.0000	C21-C25 (total saturates + aromatics)	0.8621
C3-benzene	0.0913	PAH 1 (low soluble polyaromatic hydrocarbons)	0.0172
C10-saturates	0.2382	PAH 2 (low soluble polyaromatic hydrocarbons)	0.0079
C4-benzene	0.0082	C25+ (total)	96.5153
C11-C12 (total saturates + aromatics)	0.4458		

Figure 28:Chemical composition of the modelled heavy fuel oil



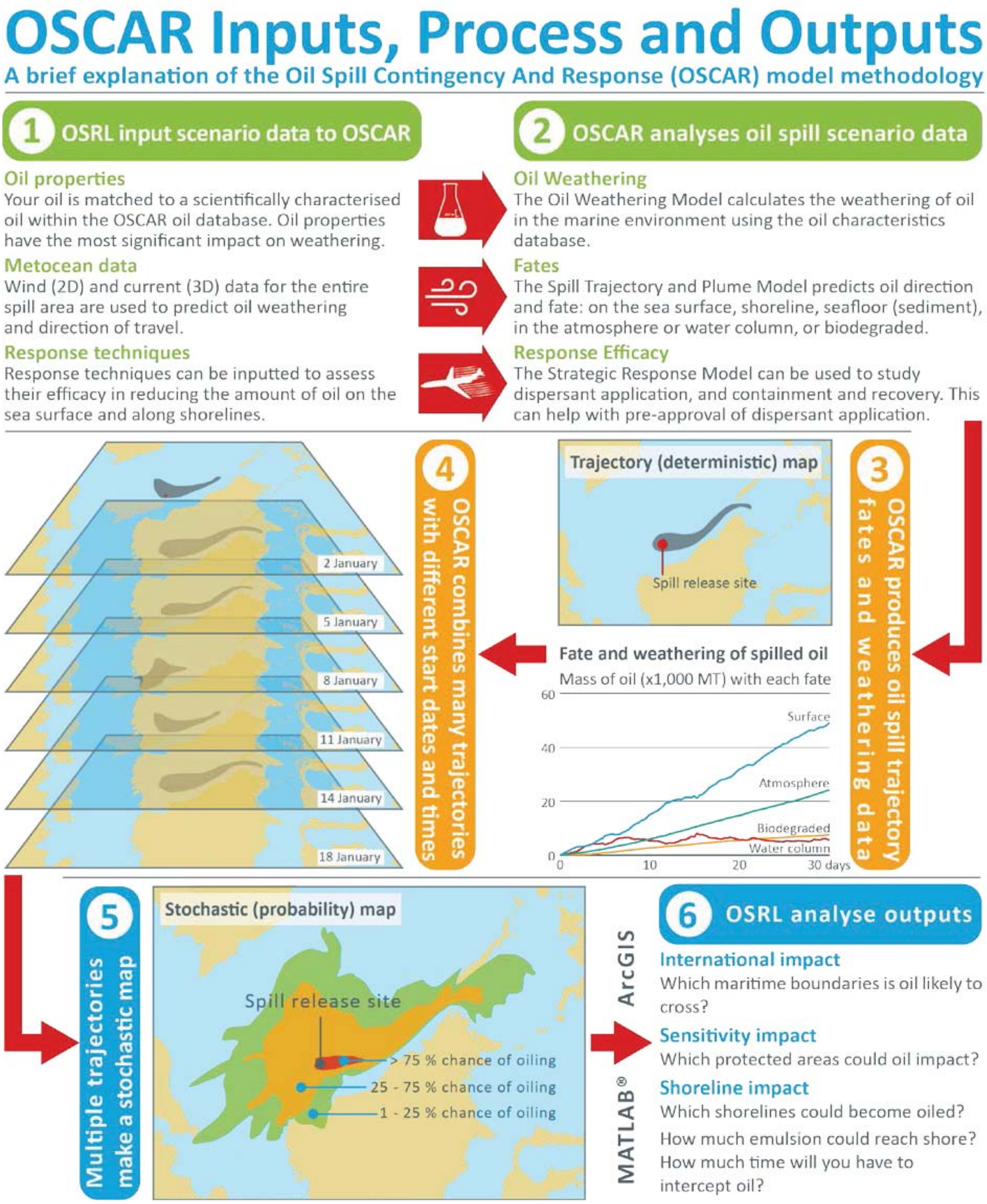
Sub-component Name	% in Oil	Sub-component Name	% in Oil
C1 – C4 gasses	1.4080	Phenols	0.0106
C5-saturates	2.2466	Naphthalenes (C0-C1 alkylated)	0.3590
C6-saturates	2.2751	Naphthalenes 2 (C2-C3 alkylated)	0.3799
Benzene	0.3792	C13-C14 (total saturates + aromatics)	5.6183
C7-saturates	2.1925	C15-C16 (total saturates + aromatics)	5.2898
C1-benzene	0.7337	C17-C18 (total saturates + aromatics)	5.2192
C8-saturates	2.8918	C19-C20 (total saturates + aromatics)	3.3851
C2-benzene	0.7900	Unresolved chromatographic material	0.0703
C9-saturates	3.2195	C21-C25 (total saturates + aromatics)	6.1293
C3-benzene	5.7448	PAH 1 (low soluble polyaromatic hydrocarbons)	0.2292
C10-saturates	3.5566	PAH 2 (low soluble polyaromatic hydrocarbons)	0.0703
C4-benzene	0.1226	C25+ (total)	41.0194
C11-C12 (total saturates + aromatics)	6.6560		

Figure 29:Chemical composition of the modelled lubricating oil

APPENDIX E. OIL SPILL MODELLING SOFTWARE AND METHODOLOGY

This project was completed using the version of OSCAR contained within the Marine Environmental Modelling Workbench (MEMW) 8.0, a model that has been fully validated and calibrated using various field observations from several experimental oil spills (Reed et al., 1995, 1996).

OSCAR predicts the movement of oil at the water's surface and throughout the water column. OSCAR consists of several interlocking modules that are activated as required. The following infographic illustrates the OSCAR modelling process.



APPENDIX F. GLOSSARY OF TERMS, ACRONYMS AND ABBREVIATIONS

°C	Degrees Celsius (1.0°C = 33.8° Fahrenheit)
µm	Micrometre (1.0 µm = 10^{-6} m)
API	American Petroleum Institute
API Gravity	API Gravity, like specific gravity, is a ratio between the densities of oil and water. Unlike specific gravity, API gravity is only used to describe oil, which it characterises as: • Light - API > 31.1 • Medium - API between 22.3 and 31.1 • Heavy - API < 22.3 • Extra Heavy - API < 10.0 API Gravity is converted to Specific Gravity using the following formula: *API gravity = (141.5/Specific Gravity) – 131.5* An API of 10 is equivalent to water, so oils with an API above 10 will float on water while oils with an API below 10 will sink. See also: *Specific Gravity, API*
ArcGIS	A geographic Information System (GIS) used to present OSCAR outputs on maps.
Asphaltene Content	The asphaltenes present the crude oil components that are (1) insoluble in n-heptane at a dilution ratio of 40 parts alkane to 1 part crude oil and (2) re-dissolves in toluene. The asphaltenes include the crude oil material highest in molecular weight, polarity and aromaticity.
bbls	Barrels of oil (a unit of volume). (1.0 bbls = 0.15899 m^3 and 1.0 m^3 = 6.2898 bbls) The conversion between mass and volume requires knowledge of the oil density. See also: *MT, API Gravity, Specific Gravity*
bbls/day	Barrels of oil per day (rate).
BONN Agreement	The BONN Agreement is an international standard and agreement on how to characterise and respond to pollution. Although aimed at pollution in the North Sea (Europe) many of the characterisation standards are internationally recognised.
FPSO	Floating Production Diesel and Offloading - a floating vessel used for producing, processing and storing oil.
GOR	Gas to Oil Ratio - the ratio of volumetric flow of produced gas to the volumetric flow of oil. Although GOR is a ratio, the volume units must be known since gas and oil volumes are measured differently. GOR changes with temperature and pressure so the condition under which GOR is measured must be known.
ITOPF	The International Tanker Owners Pollution Federation Limited
km	Kilometres (1.0 km = 1,000 m) See also: *m*
m	Metres (1.0 km = 1,000 m) See also: *µm, km*
MATLAB	Matrix Laboratory - a multi-paradigm numerical computing environment and programming language used in this study for the manipulation of data outputs from OSCAR.

MEMW	Marine Environmental Modelling Workbench - the modelling software package developed by SINTEF. The MEMW consists of three models: • **DREAM (Dose, Risk and Effects Assessment Model)** • **OSCAR (Oil Spill Contingency and Response Model)** • **ParTrack Model** When combined, these three models quantify the environmental effect of most chemical pollution activities. See also: *OSCAR, SINTEF*
MT	Metric Tonnes - this is a unit of oil mass. (1.0 MT = 1,000 kg) The conversion between mass and volume requires knowledge of the oil's API or Specific Gravity as follows: *Barrels per metric ton = 1/[(141.5/(API + 131.5) x 0.159]* See also: *bbls, API Gravity, Specific Gravity*
NOAA	National Oceanic and Atmospheric Administration – an American scientific agency focussed on metocean conditions
OSCAR	Oil Spill Contingency And Response A state of the art 3D oil spill model and simulation tool for predicting the fates and effects of oil released into the marine environment. Developed by SINTEF, it sits within the larger MEMW application. See also: *SINTEF, MEMW*
OSRL	Oil Spill Response Limited
Pour Point	The pour point of a liquid is the lowest temperature at which it shows flow characteristics. If ambient temperature is less than the liquid's pour point it will begin to solidify.
SCAT	Shoreline Cleanup Assessment Technique
SINTEF	SINTEF is an independent research organisation in Norway which develops the OSCAR model used in this study.
Specific Gravity	Specific gravity is a ratio of the density of one substance to the density of a reference substance, usually water. Specific gravity of oil is a ratio of the density of oil to the density of water. See also: *API Gravity, bbls, MT*
Stochastic	Stochastic (or probabilistic) results show the probability or likelihood of an event occurring. They provide statistical data that can be used to assess risk and identify worst-case scenarios. Stochastic results are achieved by combining many different trajectory simulations. See also: *Trajectory*
Trajectory	Trajectory or deterministic results show the impact of a single spill event over time. Can be used to assess different response options such as booms, skimmers and dispersant. See also: *Stochastic*
UTC	Coordinated Universal Time
Wax Content	Represents the crude oil components that are soluble in higher molecular weight normal alkanes (n-heptane) but are insoluble in lower molecular weight alkanes (n-pentane).

APPENDIX G. REFERENCES

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APPENDIX N-1d : OIL SPILL MODELING REPORT – SENEGAL RIVER STUDY

Oil Spill Modelling Report – Senegal River Study
Tortue Phase 1a

BP p.l.c.

Document Number: GEOM0132i R01

Issued: 05 February 2018

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GEOM0132i	R02	Final Report	LHM			05-Feb-18

LHM – Liam Harrington-Missin

DISCLAIMERS

- Modelling results are to be used for guidance purposes only and response strategies should not be based on these results alone.
- The resolution / quality of wind and current data vary between regions and models. As with any model, the quality and reliability of the results are dependent on the quality of the input data.

Considering the above, all advice, modelling, and other information provided is generic and illustrative only and not intended to be relied upon in any specific instance. The recipient of any advice, modelling or other information from, or on behalf of, OSRL acknowledges and agrees that any number of variables may impact on an oil spill and, as such, should be addressed on an individual basis. OSRL has no liability in relation to such advice, modelling or other information and the recipient of such information hereby fully indemnifies and holds harmless OSRL its officers, employees, shareholders, agents, contractors and sub-contractors against any costs, losses, claims or liabilities arising about such advice, modelling, training or other information.

TABLE OF CONTENTS

1 Introduction

The oil spill modelling undertaken to investigate the impact of various worst-case oil spill scenarios showed a risk to the Senegal River. Given its potential sensitivity to an oil spill, this study further investigates the risk specific to the Senegal River.

Oil spill risk statistics for the mouth of the Senegal River are extracted from the existing modelling data. Following that, the model outputs are scaled using salinity as a proxy for how the oil will dilute as it travels upstream and interacts with the fresh water from the river.

Assumptions must be made in undertaking this kind of study and more detail can be found in Section 4.

2 Results

The following figures and tables provide insight into how the Senegal River could be impacted in the worst-case scenario. The worst-case oil spill scenario for the Senegal River would be a significant spill from the FPSO due to a collision (or other cause) in the Summer months (April to September).

The impact of the other scenarios on the Senegal River can be seen in APPENDIX A for comparison.

The following tables and figures are presented:

- **Table 1**: Worst-case Oil Spill Risk Statistics at the mouth of the Senegal River (Boundary Conditions) – Sea Surface
- **Table 2:** Worst-case Oil Spill Risk Statistics at the mouth of the Senegal River (Boundary Conditions) – Water Column and Shoreline
- **Table 3**: Maximum Dissolved and Total Concentrations (ppb) at various locations on the Senegal River

- **Figure 1**: Senegal River Mouth Probability of Exceedance Graphs for; Maximum Dissolved Concentration (top left), Maximum Total Concentration (top right), Water column Minimum Arrival Time (bottom left) and Water Column Maximum Exposure Time (bottom right)
- **Figure 2:** Senegal River Mouth Probability of Exceedance Graphs for; Maximum Shoreline Emulsion Mass (top left), Maximum Shoreline Thickness (top right) and Shoreline Minimum Arrival Time (bottom left)
- **Figure 3**: Senegal River Mouth Probability of Exceedance Graphs for; Maximum Surface Oil Mass (top left), Maximum Surface Emulsion Mass (top right), Surface Minimum Arrival Time (bottom left) and Surface Maximum Exposure Time (bottom right)
- **Figure 4:** Senegal River Mouth Probability of Exceedance Graphs for; Maximum Surface Thickness (top left), Maximum Surface Viscosity (top right) and Maximum Surface Water Content (bottom left)

Table 1: Worst-case Oil Spill Risk Statistics at the mouth of the Senegal River (Boundary Conditions) – Sea Surface

	Surface						
	Oil Mass	Emulsion Mass	Min. Arrival Time	Max. Exposure Time	Thickness	Viscosity	Water Content
	tonnes	tonnes	days	days	µm	cP	%
Probability of Impact	69%	69%	69%	69%	69%	69%	69%
Maximum Value	15,244	15,244	14.5	40	2,679	121	0
Minimum Value[1]	<1	<1	1.5	<1	<1	24.0	0

Table 2: Worst-case Oil Spill Risk Statistics at the mouth of the Senegal River (Boundary Conditions) – Water Column and Shoreline

	Water Column				Shoreline		
	Max. Dissolved Conc^n	Max. Total Conc^n	Min Arrival Time	Max. Exposure Time	Emulsion Mass	Thickness	Min. Arrival Time
	ppb	ppb	days	days	tonnes	µm	days
Probability of Impact	67%	67%	67%	67%	67%	67%	67%
Maximum Value	1,010	1,764	16.3	31.9	439	29,709	11.5
Minimum Value	5.7	66.5	1.4	0.1	9	613	1.6

[1] This is the minimum value for spills **impacting the river mouth**. The true minimum is 0 since, 31% of spills do not impact the river mouth at all.

Table 3: Maximum Dissolved and Total Concentrations (ppb) at various locations on the Senegal River

		Probability <1 %	Probability 5 %	Probability 10 %	Probability 25 %	Probability 50 %
Maximum Dissolved Concentration [ppb]	River Mouth	1,010	420	250	195	75
	St Louis	857	356	212	165	64
	Dakar Bango Dam	765	318	189	148	57
	Ile aux Bois (South)	642	267	159	124	48
	Ile aux Bois (North)	551	229	136	106	41
	Diama Dam	0	0	0	0	0
Maximum Total Concentration [ppb]	River Mouth	1,764	950	750	600	400
	St Louis	1,497	806	636	509	339
	Lower Damn	1,336	720	568	455	303
	Ile aux Bois (South)	1,123	605	477	382	255
	Ile aux Bois (North)	962	518	409	327	218
	Diama Dam	0	0	0	0	0

The locations can be seen on the map in Figure 5.

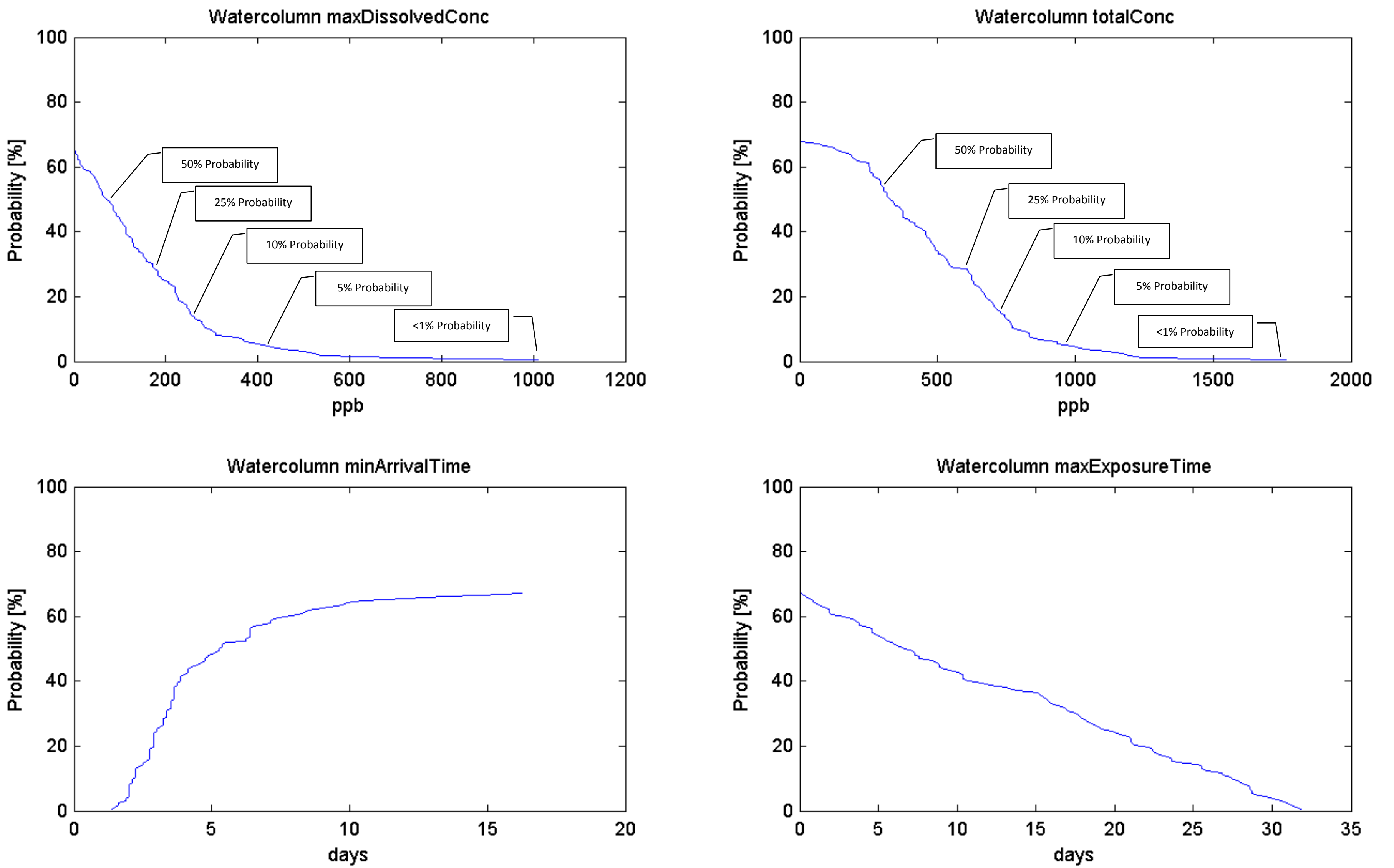

Figure 1: Senegal River Mouth Probability of Exceedance Graphs for; Maximum Dissolved Concentration (top left), Maximum Total Concentration (top right), Water column Minimum Arrival Time (bottom left) and Water Column Maximum Exposure Time (bottom right)

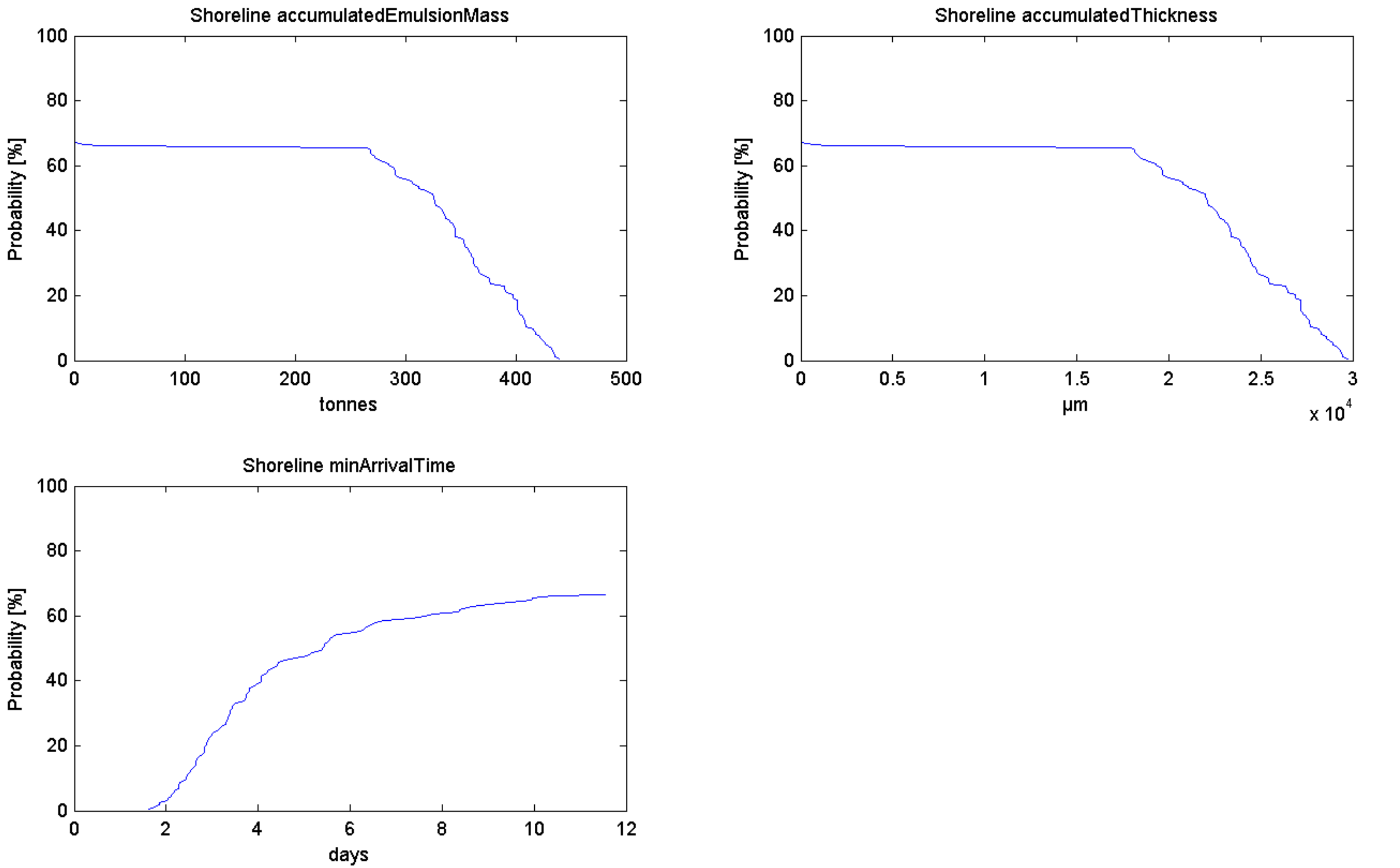

Figure 2: Senegal River Mouth Probability of Exceedance Graphs for; Maximum Shoreline Emulsion Mass (top left), Maximum Shoreline Thickness (top right) and Shoreline Minimum Arrival Time (bottom left)

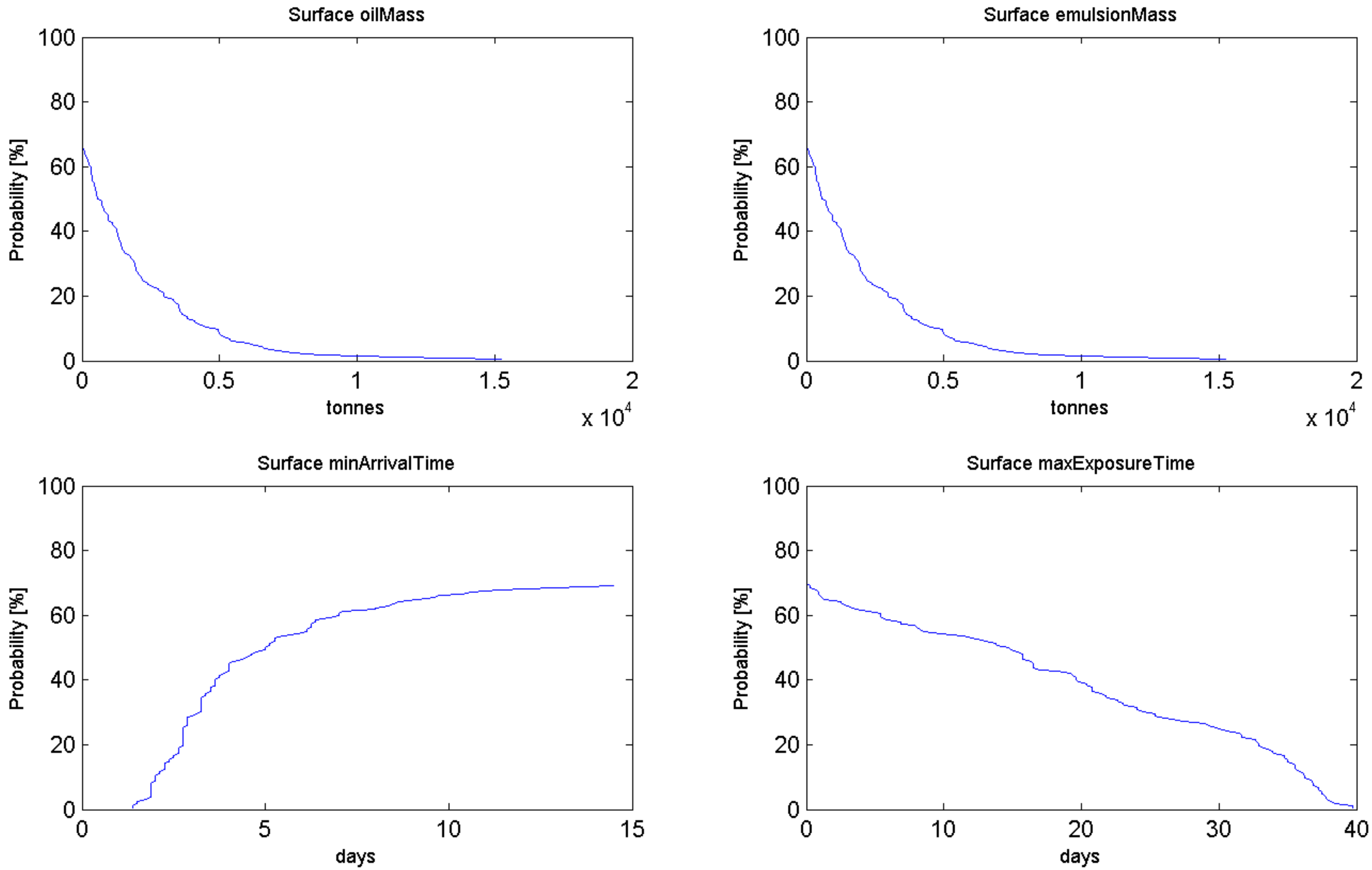

Figure 3: Senegal River Mouth Probability of Exceedance Graphs for; Maximum Surface Oil Mass (top left), Maximum Surface Emulsion Mass (top right), Surface Minimum Arrival Time (bottom left) and Surface Maximum Exposure Time (bottom right)

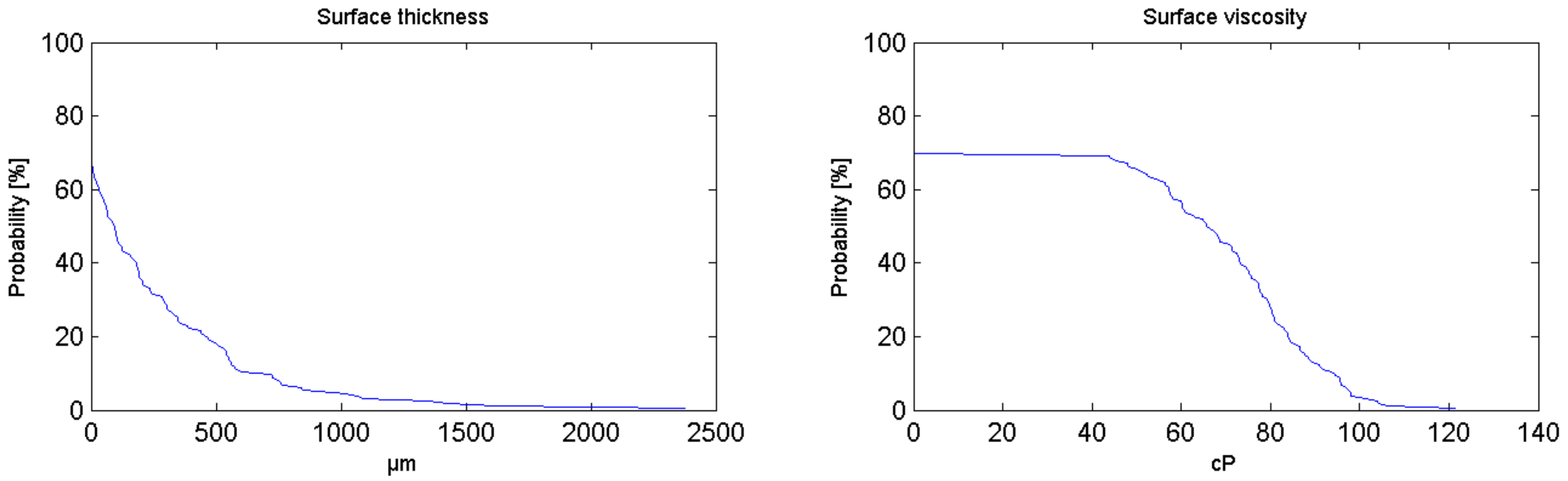

Figure 4: Senegal River Mouth Probability of Exceedance Graphs for; Maximum Surface Thickness (top left), Maximum Surface Viscosity (top right)

3 Methodology

3.1 River Mouth Boundary Conditions

To calculate the river mouth oil spill risk statistics the following method was applied:

1. The oil spill model data created as part of the oil spill modelling studies for the Well Head Failure[2], the FPSO Collision[3] and the Pipelaying Vessel Collision[4] were filtered to represent the area surrounding the mouth of the Senegal River. To mitigate for several modelling assumptions, all data within 10 km of the river mouth (15° 55' 32.4" N, 016° 30' 53.45" W) was considered representative of the river mouth.
2. Statistics for every scenario was exported (See APPENDIX A) and the worst-case scenario for the Senegal River, an FPSO collision in Summer, is presented in Section 2.

3.2 Concentrations of Dissolved and Total Oil up the Senegal River

Using a paper by Baklouti et al, 2011[5] we used the simulated spatial distribution[6] of salinity from the river mouth to the Diama Dam (See Figure 5) as a proxy for how the oil concentrations would change within the river (See Table 4).

We applied the spatial weighting to the river mouth boundary conditions (See Section 3.1) to create Table 3.

Table 4: The Spatial Weighting of Concentrations within the river.

Location	Colour Code	Salinity	Spatial Weighting
River Mouth		33 psu	1
St Louis		28 psu	0.8
Dakar Bango Dam		25 psu	0.76
Ile aux Bois (South)		21 psu	0.64
Ile aux Bois (North)		18 psu	0.55
Diama Dam		0 psu	0

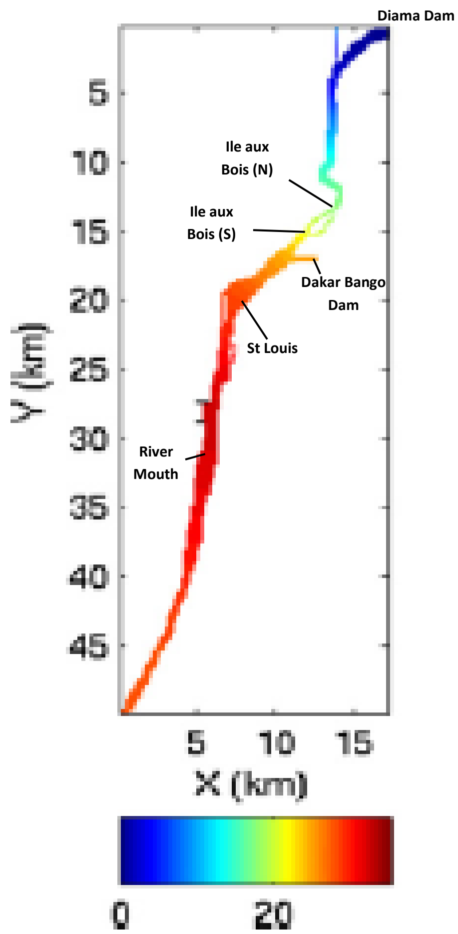

Figure 5: Exert from the Paper by Baklouti et al, 2011[5], showing the distribution of Salinity up the Senegal River. Using this data we were able to extract salinity values at various locations and use them as a proxy for how oil may dilute in the river. The colour is the salinity in psu

[2] OSRL Report Number: GEOM0132a R03
[3] OSRL Report Number: GEOM0132g R03
[4] OSRL Report Number: GEOM0132h R03
[5] Baklouti M., Chevalier C., Bouv M., Corbin D., Pagano M., Troussellier M. and Arfi R., 2011, **A study of plankton dynamics under osmotic stress in the Senegal River Estuary, West Africa, using a 3D mechanistic model**, Ecological Modelling, 222, 2704– 2721
[6] Figure 5 provides model output for salinity, not actual measurements. However, the model has been validated with field measurements made in March 2006.

4 Assumptions and Limitations

4.1 The Oil Spill Release Scenario

The FPSO collision in Summer that shows the worst-case impact (in terms of oiling at surface and in water column) to the Senegal River, is a highly improbably worst-case event. Using this scenario, ensures that oil spill contingency planning and environmental impact assessments are comprehensive and consider even the very unlikely scenarios.

In this instance, the scenario is that a collision with the FPSO causes the entire contents of both diesel and product to be released at a continuous release rate of 1,000 m^3 per hour. This results in over 163,000 m^3 of products to be released in to the environment over a period of approximately 1 week. Mitigation measures on the FPSO will almost certainly result in a far smaller release if a vessel collision were to occur.

4.2 Transport to the River Mouth

Oil spill modelling relies on metocean data (mainly wind and currents) to predict both the transport and weathering of oil in the marine environment. Offshore, the spatial and temporal variability is typically orders of magnitude larger and slower than that of the near shore environment (e.g. coastal). This (typically) makes stochastic modelling of winds and currents in the offshore environment more reliable and easier than near shore environments. Consequentially, our confidence in the model's prediction of movement and behaviour of oil as it gets close to the coast is less than offshore.

In this work, we have compensated for this by assuming oil impact within 10 km of the river mouth is representative of the river mouth. However, this method does not account for inherent inaccuracies in the underlying metocean data.

4.3 The Senegal River

Accurately representing an oil spill entering the Senegal river and travelling "upstream" is beyond the capabilities of current oil spill models. To be of use in the context of this study, the model would have to consider the following in addition to all the offshore variables:

- Local current patterns, e.g. tidal flow and river flow interactions, complicated island flows, river run off, operational management of dams etc.
- Local wind patterns, e.g. wind swirling around headlands and small islands and the sea breeze phenomena.
- Different fresh water flows due to seasonal to hourly changes.
- Drying out of land due to tidal changes or weather conditions.

This considerable number of additional variables that change rapidly in time and space, makes modelling the movement of oil in the river an unrealistic exercise.

To provide a semi-quantitative assessment of how oil in the water column may travel upstream we have made some large assumptions around the salinity of the Senegal River Basin. All our assumptions are based on worst-case, for example we assume that all the salt in the river originated from the river mouth. Salt may have leached into the river from the local environment making our spatial weighting conservative.

Whilst we could have applied the same spatial weighting to surface oiling, we chose not to as there are additional variables that play a more important part to the movement of surface oil. Specifically, the currents and winds in the area will drive the oil onto the shore.

Whilst we cannot quantitively support the following statement, the narrow entrance to the river and the narrow and complex lower reaches of the river, along with the expected weather conditions should keep a majority of the surface oil in the lower reaches, south of Saint Louis. River vessels may be the primary mode of transfer for surface oil from the lower reaches, upstream.

It should also be highlighted that all these results assume no human intervention or oil spill response whatsoever.

APPENDIX A.

The following tables compare the risk to the Senegal River Mouth for each of the scenarios. Highlighted in Red is our defined worst-case scenario selected as representing the maximum values for oiling on surface and water column. This scenario, a FPSO Collision in Summer, has been investigated in more detail in Section 2.

Table 5: Senegal River Risk Statistics - Well Head Failure

	Maximum Dissolved Conc^n [ppb]		Maximum Total Conc^n [ppb]		Surface Emulsion Mass [Tonnes]		Shoreline Emulsion Mass [Tonnes]	
	Summer (Apr to Sep)	Winter (Oct to Mar)	Summer (Apr to Sep)	Winter (Oct to Mar)	Summer (Apr to Sep)	Winter (Oct to Mar)	Summer (Apr to Sep)	Winter (Oct to Mar)
Probability	78 %	1%	78 %	1%	93%	3%	78%	<1%
Maximum Value	1.6	0.0	431	148	89.0	3.8	336	18.3
Minimum Value	0	0.0	66.1	76.5	0.2	1.2	8.5	18.3

Table 6: Senegal River Risk Statistics – FPSO Collision

	Maximum Dissolved Conc^n [ppb]		Maximum Total Conc^n [ppb]		Surface Emulsion Mass [Tonnes]		Shoreline Emulsion Mass [Tonnes]	
	Summer (Apr to Sep)	Winter (Oct to Mar)	Summer (Apr to Sep)	Winter (Oct to Mar)	Summer (Apr to Sep)	Winter (Oct to Mar)	Summer (Apr to Sep)	Winter (Oct to Mar)
Probability	67%	5%	67%	5%	69%	6%	67%	4%
Maximum Value	1,010	556	1,764	981	15,244	4,514	439	329
Minimum Value	0.0	2.6	66.5	81.5	0.4	1.3	9.1	143.8

Table 7: Senegal River Risk Statistics – Pipelaying Vessel Collision

	Maximum Dissolved Conc^n [ppb]		Maximum Total Conc^n [ppb]		Surface Emulsion Mass [Tonnes]		Shoreline Emulsion Mass [Tonnes]	
	Summer (Apr to Sep)	Winter (Oct to Mar)	Summer (Apr to Sep)	Winter (Oct to Mar)	Summer (Apr to Sep)	Winter (Oct to Mar)	Summer (Apr to Sep)	Winter (Oct to Mar)
Probability	87%	24%	87%	24%	90%	28%	76%	16%
Maximum Value	432	636	1,194	764	5,084	3,218	444	336
Minimum Value	0.0	0.8	66.3	66.1	0.2	0.2	7.5	8.9

APPENDIX N-2 : RISK STUDY CONSEQUENCE MODELING REPORT

Ahmeyim/Guembeul Project

Consequence Modelling

BP

January 2018

Contains *private* information

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Table of Contents

Executive Summary

BP is currently developing options for facilities to recover gas from the Ahmeyim and Guembeul fields offshore Mauritania / Senegal in West Africa. The Phase 1 facilities will include an FPSO, which processes, conditions and exports gas to a Floating Liquefied Natural Gas vessel. The FLNG further conditions, liquefies and offloads the gas onto an LNG carrier for export. The FLNG forms part of a 'Near Shore Hub' (NSH). The Hub comprises a breakwater to protect the LNG processing and carrier loading operations, a Quarters and Utilities Platform (QU platform) and the 'trestle' which is a walkway, boat landing and berthing facility running between the QU platform and the FLNG and LNG carrier. The gas from the FPSO arrives at the FLNG via a riser platform, which provide facilities for pigging and emergency isolation.

BP is required to submit an 'Environmental and Societal Impact Assessment' to quantify hazardous effects from all events identified in the preliminary risk analysis as category 4 or 5 consequence. To support the ESIA, BP has requested that Atkins Limited (Atkins) undertake consequence modelling of fires, explosions and cryogenic spills resulting from identified potential Major Accident Events (MAEs) associated with hydrocarbon releases on the FPSO and Near Shore Hub (i.e. including the FLNG).

Consequence modelling has been completed for a representative failure (50 mm) and for a credible worst case failure scenario for each of the hydrocarbon MAEs. The results of the modelling calculations are presented in this report in terms of hazard ranges to thermal radiation, thermal dose, explosion overpressure, flammable gas concentrations and cryogenic spill extent. The results are summarised as follows:

Jet Fires

Gas jet fires have been modelled for a representative failure (50 mm) associated with the riser and topsides gas inventories on the FPSO and NSH. The largest gas jet fires on the FPSO are from a failure of the production riser (MAE F-01) while for the NSH the greatest threat is from a failure of the gas import riser (MAE N-01). Thermal radiation of 10kW/m^2 is the threshold for "third-degree burns and very significant lethal effects" as defined by the risk study guide for the Republic of Senegal [6], while 3kW/m^2 is defined as the threshold for "significant injury". For the FPSO production riser distances to 10kW/m^2 and 3kW/m^2 are 87m and 117m respectively; for the gas import riser on the NSH, distances to the same effect levels are 71m and 93m.

Jet fires have also been modelled for liquid and two-phase inventories on the FPSO and FLNG – liquid jet / spray fires have been considered if there is a significant likelihood of gas flashing on release or of a liquid spray forming. The largest two-phase jet / liquid spray fires are from a 50mm failure of the liquid side of the slug catchers on the FPSO (MAE F-04) or the liquid side of the fractionation unit on the FLNG (MAE N-09). The impact distances to 10kW/m^2 and 3kW/m^2 for MAE F-04 are 167m and 226m respectively; for MAE N-09 distances to the same effect levels are 139m and 182m.

Pool Fires

Pool fires have been modelled for representative failures and credible worst case failures of non-flashing liquid inventories. For the FPSO, the largest pool fire effects are from a release of hydrocarbon liquid associated with the MP separator (MAE F-07) with the downwind distances to 10kW/m^2 and 3kW/m^2 calculated as 41m and 117m respectively. For the NSH the largest pool fire is from an unrestricted spill onto the sea surface from a storage / cargo tank failure of the FLNG / LNGC (MAE N-17) with the downwind distances to 10kW/m^2 and 3kW/m^2 calculated as 350m and 566m.

Fireballs

Fireballs have been modelled for a catastrophic failure (credible worst case) of the topsides gas and flashing liquid inventories and for full bore ruptures of the risers. A thermal dose of 2600 TDU is the threshold for third degree burns and very significant lethal effects while 600 TDU is the threshold for significant injury [6]. The largest fireball on the FPSO is for a rupture of the production riser (MAE F-01) with distances to 2600 TDU and 600 TDU of 167m and 434m. For the NSH the largest fireball is from a rupture of the gas import riser (MAE N-01). The distances to 2600 TDU and 600 TDU are 143m and 382m respectively.

Flammable Gas Dispersion

Flammable gas dispersion has been modelled for representative and credible worst case releases of pressurised liquids associated with the refrigeration and liquefaction units on the FLNG and for a credible worst case failure of the FLNG / LNGC. The largest flammable gas cloud is an unrestricted spill from a catastrophic cargo tank failure of the FLNG / LNGC (MAE N-17). The maximum downwind distance to LFL is calculated as 1076m.

Vapour Cloud Explosions

VCEs have been modelled for representative and credible worst case releases of flammable vapour into congested modules of the FPSO and FLNG. The threshold for "very significant lethal effects" from explosion overpressure is 0.35 bar while the "threshold of irreversible effects" is 0.02 bar [6]. The largest explosions on the FPSO are from flashing vapour associated with a liquid release of the LP separator (MAE F-08) with hazard ranges to 0.35bar and 0.02bar of 92m and 1154m. For the FLNG, the largest explosions are due to a gas release from the liquefaction unit (MAE N-09) or a release from the refrigerant loops (MAEs N-13 and N-14) within the LNG trains. The hazard ranges to 0.35bar and 0.02bar are 106m and 1045m.

BLEVEs

Fire engulfment of the refrigerant storage / make-up vessels on the FLNG has the potential to result in a BLEVE. The largest impact distances are associated with a fireball following a BLEVE of the propane refrigerant vessel. The distances to 2600 TDU and 600 TDU for this event are 49m and 243m respectively.

Cryogenic Spill

The impact of cryogenic pools has been determined for low temperature liquid releases on the FLNG capable of causing embrittlement of steel and presenting a threat to personnel within immediate range of the spill. The largest spills on the FLNG are from catastrophic failures of the LNG flash gas drum (MAE N-11) and the ethylene refrigerant storage vessel (MAE N-15). The release spreads to form a pool of 56m diameter which is approximately half of the deck area of the FLNG – it is considered that the pool will be limited from spreading further due to coaming arrangements and other restrictions, or from the spill flowing overboard. The largest spill onto the sea is from an unrestricted spill from a catastrophic cargo tank failure of the FLNG / LNGC (MAE N-17). The pool spreads to a diameter of ~126m.

1. Introduction

1.1. Ahmeyim/Guembeul Project Background

BP is currently developing options for facilities to recover gas from the Ahmeyim/Guembeul fields offshore Mauritania / Senegal in West Africa.

The location of the field is shown in Figure 1-1.

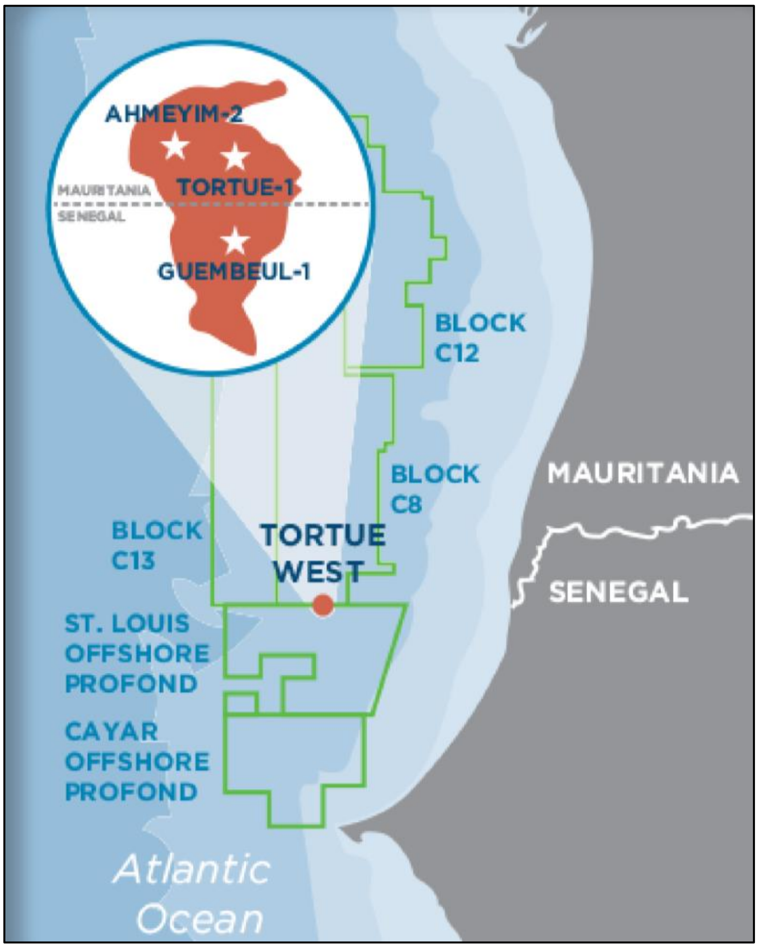


Figure 1-1 Field Location

The Phase 1 facilities will include an FPSO located about 50km from offshore, which will process up to 470MMscfd by separating condensate from the gas stream coming from nine subsea wells located at two drill centres some 80km away. Condensate production will be about 10,000bpd and will be exported via offtake tanker. The conditioned gas is exported via a 40km pipeline to a Floating Liquefied Natural Gas vessel, which conditions, liquefies and offloads the gas onto an LNG carrier for export. The FLNG is supported from a ‘Near Shore Hub (NSH)’, which is located on the Mauritania and Senegal maritime border. The Hub comprises a breakwater to protect the LNG processing and carrier loading operations, a Quarters and Utilities Platform (QU platform) and the ‘trestle’ which is a walkway, boat landing and berthing facility running between the QU platform and the FLNG and LNG carrier. The gas from the FPSO arrives at the FLNG via one riser platform, which provides pigging, isolation and potential future take-off points.

Figure 1-2 shows the expected layout of the Near Shore Hub and Figure 1-3 shows the expected layout of the FPSO. The FPSO is located approximately 40km to the West of the Hub.

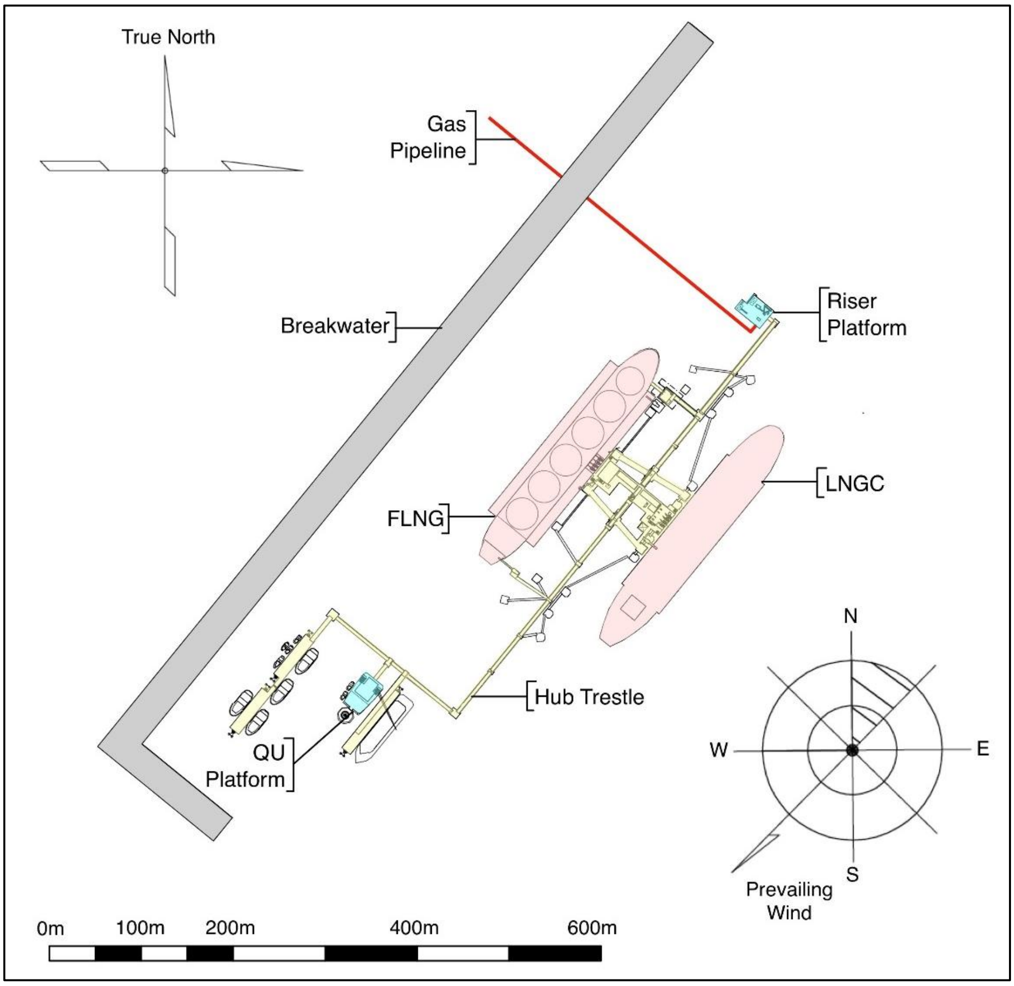


Figure 1-2 Near Shore Hub Layout

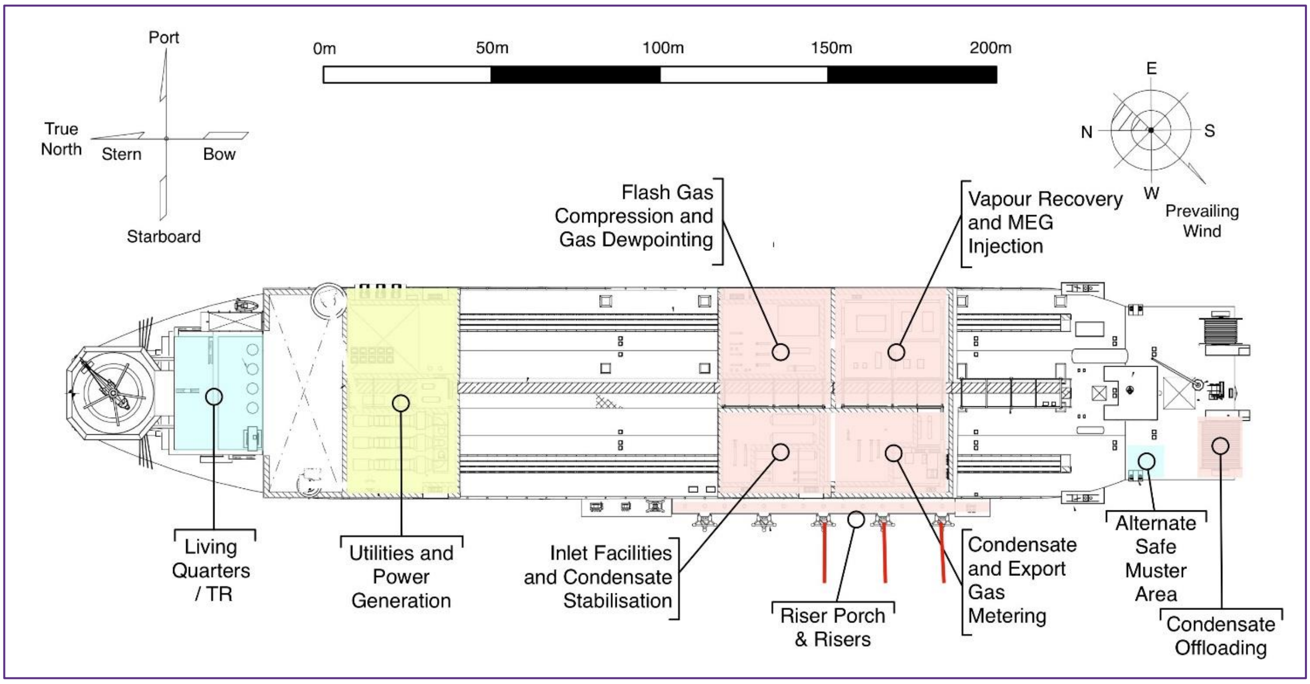


Figure 1-3 FPSO Layout

1.2. Purpose

The purpose of this study is to determine the hazardous effect distances for fires, explosions and cryogenic spill scenarios associated with major accident events on the FPSO and Near Shore Hub for the Ahmeyim/Guembeul Project. The output of the study is to be used in support of the ESIA Risk Study submission.

1.3. Scope

Hazardous effect modelling is based upon the Major Accident Events (MAEs) identified as part of the ESIA Risk Study, which have been assessed qualitatively in the Preliminary Hazard Analysis (PHA) and ranked as consequence category 4 (critical) and 5 (catastrophic):

- Critical consequences - 1 to 3 deaths or significant effects on the environment;
- Catastrophic consequences - Several deaths (more than 3) or extensive damages to the environment.

To facilitate the PHA and support the identification of the MAEs, a set of simplified process flow diagrams has been developed. The process flow diagrams form the basis for the major accident events carried forward from the PHA for detailed consequence modelling. The simplified process flow diagrams are included in Appendix A.

2. Failure Scenarios

Modelling of fires, explosions and cryogenic spill effects has been completed for a total of 32 of the MAEs identified in the ESIA study – 19 are for the Near Shore Hub and 13 for the FPSO. A list of all the MAEs for which hazardous effect modelling has been completed is shown in Table 2-1, along with the consequence category (S4 or S5, as outlined in Section 1.3), the phase, i.e. the phase of hydrocarbon at process conditions, and the hazardous scenarios modelled. Selection of the scenarios modelled for each MAE is outlined in Section 3.

Table 2-1 MAEs Modelled

MAE ID	Major Accident Event	Location	Phase	Hazardous Scenarios Modelled
N-01	Gas Release from Import Gas Riser (S5)	NSH	Gas	Jet Fire (50mm), Fireball (Rupture)
N-02	Gas Release from Trestle Feed Gas Flowline / Hose to FLNG (S4)	NSH	Gas	Jet Fire (50mm), Fireball (Full Inventory)
N-03	Gas Release from Trestle Fuel Gas Flowline to QU Platform (S4)	NSH	Gas	Jet Fire (50mm), Fireball (Full Inventory)
N-04	Gas Release from FLNG Inlet Metering and Amine Treatment (S4)	NSH	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-05	Gas Release from FLNG Dehydration and Regeneration (S4)	NSH	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-06	Gas Release from FLNG Boil Off Gas / Flash Gas Compression (S4)	NSH	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-07	Fuel Gas Release from FLNG HP Fuel Gas System (S4)	NSH	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-08	Gas Release from FLNG Fractionation (S4)	NSH	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-09	Light Hydrocarbon Liquid Releases from FLNG Fractionation (S4)	NSH	Liquid	LFL (50mm & Full Inventory), Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-10	LNG Release from FLNG Liquefaction Process (S4)	NSH	Liquid	Cryogenic Pool (50mm & Full Inventory), LFL (50mm & Full Inventory), Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-11	LNG Release from FLNG Flash Gas Drum (S4)	NSH	Liquid	Cryogenic Pool (50mm & Full Inventory), LFL (50mm & Full Inventory), Explosion, Jet Fire (50mm), Pool Fire (50mm & Full Inventory)
N-12	BLEVE of Vessel on FLNG Containing Refrigerant (S4)	NSH	Liquid	Fire Ball (Propane and Ethylene - Full Inventory)
N-13	Gas Release from FLNG SMR Refrigerant Closed Loop (S4)	NSH	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-14	Liquid Release from FLNG SMR Refrigerant Closed Loop (S5)	NSH	Liquid	Cryogenic Pool (50mm & Full Inventory), LFL (50mm & Full Inventory), Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-15	Refrigerant Release from FLNG Refrigerant Storage (S5)	NSH	Liquid	Cryogenic Pool (50mm & Full Inventory), LFL (50mm & Full Inventory), Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-16	Gas Release (Fuel Gas) in QU Platform Utility Space / Area (S4)	NSH	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
N-17	LNG Release from FLNG / LNGC Storage Tanks (S5)	NSH	Liquid	Cryogenic Pool (750mm), LFL (750mm), Pool Fire (750mm)
N-18	LNG Release during LNGC Loading (S4)	NSH	Liquid	Cryogenic Pool (50mm & Full Inventory), LFL (50mm & Full Inventory), Jet Fire (50mm), Pool Fire (50mm & Full Inventory)

MAE ID	Major Accident Event	Location	Phase	Hazardous Scenarios Modelled
F-01	Hydrocarbon Release from Production Riser	FPSO	Two-phase	Jet Fire (50mm), Fireball (Rupture)
F-02	Gas Release from Export Gas Risers	FPSO	Gas	Jet Fire (50mm), Fireball (Rupture)
F-03	Gas Release from Reception Facilities (Slug Catchers)	FPSO	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
F-04	Liquid Release from Reception Facilities (Slug Catchers)	FPSO	Liquid	Explosion, Jet Fire (50mm); Pool Fire (50mm & Full Inventory)
F-05	Gas Release from Gas Processing	FPSO	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
F-06	Liquid Release from Gas Processing	FPSO	Liquid	Explosion, Jet Fire (50mm); Pool Fire (50mm & Full Inventory)
F-07	Liquid Release from MP Separator	FPSO	Liquid	Explosion, Jet Fire (50mm); Pool Fire (50mm & Full Inventory)
F-08	Liquid Release from LP Separator	FPSO	Liquid	Explosion, Jet Fire (50mm); Pool Fire (50mm & Full Inventory)
F-09	Liquid Release from LLP Separator	FPSO	Liquid	Pool Fire (50mm & Full Inventory)
F-10	Gas Release from Flash Gas Compression	FPSO	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
F-11	Gas Release from Fuel Gas System	FPSO	Gas	Explosion, Jet Fire (50mm), Fireball (Full Inventory)
F-12	Injection Chemical Release Topsides	FPSO	Liquid	Pool Fire (50mm & Full Inventory)
F-14	Condensate Storage Tank Fire	FPSO	Liquid	Pool Fire (single cargo tank)

3. Modelling Basis

Modelling of hazardous effects from fires and explosions associated with the MAEs identified in Section 2 has been completed using the PHAST software package from DNV. Apart from where noted in the assumptions below, PHAST modelling is aligned with BP's agreed approach or using default PHAST parameters.

3.1. Inventory Size and Operating Conditions

Fire, gas dispersion and explosion modelling is completed for each of the MAEs using input data for system pressure, temperature, composition etc. and an estimate of the mass that could be released or involved in a fire or explosion. The mass involved for each of the topsides and the cargo tank MAEs has been approximated by using the isolated mass within each MAE section while for the pipeline and loading arm MAEs the mass released prior to isolation is also considered.

For MAEs on the Near Shore Hub the isolated section mass, plus the operating conditions (pressure, temperature, composition etc.), are mostly taken from BP Major Accident Risk (MAR) study with the following exceptions (for these cases inventory data is not available in MAR study and hence the inputs are based on Atkins previous project experience).

- Volume and operating conditions for fractionator and associated reflux conditioner, reflux drum and fractionation reboiler (MAE N-08 and N-09)
- Volume and operating conditions for LNG stream in main cryogenic heat exchanger (MAE N-10)
- Volume and operating conditions for gas side of Single Mixed Refrigerant (SMR) refrigerant loop (MAE N-13)
- Volume and operating conditions for LNG offloading (MAE N-18)

For MAEs on the FPSO the isolated section mass is calculated by considering volumes contained in major vessels plus supporting pipework. Vessel dimensions taken from the Major Equipment List (MEL). The operating pressure, temperature and composition for MAEs on the FPSO are taken from the 'Heat and Material Balance Phase 1A' [Ref 1] with the most representative stream selected for consequence modelling calculations.

3.2. Failure Sizes

Two release sizes are modelled – a representative breach of 50mm and a credible worst case failure. The failures have been modelled as follows:

Gas and Two-Phase Process Inventories
Gas and two-phase process inventories are modelled as a 50mm release and an instantaneous failure with release of the full MAE inventory.

Liquid and Sub-Cooled Liquid Process Inventories
Liquid and sub-cooled liquid process inventories are modelled as a 50mm breach and a release of the largest liquid vessel inventory over a 60 second period – modelled in PHAST as a spill.

Pipelines and Risers
Pipeline and risers are modelled as a 50mm failure and a full-bore rupture based on the internal diameter of the line.

Cargo Storage Tanks
The following approaches for failure of a cargo storage tank are considered:

- ACDS 1991 [Ref 2]: For gas carriers, one whole tank released in 300 seconds.

- Pitblado et al 2004 [Ref 3]: 750mm hole (maximum credible hole from accidental operational events), release of one cargo tank. Note: a maximum hole size of 1500mm is quoted but this is for intentional impacts, e.g. terrorist activity, and is not considered relevant for this study.

- SANDIA 2004 4: 0.5 to 1m^2 effective breach size, release of one cargo tank. This references the Pitblado et al paper [Ref 3]: as the source for the breach area.

- TNO: Release of 180m^3 over 1800 seconds (see Table 3.20 in [Ref. 5]).

The Pitblado paper [Ref 3]: is considered most appropriate for this study based on the type of impacts that are possible and so cargo storage tank failures are modelled as a breach of 750 mm with the entire contents of one tank released.

Loading Arms

Loading arms are modelled as a 50mm failure and a rupture of a single loading arm with one minute of outflow.

3.3. Meteorological Conditions

Wind Speed and Stability Class

Modelling of fires and gas dispersion is completed for two representative wind speeds – an average wind speed and a low wind speed.

Atmospheric stability is influenced by temperature differences between the ground or sea and the air; when the ground heats up by the sun during the day, this leads to unstable conditions (Pasquill classes A, B, C). Conversely, during still nights with clear skies, the ground can cool sufficiently (due to radiation back into space), to create stable conditions (Pasquill stability class F). When the ground and the air are at the same temperature, conditions are neutral. Also, when the wind is more than 2m/s, this introduces added turbulence which means that even F conditions can be assumed neutral. Sea surface temperatures do not change in the same way as the ground, and therefore conditions over the sea can be assumed as neutral always. On this basis, Pasquill stability class D (neutral) is typically assumed in all cases during day time or night time, regardless of wind speed.

The two representative conditions are therefore as follows:

- D2; this category is chosen to represent low wind speed conditions: wind speed taken as 2 m/s with neutral stability class

- D5; this category is chosen to represent the average conditions: mean wind speed approximated as 5 m/s with neutral stability class

Sea Temperature

The average temperatures for deeper water are considered most appropriate – these range from 15.9ºC in February to 25.3ºC in September. A sea temperature of 17ºC is chosen as representative for the PHAST modelling.

Air Temperature

The average minimum is 16.4ºC in December and the average maximum is 33.7ºC in October. An air temperature of 20ºC is used as representative.

3.4. Fires

3.4.1. Jet Fires

Jet fires are modelled for gas, flashing liquid and liquid spray releases associated with a 50mm breach with potential for liquid releases to flash or form a spray based on the following rule-set:

- Condensate and other lighter components are assumed to flash on release or generate a spray at pressures above 4 barg.

Jet fires are orientated horizontally to give the worst extent hazard range (note: this differs from typical BP approach which is to model these at 45 degrees to the horizontal).

Impact from jet fires due to thermal radiation is based on the hazard levels defined in the Senegal Risk Study Guide [Ref 6]. These are shown in Table 3-1 below.

Table 3-1 Thermal Radiation Hazard Levels

Criteria	Impact
3 kW/m^2	Threshold of significant injury (blisters in 30s for unprotected persons)
5 kW/m^2	Threshold of first lethal effects, threshold of destruction of windows by thermal effect
10 kW/m^2	Threshold of very significant lethal effects, third-degree burns, domino effect, risk of fire for combustible material
20 kW/m^2	Destruction or breaking of structural elements, concrete holds for some hours

3.4.2. Pool Fires

Pool fires are modelled for all non-flashing liquid scenarios and for liquid releases which have potential to form a spray – these are also considered since a pool may be formed if the spray is directed vertically downwards.

For continuous releases (50mm and full-bore ruptures) the ‘early’ pool fire model within PHAST is used – i.e. the extent of the pool is determined by the equilibrium of the spill rate into the pool and the burn rate of the fire.

For releases on the FPSO or FLNG the maximum extent of a pool is initially limited to an area of 50m x 50m – this is considered representative of coaming arrangements restricting extensive spreading of a release on the topsides. However, coaming will not fully contain hydrocarbon liquids from catastrophic failures or full bore ruptures associated with the largest inventories. For releases spreading beyond a pool size of 50m x 50m, it is expected that hydrocarbon will spill overboard. The primary concern for these releases is from topsides pool fires and so impact from the overboard spill is not included in the analysis. For releases onto the sea (loading arm failures, risers etc.) no cap is included – pools are considered to spread to a maximum extent without restriction.

Impact from pool fires due to thermal radiation is based on the hazard levels defined in the Senegal Risk Study Guide. These are shown in Table 3-1 above.

3.4.3. Fireballs

Fireballs are modelled for all credible worst case failures associated with a gas inventories and for liquid process inventories where most of the material will flash in the event of a catastrophic rupture. For pipeline and riser releases, the flammable mass involved in the fireball is approximated as the released mass in the first 45 seconds following a full-bore rupture.

Impact from fireballs due to thermal dose is based on the hazard levels defined in the Senegal Risk Study Guide and shown in Table 3-2 below, with thermal dose taken at an elevation of 0m.

Table 3-2 Thermal Dose Hazard Levels

Criteria	Impact
600 $kW^{4/3}$ s	Threshold of significant injury (blisters in 30s for unprotected persons)
1,000 $kW^{4/3}$ s	Threshold of first lethal effects
2,600 $kW^{4/3}$ s	Threshold of very significant lethal effects, third-degree burns

3.5. Flammable Gas Dispersion

Flash fires are modelled for failures resulting in dispersion of flammable gas significantly beyond the extent of the FPSO or NSH. The cases are limited to pressurised liquid releases associated with the refrigeration and liquefaction units on the FLNG and a credible worst case failure of a cargo tank on the LNGC / FLNG. Modelling of flammable gas dispersion is carried out using the Unified Dispersion Model (UDM) within PHAST.

Within the PHAST calculations for flash fires, releases are orientated downwards to reduce the momentum. This is considered representative of impact on neighbouring equipment and structures and generally gives the largest hazardous footprint (note: this differs from typical BP approach which assumes horizontal orientation for 50mm releases).

Dispersion modelling is completed using roughness lengths as follows:

- For releases on the FPSO and FLNG a roughness length of 0.05m is used; this is in-line with BP's usual approach.
- For releases over the sea, i.e. from LNGC or FLNG cargo tanks, a lower roughness length of 0.2mm (applicable for open water based on guidance within PHAST) is used.

There are no criteria for flammable gas dispersion in the Senegal Risk Study Guide, therefore the LFL envelope/distance for flashfire is applied as shown in Table 3-3 below. Effect distances are measured at heights of between 0m and 5m – this is considered representative of the range of elevations for personnel on the FPSO or FLNG.

Table 3-3 Flammable Gas Dispersion Hazard Levels

Criteria	Impact
100% LFL	Extent of main flammable gas cloud

3.6. Explosions

3.6.1. Vapour Cloud Explosions

VCEs are modelled for failure scenarios with flammable vapour reaching congested regions on the NSH and FPSO – ignition of a release in these areas may generate overpressures sufficient to impact personnel, equipment or structures. It is noted that ethylene (N-15) also has potential for detonation due to high reactivity. Such a VCE would involve all vapour within a flammable cloud, i.e. the explosion would not be limited to build-up of gas within a congested region. Overpressures from detonation can be significantly higher than from deflagration although the impulse durations are generally lower. Modelling of VCEs on the FLNG has used a consistent approach as for the BP MAR study which has only considered impact from deflagration of ethylene. It is recommended that assessment of detonation of ethylene is considered as part of the next stage of the design.

Modelling of VCEs for FPSO and NSH

Congested volumes for the FLNG are taken from the MAR study which considers VCEs due to flammable vapour released into the sponson structures attached to the port and starboard sides of the FLNG hull. The sponson dimensions are 10m x 203m with an estimated height of 10m, giving a congested volume of 20,300m^3 on each side of the vessel. In addition, explosions are considered for releases on the QU platform which is estimated to have a congested volume of 500m^3.

Congested volumes for the FPSO are based on a review of the FPSO deck area, with VCEs considered for flammable gas build-up in four modules towards the fore. These modules are shown in Figure 1-3 with the estimated footprint area as 60m x 70m and an assumed module height of 5m, giving a volume of 21,000m^3. The four fore modules on the FPSO are:

- Inlet facilities and condensate stabilisation
- Condensate and export gas metering
- Flash gas compression and gas dewpointing
- Vapour recovery and MEG injection

The congested regions considered for each MAE are shown in Table 3-4.

For explosions from 50mm and credible worst case failures, the volume of flammable vapour is capped based on either the released inventory mass associated with the MAE or the volume of the congested region, whichever is smaller. Overpressures are therefore the maximum size possible with one set of results presented for each MAE.

Explosion effects are calculated using the TNO Multi-Energy Method (MEM) within PHAST, which is noted as being conservative. Strength curve 7 is used for all releases on the FLNG except for ethylene which is modelled using strength curve 10 to reflect the fact that it is a more reactive material (although, as noted above, the scenario considered is an explosion within the congested regions of the FLNG, not a detonation). Congestion on the FPSO is expected to be low due to the deck size available. Therefore, strength curve 6 is used for all releases on the FPSO. All releases – both representative and credible worst case – are assumed to have potential to completely fill the source module of each release.

Table 3-4 Congested Regions for VCE Modelling

MAE ID	Congested Region	Congested Volume (m^3)	Notes
N-01	-	-	Potential for VCE discounted – release at riser platform / trestle considered to be into a non-congested area
N-02	-	-	As per N-01
N-03	-	-	As per N-01
N-04	Starboard sponson	20,300	Representative (50mm) and credible worst case failures considered as releases into full sponson volume on starboard side
N-05	Starboard sponson	20,300	As per N-04
N-06	Starboard sponson	10,150	Representative (50mm) and credible worst case failures considered as releases into 50% of sponson volume on starboard side (as per BP MAR study)
N-07	Starboard sponson	10,150	As per N-06
N-08	Port sponson	20,300	Representative (50mm) and credible worst case failures considered as releases into full sponson volume on portside (as per BP MAR study)
N-09	Port sponson	20,300	As per N-08
N-10	Port sponson	20,300	As per N-08

MAE ID	Congested Region	Congested Volume (m^3)	Notes
N-11	Port sponson	20,300	As per N-08
N-12	-	-	N/A – no explosion to be considered for this MAE
N-13	Port sponson	20,300	As per N-08
N-14	Port sponson	20,300	As per N-08
N-15	Port sponson	12,180	Representative (50mm) and credible worst case failures considered as releases into 60% of sponson volume on portside (as per BP MAR study)
N-16	QU Platform	500	Representative (50mm) and credible worst case failures considered as releases into congested volume on QU platform
N-17	-	-	As per N-01
N-18	-	-	Release onto sea surface – non-congested region – VCE discounted
F-01	-	-	Assumed that riser balcony positioned so that flammable gas from riser leak does not reach topsides (i.e. remains outboard of the FPSO). Potential for VCE discounted.
F-02	-	-	As per F-01
F-03	Forward modules of FPSO	21,000	Representative (50mm) and credible worst case failure considered as releases into congested volume of four forward modules of FPSO
F-04	Forward modules of FPSO	21,000	As per F-03
F-05	Forward modules of FPSO	21,000	As per F-03
F-06	Forward modules of FPSO	21,000	As per F-03
F-07	Forward modules of FPSO	21,000	As per F-03
F-08	Forward modules of FPSO	21,000	As per F-03
F-09	-	-	VCE discounted – condensate release with small fraction of light ends
F-10	Forward modules of FPSO	-	As per F-03
F-11	Forward modules of FPSO	21,000	As per F-03
F-12	-	-	N/A – no explosion to be considered for this MAE
F-14	-	-	N/A – no explosion to be considered for this MAE

VCE hazard ranges are based on the overpressure effect levels defined in the Senegal Risk Study Guide and shown in Table 3-5 below.

Table 3-5 Overpressure Hazard Levels

Criteria	Impact
0.02 bar	Threshold of irreversible effects corresponding to the area with indirect effects on human beings, threshold of destruction of windows greater than 10%
0.05 bar	Threshold of irreversible effects corresponding to the area with significant hazards to human beings, threshold of light damages to structures, destruction of 75% of windows
0.14 bar	Threshold of initial lethal effects, threshold of domino effect, partial collapse of walls and roofs of houses
0.35 bar	Threshold of very significant lethal effects, threshold of very serious damage to structures, destruction of buildings, breaking of pipelines

3.6.2. BLEVEs

BLEVEs are modelled for catastrophic failures associated with the refrigerant storage vessels on the FLNG. The primary hazard of concern resulting from a BLEVE is a fireball following the vessel rupture and release of the flammable material.

BLEVEs are assumed to occur at a burst pressure of 20 bar and the radiation effects are modelled after assuming the full contents of the vessel are included in the fireball. Impact from fireballs due to thermal dose is based on the hazard threshold levels shown in Table 3-2.

3.7. Cryogenic Spills

Cryogenic impact is considered for liquid releases with potential to cause embrittlement of steel or presenting a risk to personnel within the immediate range of a spill. Embrittlement of steel occurs at -40ºC and therefore releases are considered as a cryogenic hazard if the liquid temperature following release is significantly lower than -40ºC – for example, -50ºC or lower.

Cryogenic spills are modelled for non-flashing liquid cryogenic failure scenarios by considering the extent of an un-ignited liquid pool. The maximum extent of a pool on the FLNG is limited to an area of 50m x 50m to reflect coaming arrangements etc. Cryogenic liquid spreading beyond an area of 50m x 50m is expected to spill overboard. The primary concern for these releases is from impact on the topsides and so cryogenic liquid spilt overboard is not included in the analysis.

However, the extent of a cryogenic pool on the sea surface is considered for a cargo tank failure (N-17) and a loading arm failure (N-18) – the spill from these releases is unrestricted.

4. FPSO and Subsea Failure Scenarios

This section outlines each of the FPSO and subsea MAEs for which fire and explosion modelling has been completed and presents the hazard effect distances for these scenarios.

4.1. MAE F-01: Hydrocarbon Release from Production Riser

4.1.1. Event Description

This MAE is for a loss of containment of a 16” production riser on the FPSO which starts at the subsea production wells and extends to the riser ESDVs at the riser balcony on the portside of the vessel. The riser inventory for F-01 is based on provision of an SSIV at the PLEM, although it is noted that this assumption does not make a significant impact on the fire sizes presented in the sections below but does impact the release duration.

Modelling of fires for this MAE has been completed using input data based on FPSO Major Hazard Inventory (Appendix B.1.2) and are outlined in the table below.

Table 4-1 MAE F-01 Stream Parameters

Parameter	Input
Process Unit	Riser Balcony
Assumed Material	Methane
Pressure (bara)	97
Temperature (deg C)	3
Phase	Gas
Inventory (kg)	48,523
Outflow Rate for Representative Failure (50mm) (kg/s)	39.3
Estimated Release Duration for Representative (50mm) Failure	15-30 minutes

4.1.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE F-01. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-1 and Table 4-2 respectively.

Table 4-2 MAE F-01 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	117	171
	5	101	133
	10	85	94
	20	72	65
5/D	3	115	171
	5	101	134
	10	87	94
	20	76	65

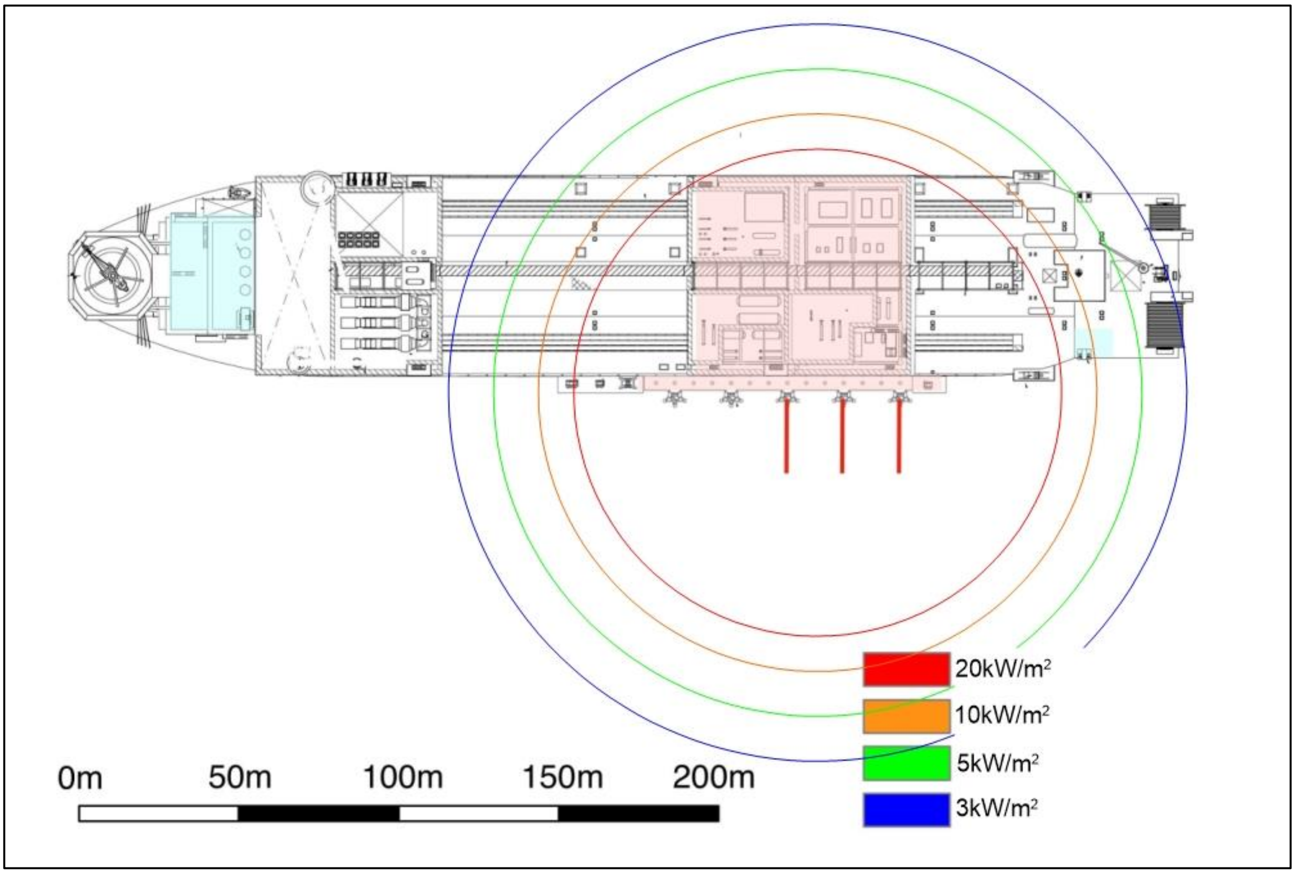


Figure 4-1 MAE F-01 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE F-01. The mass involved in the fireball is assumed to be the mass released in the first 30 seconds following rupture of the of the riser. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in

Figure 4-2 and Table 4-3 respectively.

Table 4-3 MAE F-01 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
131	600	434
	1000	337
	2600	167

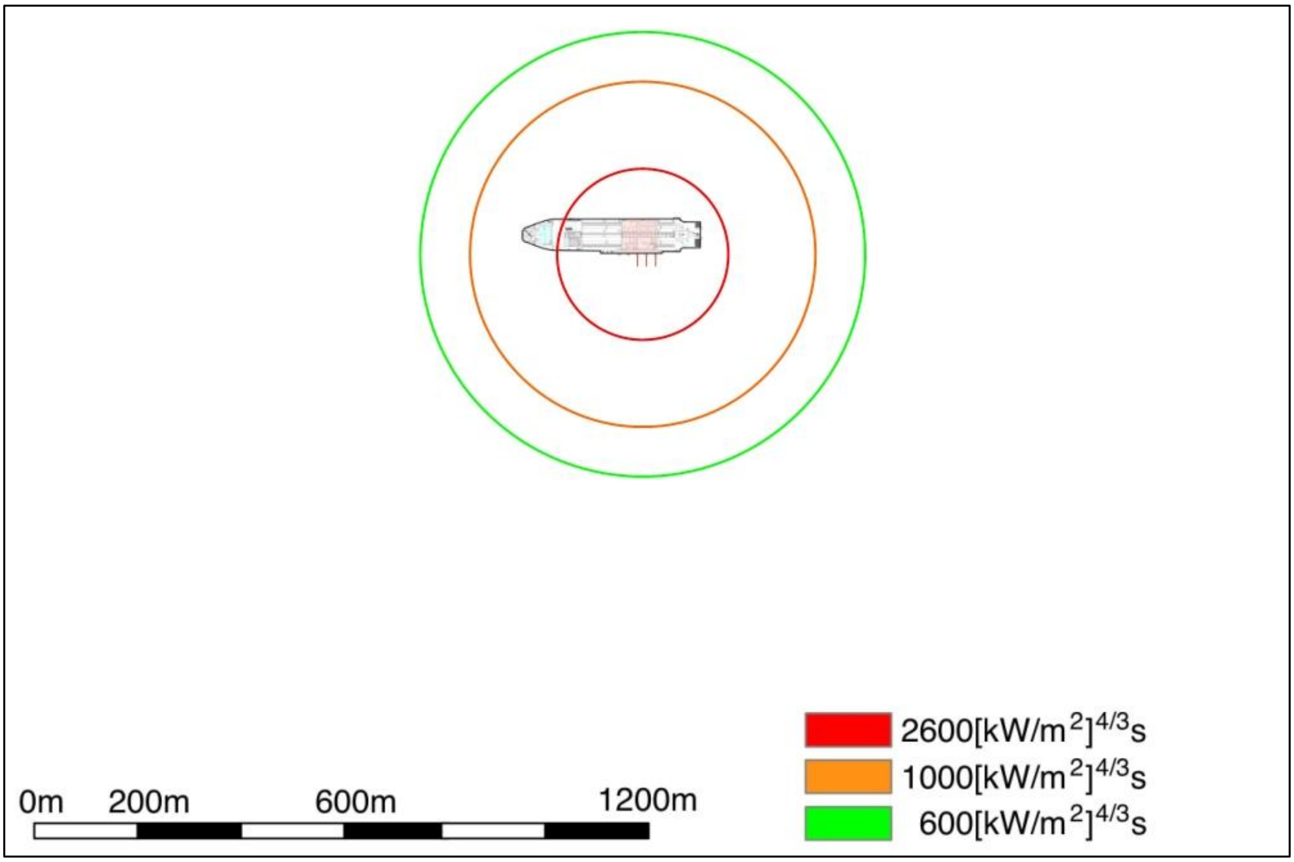


Figure 4-2 MAE F-01 Fireball Contour for Catastrophic Failure (scale in m)

4.2. MAE F-02: Gas Release from Export Gas Risers

4.2.1. Event Description

This MAE is for a loss of containment of the gas export riser which starts at the gas export riser ESDV at the riser balcony of the FPSO and transfers raw gas from the FPSO to the Near Shore Hub – a distance of approximately 40km. The riser inventory for F-02 is based on provision of an SSIV at the PLEM, although it is noted that this assumption does not make a significant impact on the fire sizes presented in the sections below but does impact the release duration.

The stream conditions for this MAE was obtained from the FPSO Major Hazard Inventory (Appendix B.1.2) and is shown below.

Table 4-4 MAE F-02 Stream Parameters

Parameter	Input
Process Unit	Riser Balcony
Assumed Material	Methane
Pressure (bara)	79
Temperature (deg C)	15
Phase	Gas
Inventory (kg)	30,600
Outflow Rate for Representative Failure (50mm) (kg/s)	25.8
Estimated Release Duration for Representative (50mm) Failure	15-30mins

4.2.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE F-02. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-3 and Table 4-5 respectively.

Table 4-5 MAE F-02 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	96	140
	5	84	109
	10	71	77
	20	61	52
5/D	3	95	141
	5	84	109
	10	73	77
	20	64	52

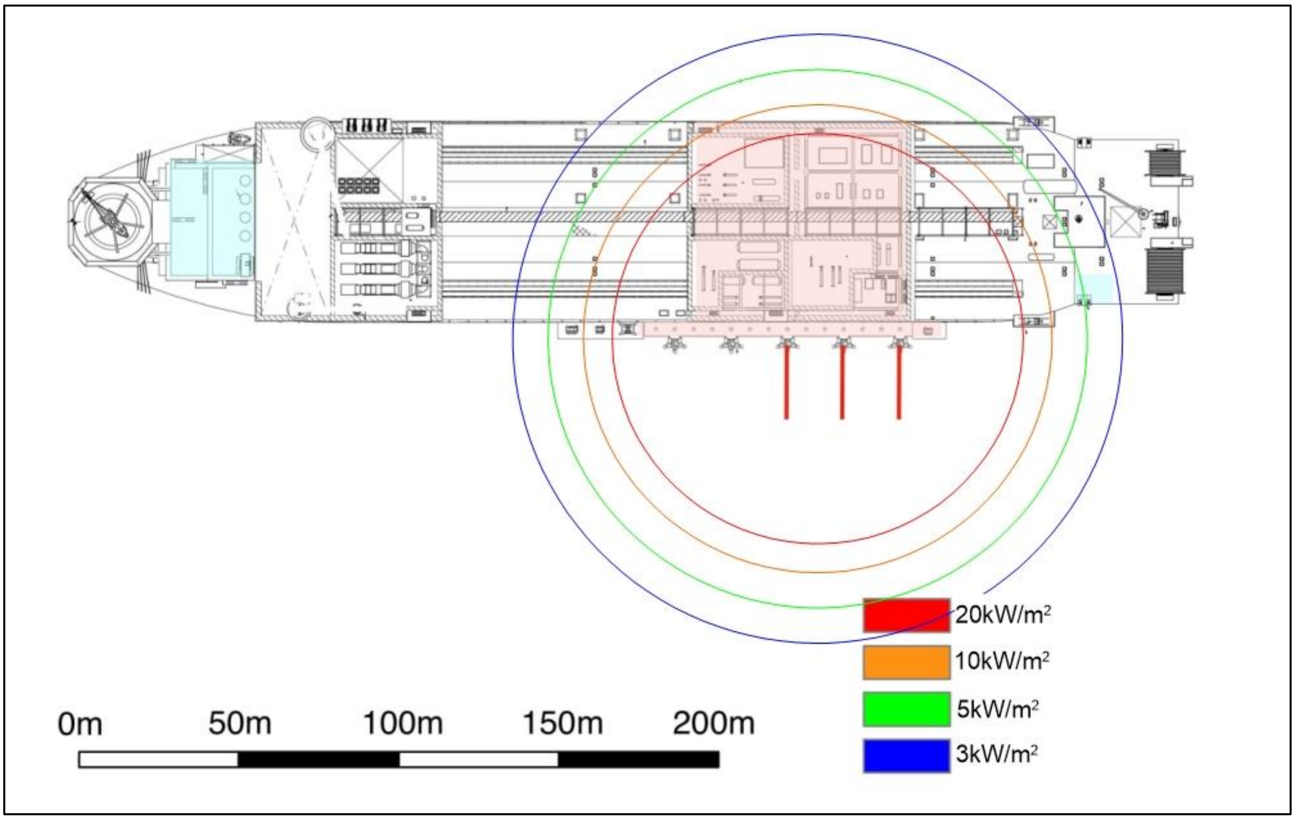


Figure 4-3 MAE F-02 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE F-02. The mass involved in the fireball is assumed to be the mass released in the first 30 seconds following rupture of the of the riser. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 4-4 and Table 4-6 respectively.

Table 4-6 MAE F-02 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
119	600	398
	1000	301
	2600	151

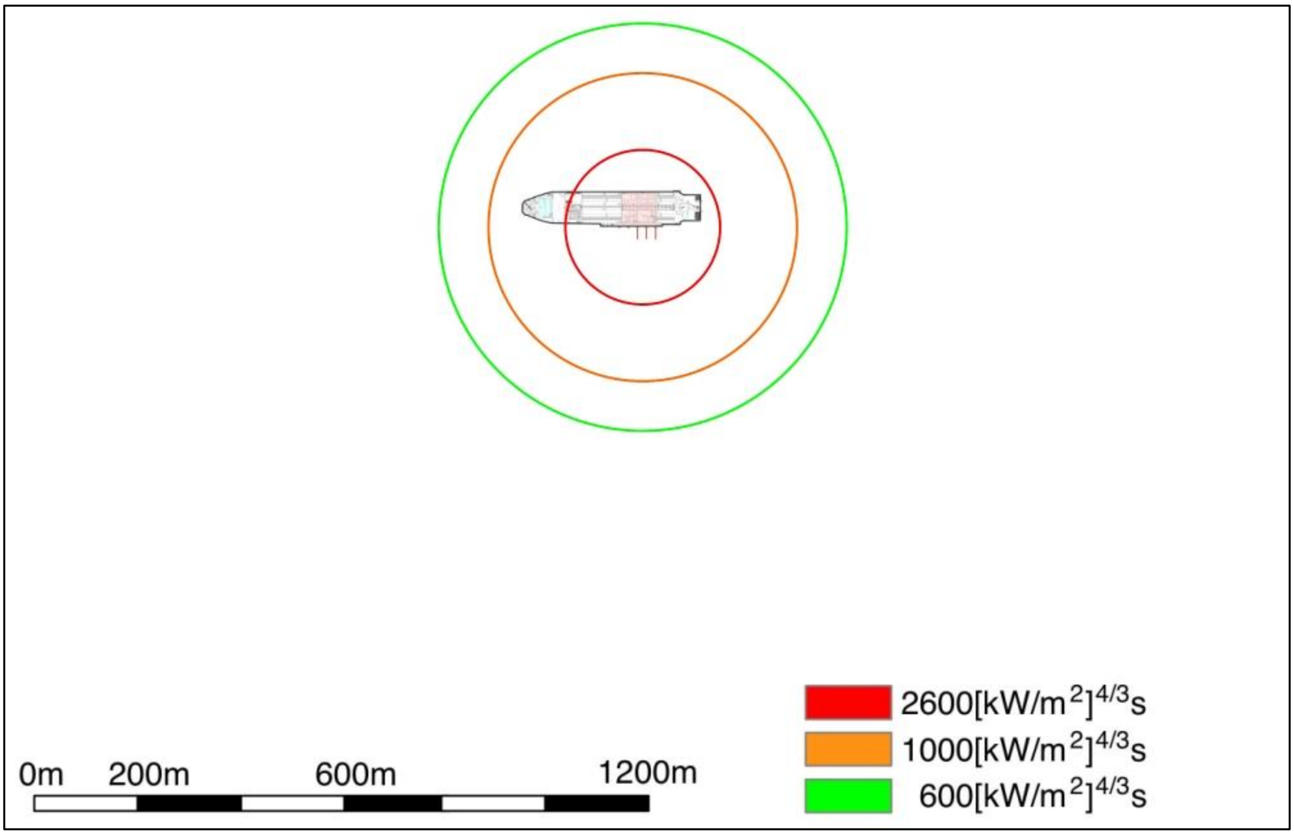


Figure 4-4 MAE F-02 Fireball Contour for Catastrophic Failure (scale in m)

4.3. MAE F-03: Gas Release from Reception Facilities (Slug Catchers)

4.3.1. Event Description

This MAE is for a loss of containment of the gas side of the slug catcher and associated pipework which is located in the reception facilities of the FPSO (Module P3). The section starts at the production riser ESDV and ends at the ESDVs downstream of the slug catchers. The section includes the following major equipment items:

- Pig Launcher
- Slug Catcher (x2) (vapour space)

Modelling of fires and explosions for this MAE has been completed using the input data outlined in the table below.

Table 4-7 MAE F-03 Stream Parameters

Parameter	Input
Process Unit	Reception Facilities
Assumed Material	Methane
Pressure (bara)	93
Temperature (deg C)	1.4
Phase	Gas
Inventory (kg)	13,319
Outflow Rate for Representative Failure (50mm) (kg/s)	32.5
Estimated Release Duration for Representative (50mm) Failure	5-15mins
Congested Volume (m^3)	21,000

4.3.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE F-03. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-5 and Table 4-8 respectively.

Table 4-8 MAE F-03 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	107	157
	5	94	123
	10	79	87
	20	67	59
5/D	3	106	158
	5	94	123
	10	81	87
	20	71	59

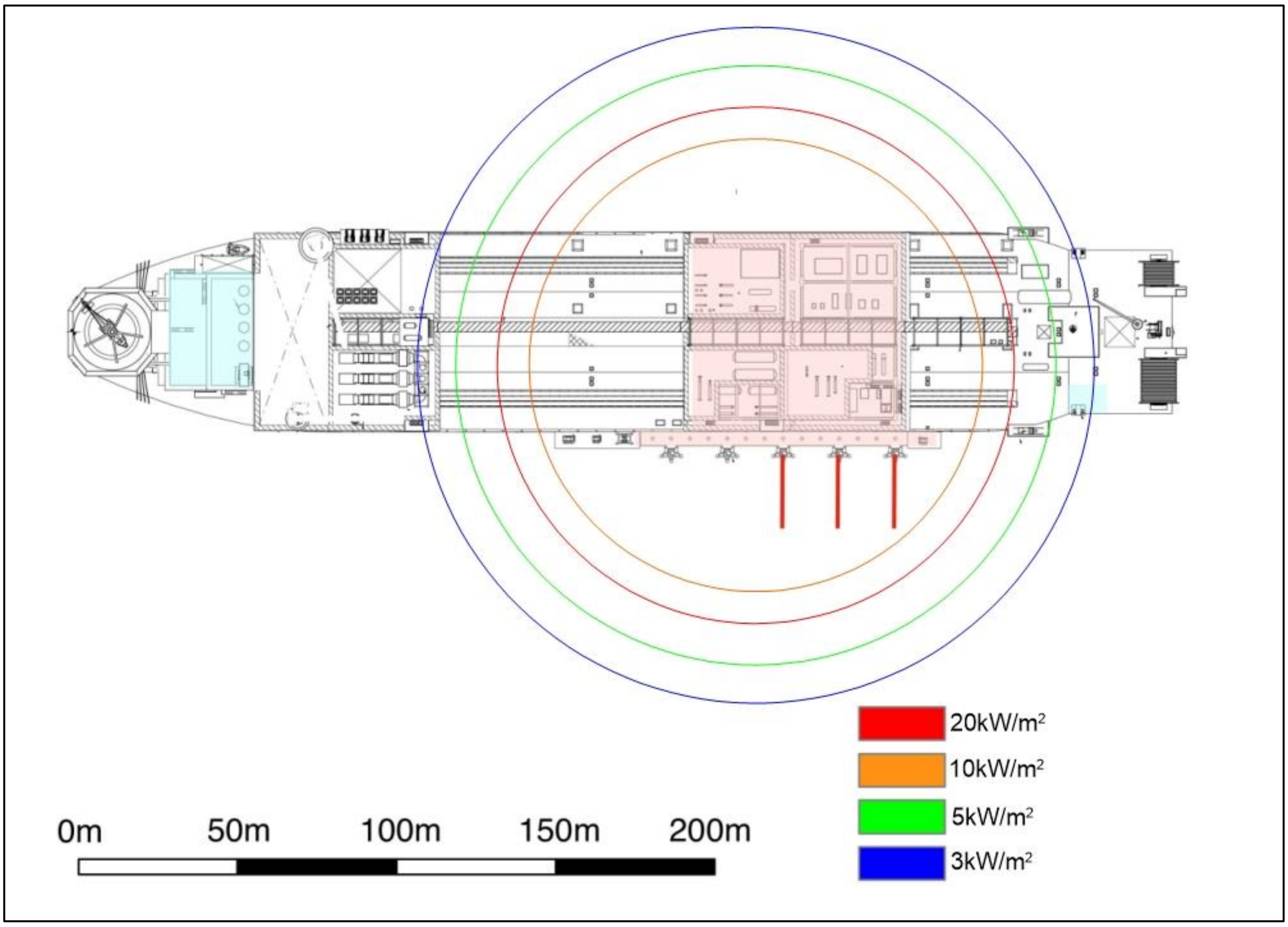


Figure 4-5 MAE F-03 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE F-03. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 4-6 and Table 4-9 respectively.

Table 4-9 MAE F-03 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
71	600	198
	1000	147
	2600	42

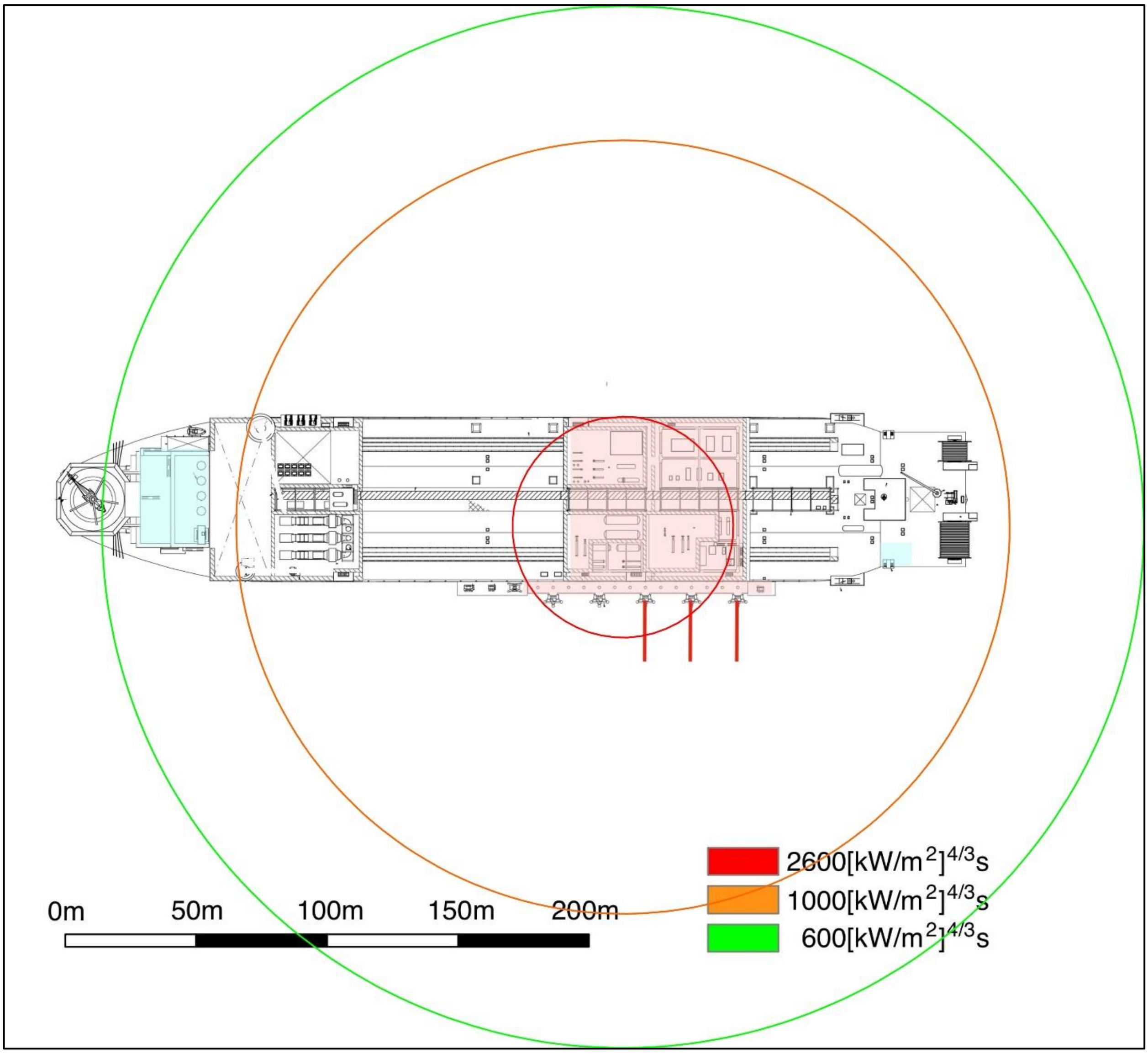


Figure 4-6 MAE F-03 Fireball Contour for Catastrophic Failure (scale in m)

4.3.3. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (Flash Gas Compression, Inlet Facilities, Condensate and Export Gas Metering and Vapour Recovery modules) following loss of containment for MAE F-03 will result in a vapour cloud explosion. Overpressure results are calculated for a VCE within the forward most modules of the FPSO. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) is able to completely fill these modules. The contour plot and overpressures associated with 100% fill of this volume is shown in Figure 4-7 and Table 4-10 respectively.

Table 4-10 MAE F-03 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1019
0.05	445
0.14	182
0.35	81

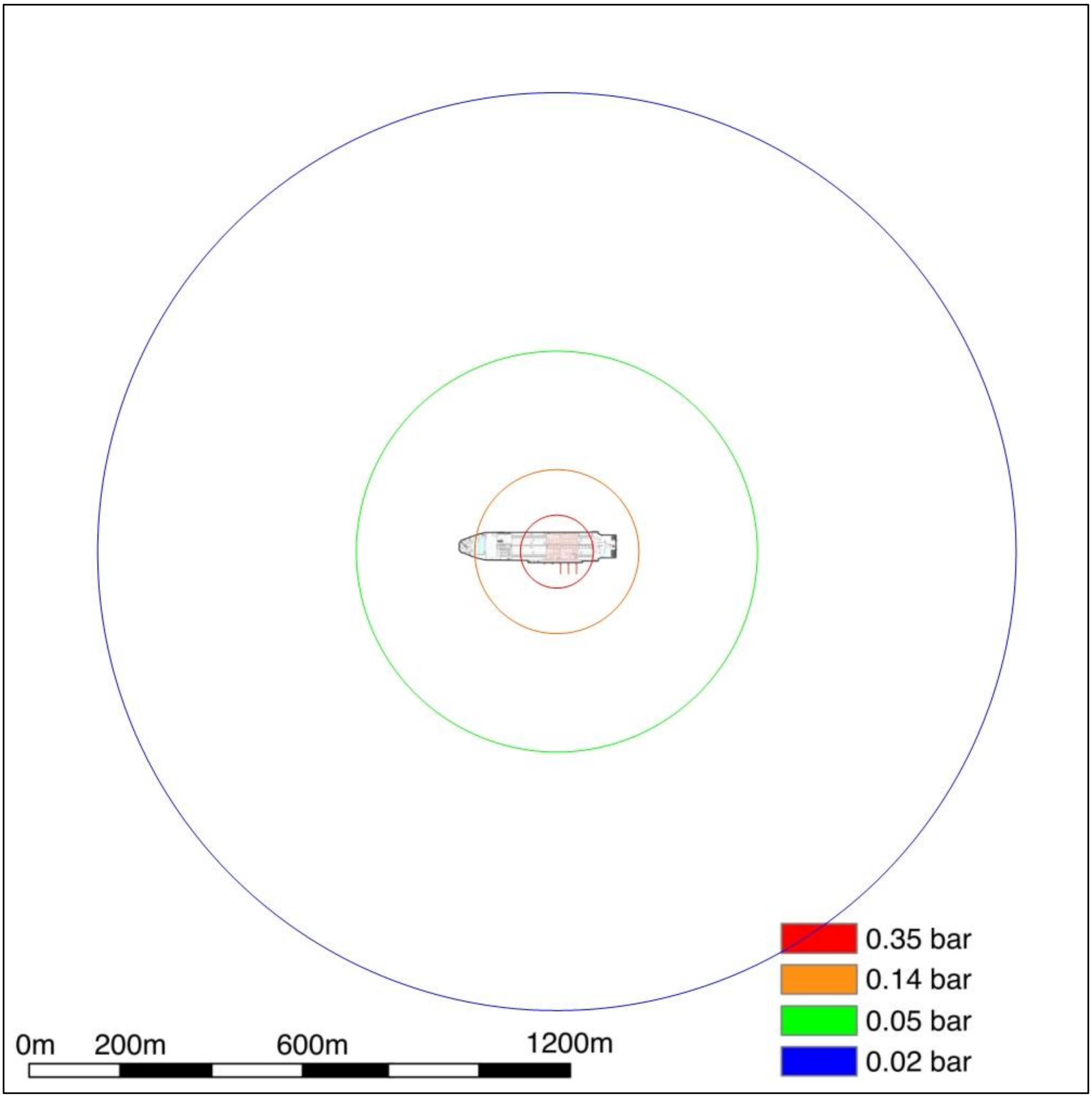


Figure 4-7 MAE F-03 Explosion Contours (scale in m)

4.4. MAE F-04: Liquid Release from Reception Facilities (Slug Catchers)

4.4.1. Event Description

This MAE is for a loss of containment of the liquid side of the slug catchers and associated pipework which is in the reception facilities of the FPSO (Module P3). The section includes the two slug catchers and ends at the ESDVs downstream of the slug catchers.

Modelling of fires and explosions for this MAE has been completed using the input data outlined in the table below and stream conditions taken from the FPSO Major Hazard Inventory (Appendix B.1.2).

Table 4-11 MAE F-04 Stream Parameters

Parameter	Input
Process Unit	Reception Facilities
Assumed Material	Condensate: (mol fraction) Water: 0.23 Propane: 0.34 i-Pentane: 0.02 Benzene: 0.01 Toluene: 0.01 Xylene: 0.01 C6: 0.02 C7: 0.04 C8: 0.05 C9: 0.02 C20: 0.14
Pressure (bara)	93
Temperature (deg C)	1.4
Phase	Liquid
Inventory (kg)	36,807
Outflow Rate for Representative Failure (50mm) (kg/s)	152.9
Estimated Release Duration for Representative (50mm) Failure	1-5mins
Congested Volume (m^3)	21,000

4.4.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) may result in a liquid spray / jet fire for MAE F-04 if the release is directed horizontally into an open space (e.g. outboard of the FPSO). The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-8 and Table 4-13 respectively.

Table 4-12 MAE F-04 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	226	366
	5	197	283
	10	167	201
	20	145	148
5/D	3	195	317
	5	168	246
	10	140	173
	20	120	126

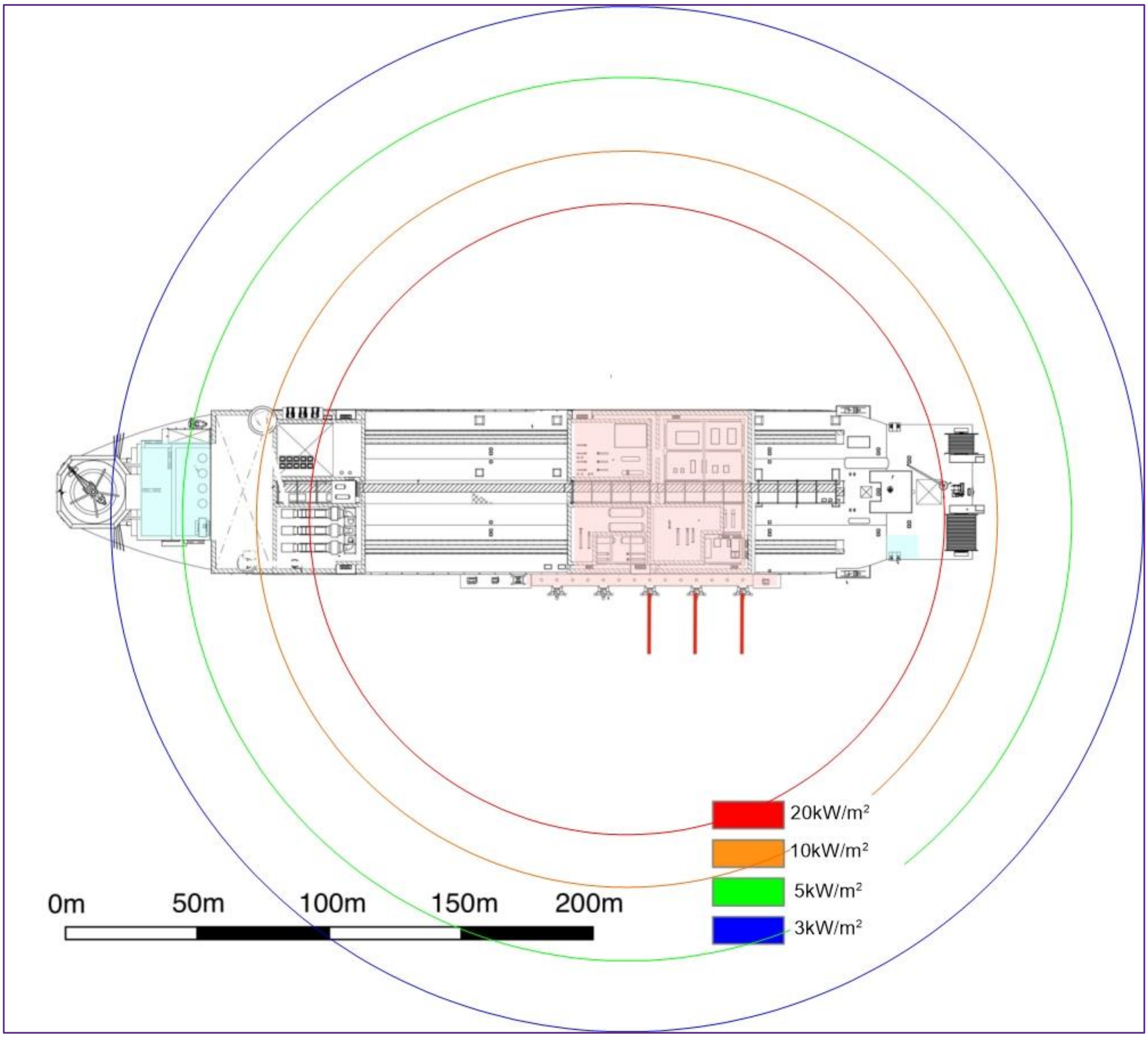


Figure 4-8 MAE F-04 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following loss of containment from a representative failure (50 mm) could also result in a liquid pool fire for MAE F-04 if the release is directed downwards and the momentum removed. The hazard ranges and contour plots due to thermal radiation impact for a pool fire are shown in Table 4-13 and Figure 4-9 respectively.

Table 4-13 MAE F-04 50mm Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	74	114
	5	54	80
	10	30	52
	20	23	46
5/D	3	86	121
	5	67	88
	10	33	57
	20	24	46

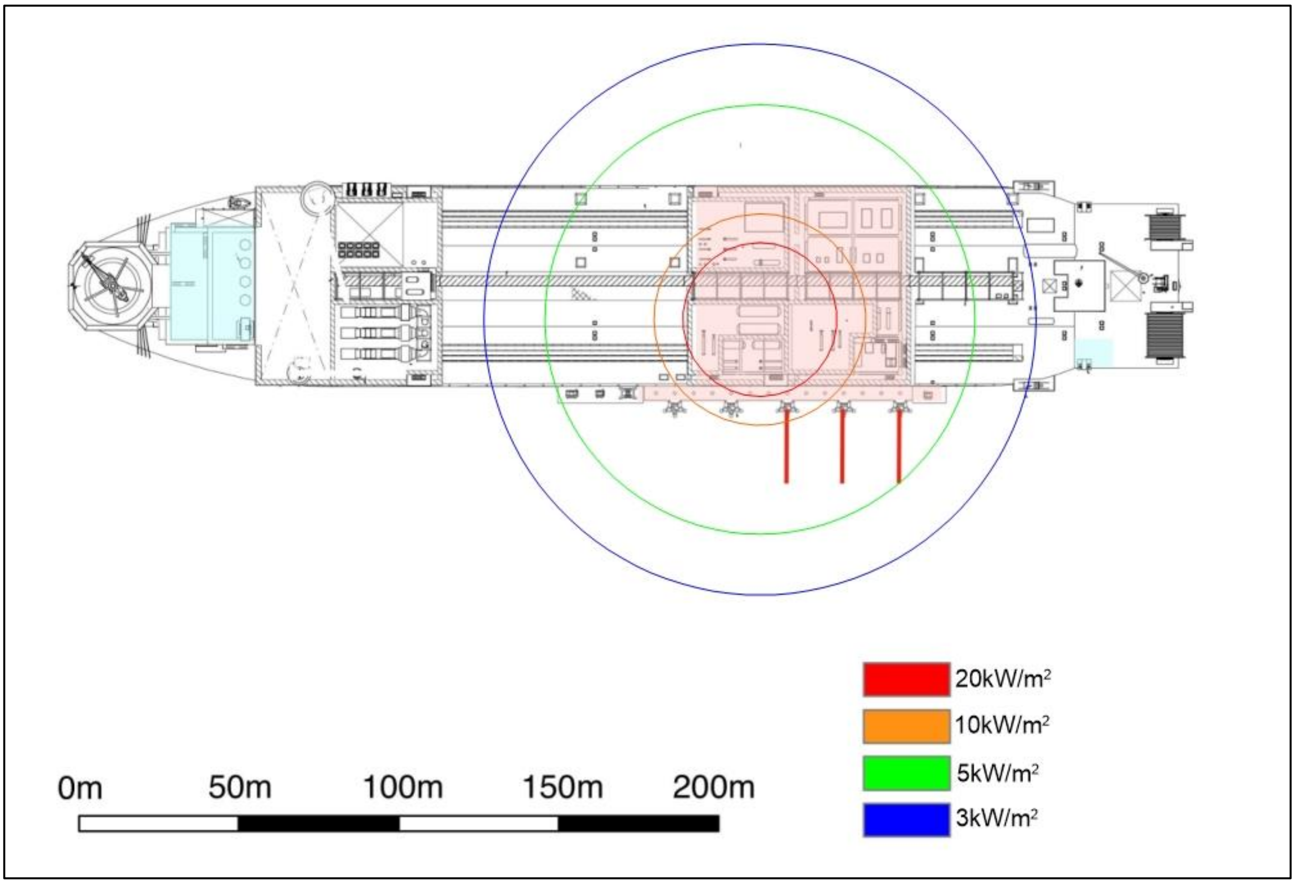


Figure 4-9 MAE F-04 Radiation Contours for Pool Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a liquid pool fire for MAE F-04. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-10 and Table 4-14 below.

Table 4-14 MAE F-04 Catastrophic Failure Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	90	140
	5	65	99
	10	37	66
	20	30	58
5/D	3	105	149
	5	81	109
	10	41	71
	20	30	59

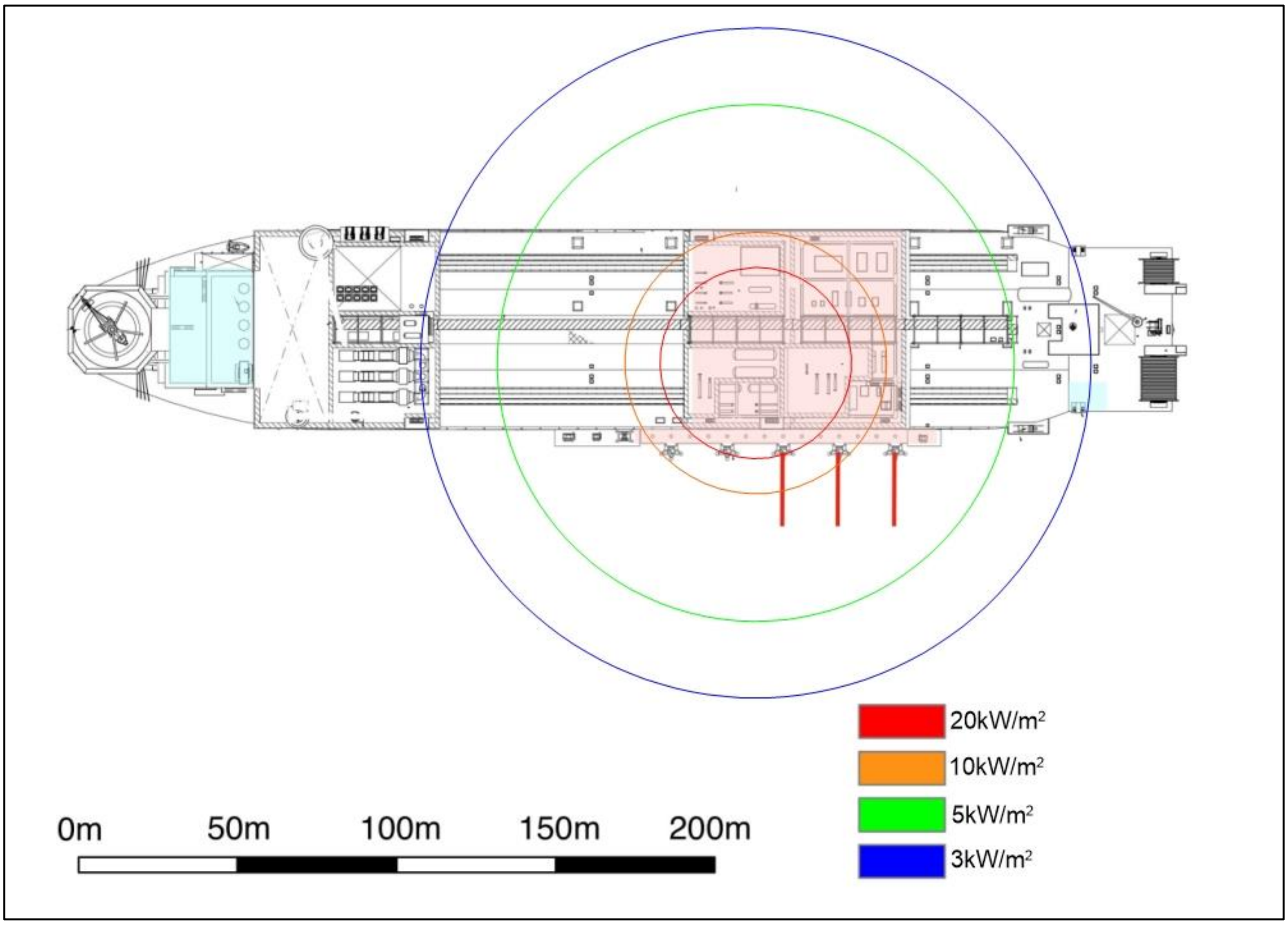


Figure 4-10 MAE F-04 Radiation Contours for Pool Fire from Catastrophic Failure (scale in m)

4.4.3. Explosion Results

Ignition of flammable vapour dispersed into a congested region (the Flash Gas Compression, Inlet Facilities, Condensate and Export Gas Metering and Vapour Recovery modules) following loss of containment for MAE F-04 will result in a vapour cloud explosion. Overpressure results are calculated for a VCE within these modules on the FPSO. The flammable mass involved in the explosion from a representative failure (50 mm) and a catastrophic failure (credible worst case) is limited by the inventory within the section. The contour plot and overpressures associated with an explosion due to vapour released into these modules are shown in Figure 4-11 and Table 4-15 respectively.

Table 4-15 MAE F-04 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1078
0.05	471
0.14	192
0.35	86

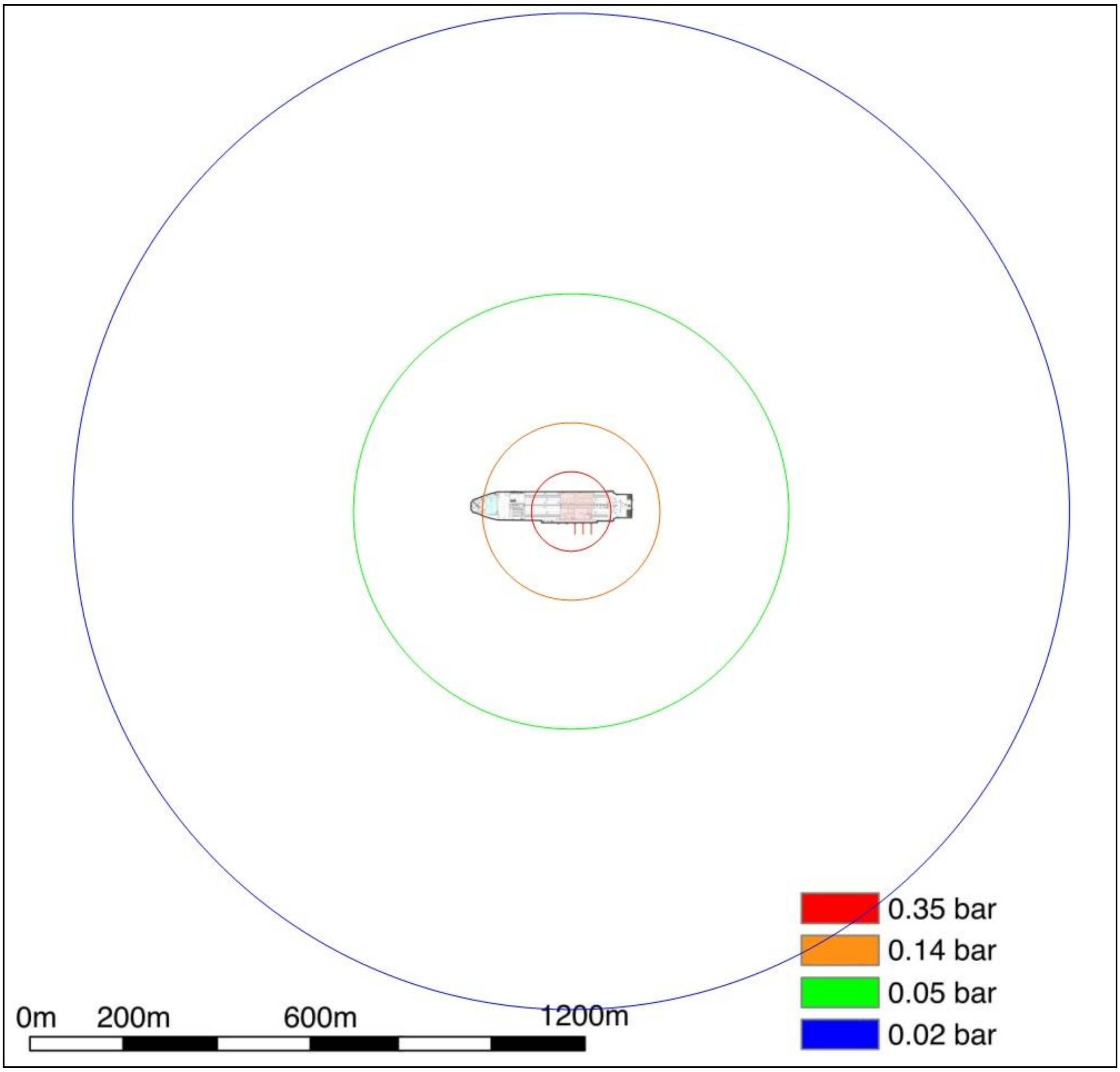


Figure 4-11 MAE F-04 Explosion Contours (scale in m)

4.5. MAE F-05: Gas Release from Gas Processing

4.5.1. Event Description

This MAE is for a loss of containment of the gas processing and metering unit, downstream of the slug catchers and upstream of the gas export riser ESDV (assuming no gas export compression). The section includes the following major equipment items:

- Expander Scrubber
- Turbo Expander
- Low Temperature Scrubber
- Gas Metering

Modelling of fires and explosions for this MAE has been completed using the input data outlined in the table below and stream conditions taken from the FPSO Major Hazard Inventory (Appendix B.1.2).

Table 4-16 MAE F-05 Stream Parameters

Parameter	Input
Process Unit	Gas Treatment and Metering
Assumed Material	Methane
Pressure (bara)	91
Temperature (deg C)	15
Phase	Gas
Inventory (kg)	3,063
Outflow Rate for Representative Failure (50mm) (kg/s)	30.1
Estimated Release Duration for Representative (50mm) Failure	1-5mins
Congested Volume (m^3)	21,000

4.5.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE F-05. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-12 and Table 4-17 respectively.

Table 4-17 MAE F-05 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	104	152
	5	90	118
	10	76	83
	20	65	57
5/D	3	102	152
	5	91	118
	10	78	83
	20	69	57

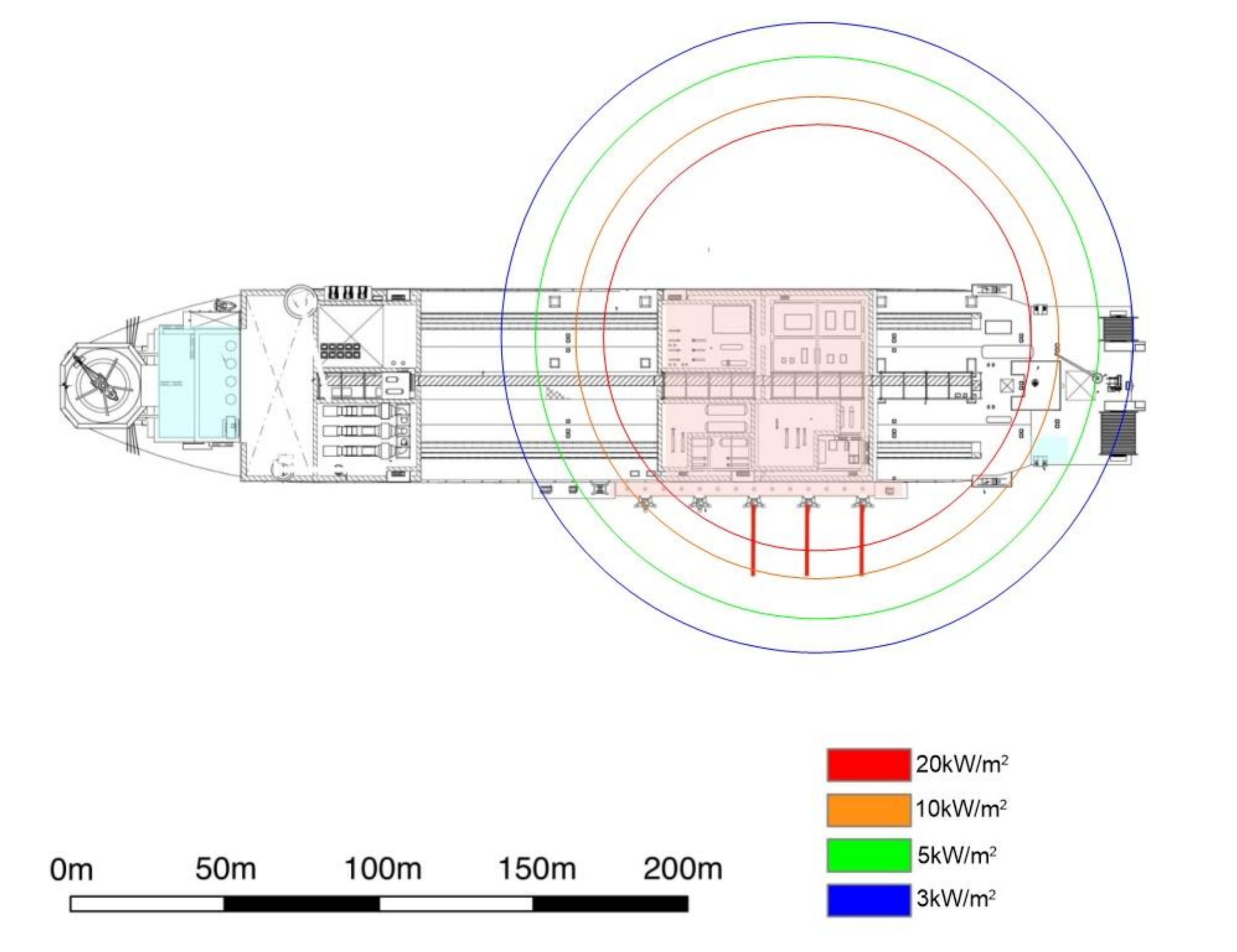
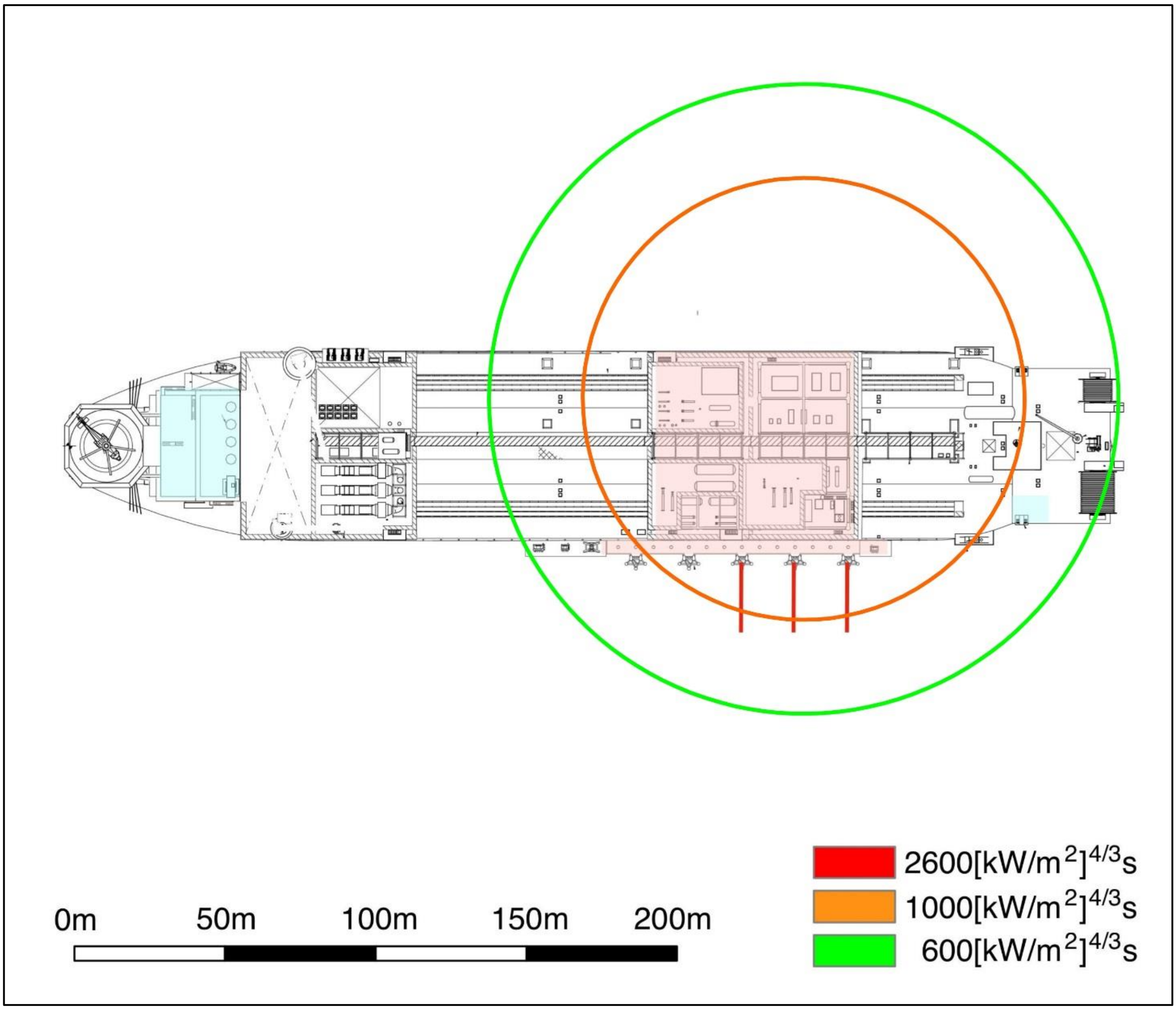


Figure 4-12 MAE F-05 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE F-05. The contour plot hazard ranges due to the thermal dose from the fireball are shown in Figure 4-13 and Table 4-18 shows the hazards ranges.

Table 4-18 MAE F-05 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ($[kW/m^2]^{4/3}$ s)	Distance from Release Point (m)
44	600	104
	1000	73
	2600	Not Reached



NOTE: The higher thermal dose level was not reached.

Figure 4-13 MAE F-05 Fireball Contour for Catastrophic Failure (scale in m)

4.5.3. Explosion Results

Ignition of flammable gas dispersed into a congested region (the Flash Gas Compression, Inlet Facilities, Condensate and Export Gas Metering and Vapour Recovery modules) following loss of containment for MAE F-05 will result in a vapour cloud explosion. Overpressure results are calculated for a VCE within these modules on the FPSO. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) is able to completely fill these modules. The contour plot and overpressures from this explosion is shown in Figure 4-14 and Table 4-19 respectively.

Table 4-19 MAE F-05 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1019
0.05	445
0.14	182
0.35	81

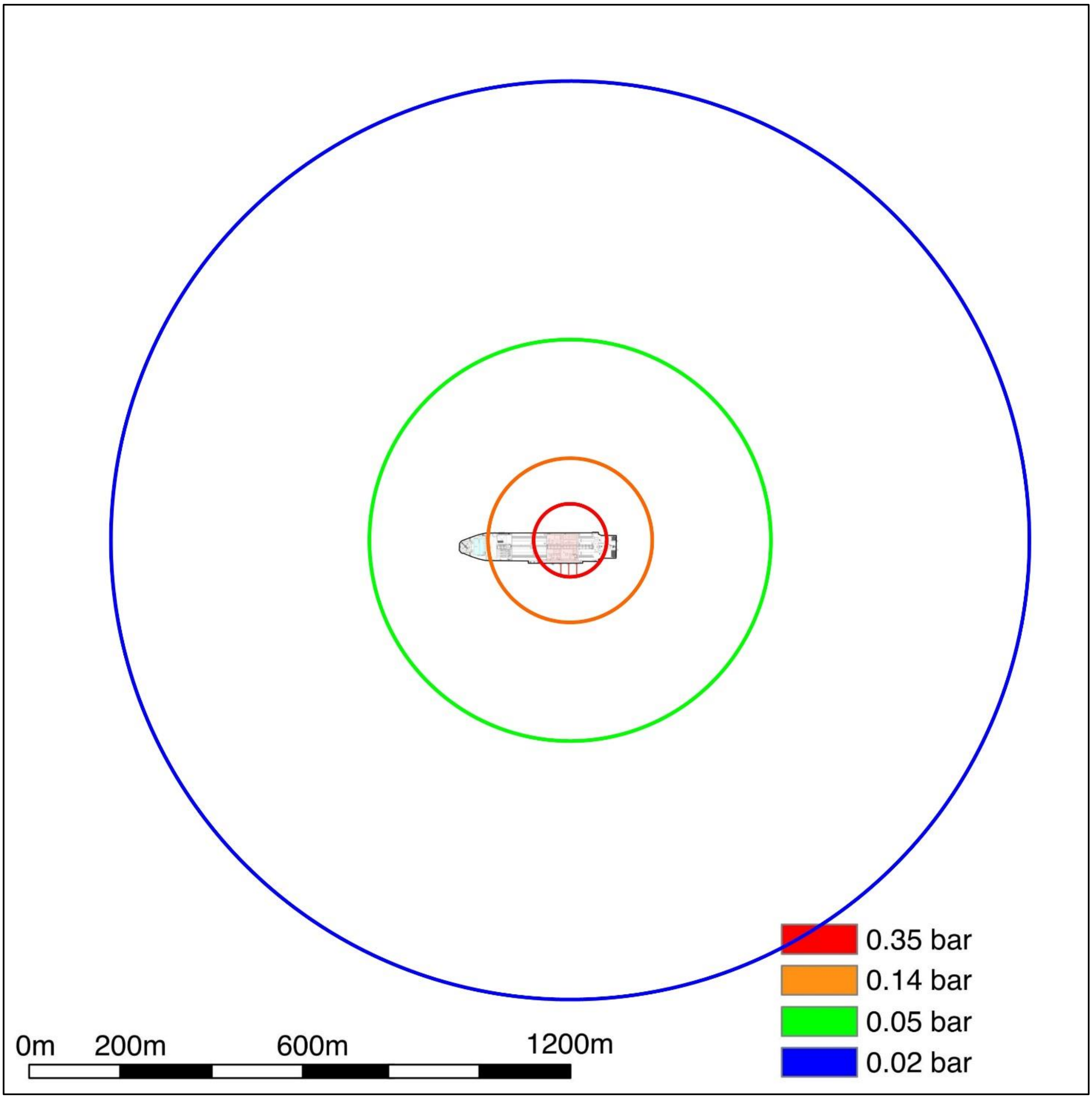


Figure 4-14 MAE F-05 Explosion Contours (scale in m)

4.6. MAE F-06: Liquid Release from Gas Processing

4.6.1. Event Description

This MAE is for a loss of containment of the liquid side of the gas processing unit – i.e. on the liquid side of the Expander Scrubber.

Modelling of fires and explosions for this MAE has been completed using the input data outlined in the table below and stream conditions taken from the FPSO Major Hazard Inventory (Appendix B.1.2).

Table 4-20 MAE F-06 Stream Parameters

Parameter	Input
MAR Inventory	Gas Treatment (Liquid)
Process Unit	Gas Treatment
Assumed Material	Condensate: (mol fraction) Water: 0.23 Propane: 0.34 i-Pentane: 0.02 Benzene: 0.01 Toluene: 0.01 Xylene: 0.01 C6: 0.02 C7: 0.04 C8: 0.05 C9: 0.02 C20: 0.14
Pressure (bara)	91
Temperature (deg C)	-3.5
Phase	Liquid
Inventory (kg)	1,384
Outflow Rate for Representative Failure (50mm) (kg/s)	138.9
Estimated Release Duration for Representative (50mm) Failure	<1min
Congested Volume (m^3)	21,000

4.6.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) may result in a liquid spray / jet fire for MAE F-06 if the release is directed horizontally into an open space (e.g. outboard of the FPSO). The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-15 and Table 4-22 respectively. A spray fire would be a short duration event as the time to release the liquid inventory within the expander scrubber is limited (<10 seconds). However, the spray fire would be followed by a gas jet fire due to follow-through of the gas inventory of the expander scrubber and connecting pipework and equipment (see MAE F-05).

Table 4-21 MAE F-06 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	211	337
	5	180	263
	10	146	184
	20	117	124
5/D	3	179	341
	5	161	267
	10	143	189
	20	130	130

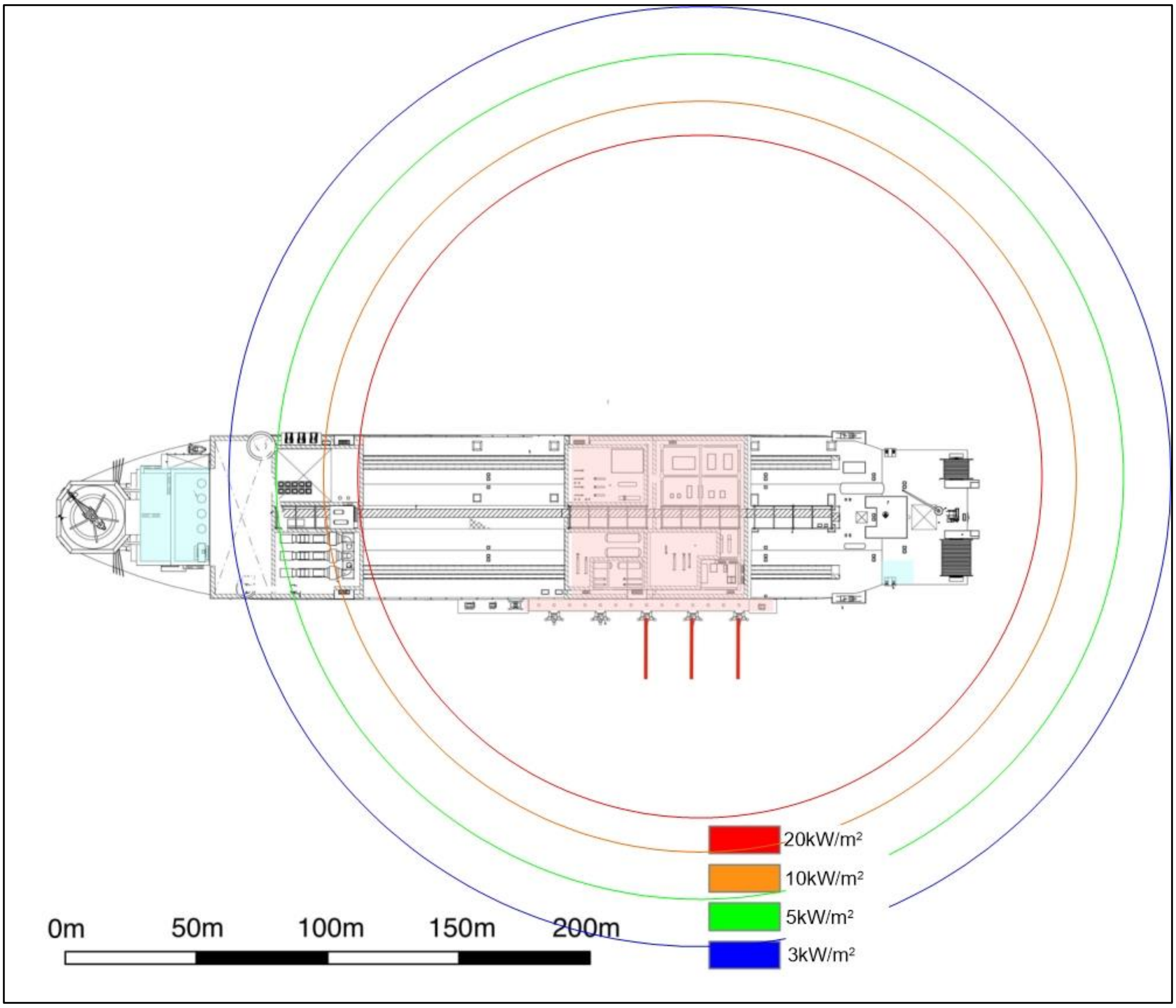


Figure 4-15 MAE F-06 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following loss of containment from a representative failure (50 mm) could also result in a liquid pool fire for MAE F-06 if the release is directed downwards and the momentum removed. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-16 and Table 4-22 respectively.

Table 4-22 MAE F-06 50mm Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	39	60
	5	31	43
	10	19	27
	20	10	18
5/D	3	42	61
	5	35	46
	10	24	29
	20	12	19

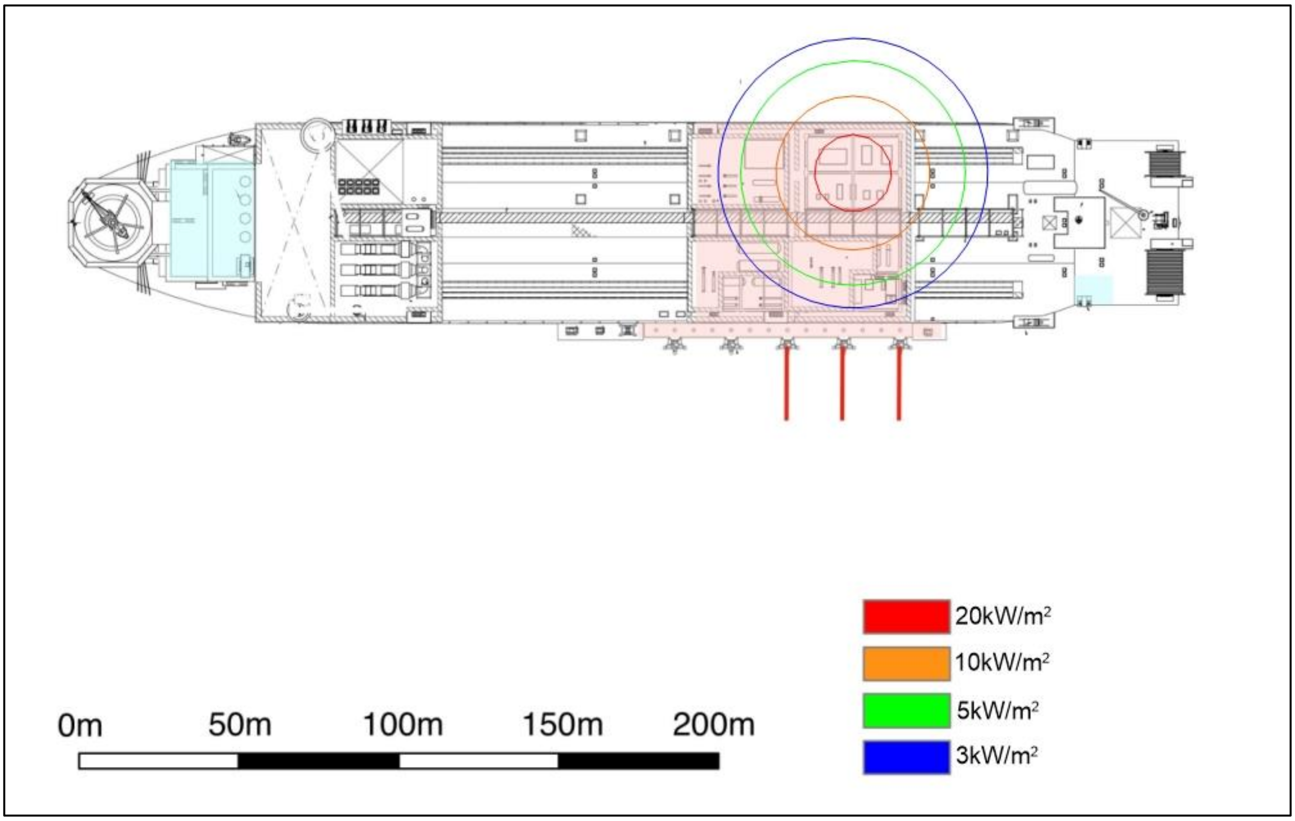


Figure 4-16 MAE F-06 Radiation Contours for Pool Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a liquid pool fire for MAE F-06. The liquid inventory for this failure case is limited to 1,384kg, which is the volume of the liquid side of the Expander Scrubber. A catastrophic failure (credible worst case) is modelled as a release of the liquid inventory within 60 seconds (as per Section 3.2), however, due to the small liquid inventory the release rate is smaller than the representative failure (50mm). Pool fire hazard ranges for a catastrophic failure should therefore be represented by Figure 4-16 and Table 4-22.

4.6.3. Explosion Results

Ignition of flammable gas dispersed into a congested region (Flash Gas Compression, Inlet Facilities, Condensate and Export Gas Metering and Vapour Recovery modules) following loss of containment for MAE F-06 will result in a vapour cloud explosion. Overpressure results are calculated for a VCE within these modules on the FPSO. The flammable mass involved in the explosion from a representative failure (50 mm) and a catastrophic failure (credible worst case) is limited to the total flammable inventory within the section. The contour plot and overpressures associated with this explosion are shown in Figure 4-17 and Table 4-23 respectively.

Table 4-23 MAE F-06 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	973
0.05	425
0.14	174
0.35	77

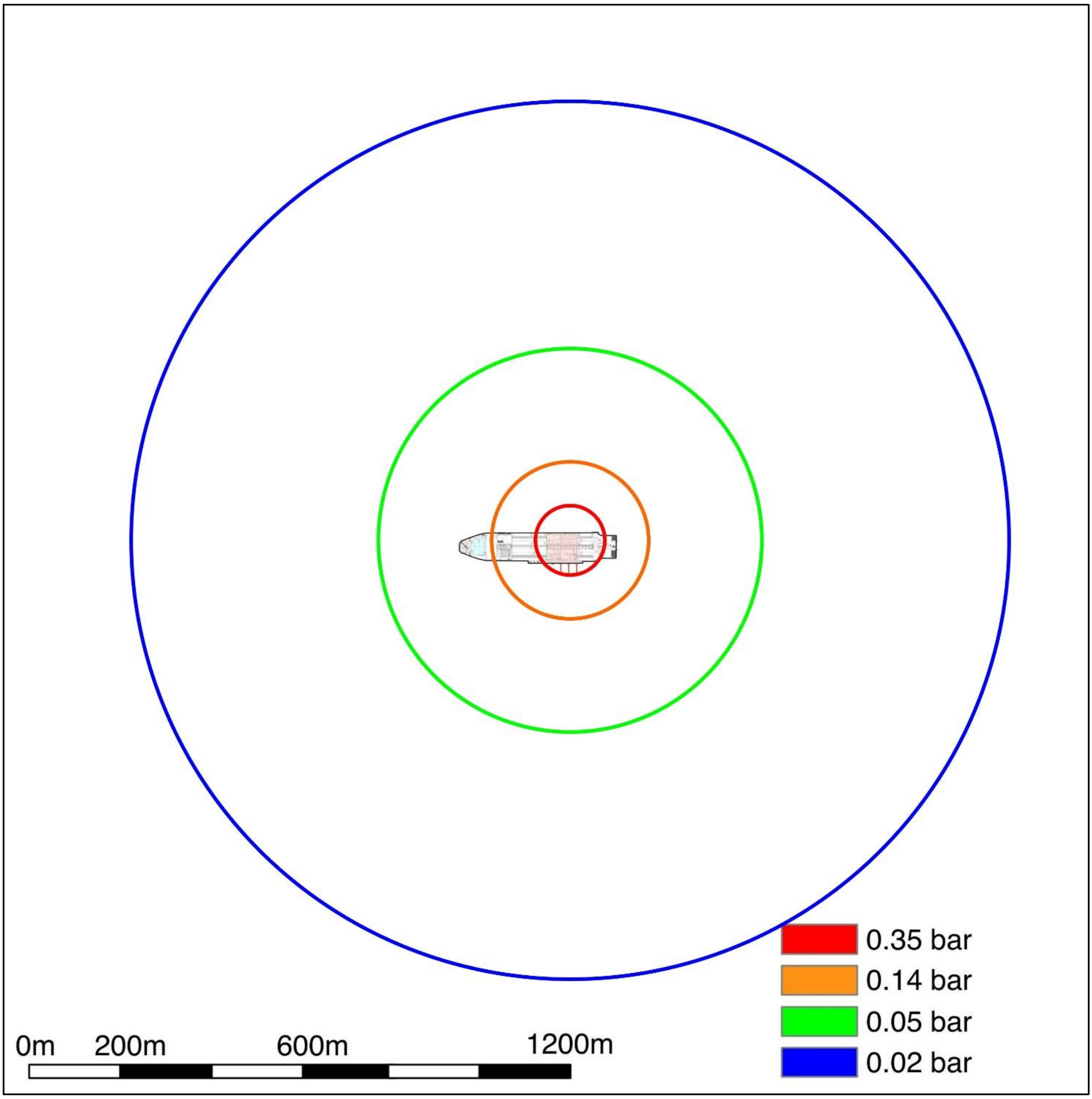


Figure 4-17 MAE F-06 Explosion Contours (scale in m)

4.7. MAE F-07: Liquid Release from MP Separator

4.7.1. Event Description

This MAE is for a loss of containment of the liquid side MP separator which is downstream of the expander scrubber and the two slug catchers. Modelling of fires and explosions for this MAE has been completed using the input data outlined in the table below and stream conditions taken from the FPSO Major Hazard Inventory (Appendix B.1.2).

Table 4-24 MAE F-07 Stream Parameters

Parameter	Input
Process Unit	Condensate Separation
Assumed Material	Condensate: (mol fraction) Water: 0.07 Propane: 0.26 i-Pentane: 0.04 Benzene: 0.03 Toluene: 0.02 Xylene: 0.02 C6: 0.04 C7: 0.07 C8: 0.10 C9: 0.04 C20: 0.27
Pressure (bara)	40
Temperature (deg C)	45
Phase	Liquid
Inventory (kg)	23,906
Outflow Rate for Representative Failure (50mm) (kg/s)	100.1
Estimated Release Duration for Representative (50mm) Failure	5-15mins
Congested Volume (m^3)	21,000

4.7.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) may result in a liquid spray / jet fire for MAE F-07 if the release is directed horizontally into an open and uncongested space, e.g. outboard of the FPSO. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-18 and Table 4-25 respectively.

Table 4-25 MAE F-07 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	165	269
	5	143	208
	10	120	147
	20	104	107
5/D	3	143	235
	5	123	182
	10	102	128
	20	87	92

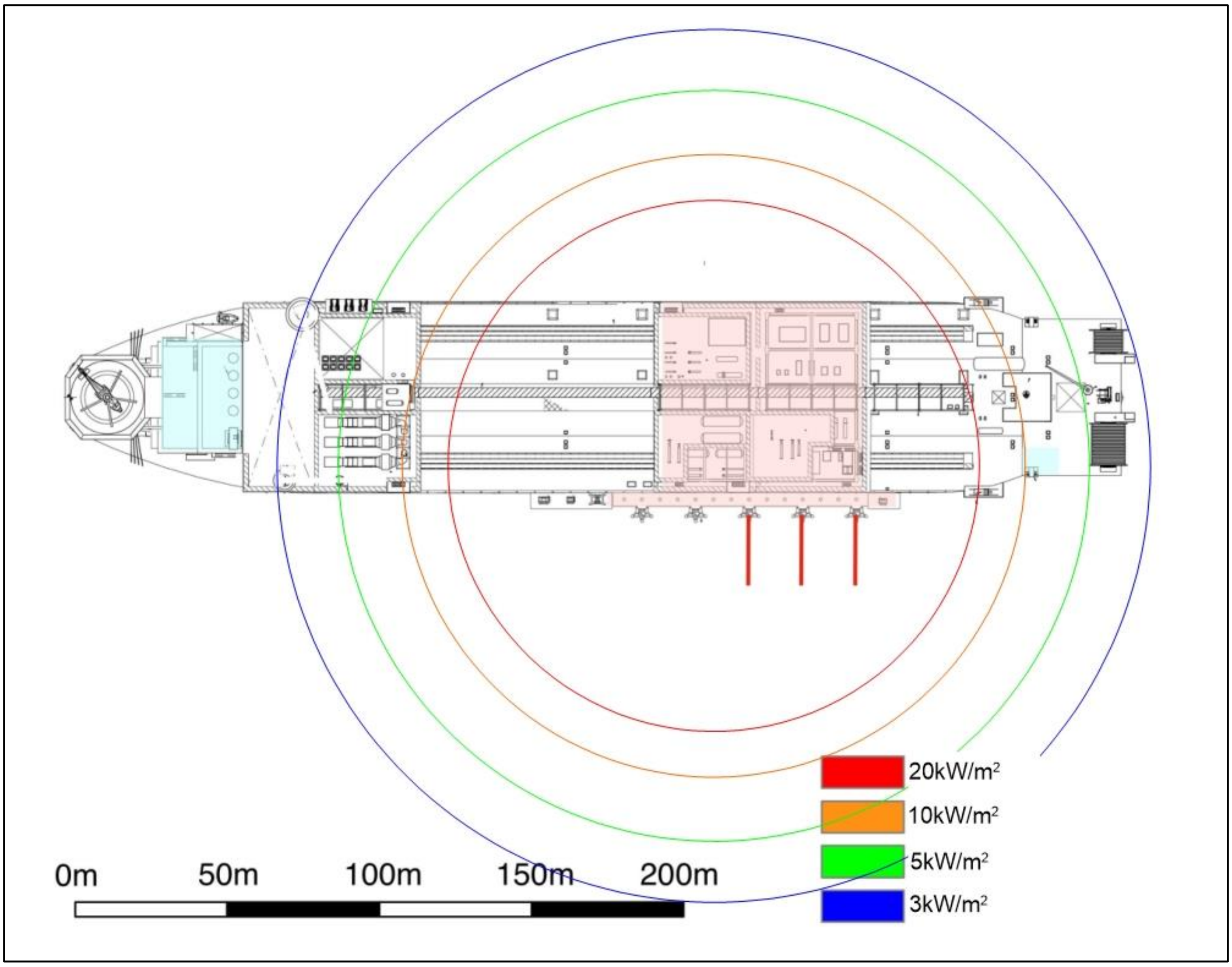


Figure 4-18 MAE F-07 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following loss of containment from a representative failure (50 mm) may also result in a liquid pool fire for MAE F-07 if the release is directed downwards and the momentum of the released fluid is removed. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-19 and Table 4-26 respectively.

Table 4-26 MAE F-07 50mm Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	58	84
	5	42	58
	10	22	36
	20	14	27
5/D	3	69	89
	5	54	63
	10	26	39
	20	15	29

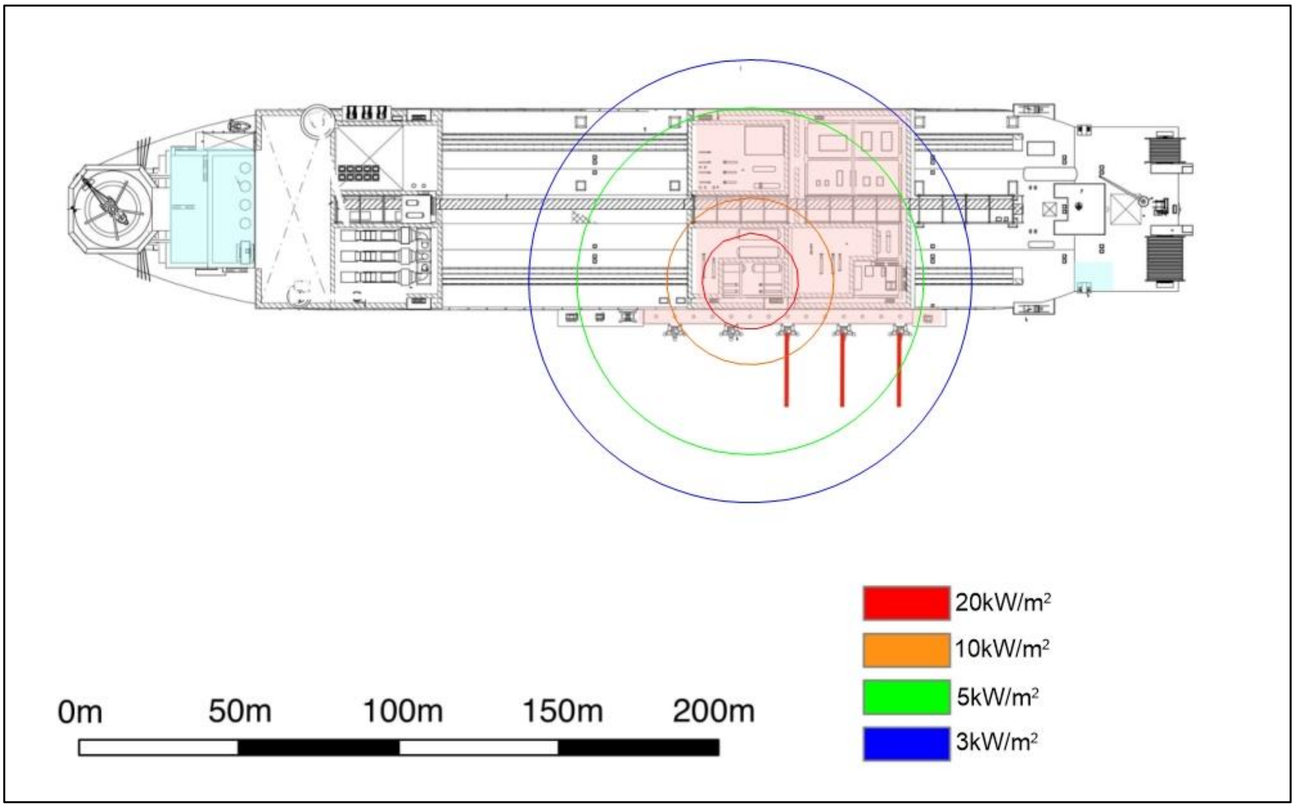


Figure 4-19 MAE F-07 Radiation Contours for Pool Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a liquid pool fire for MAE F-07. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-20 and Table 4-27 respectively.

Table 4-27 MAE F-07 Catastrophic Failure Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	97	145
	5	66	100
	10	37	63
	20	30	58
5/D	3	117	156
	5	84	110
	10	41	71
	20	30	59

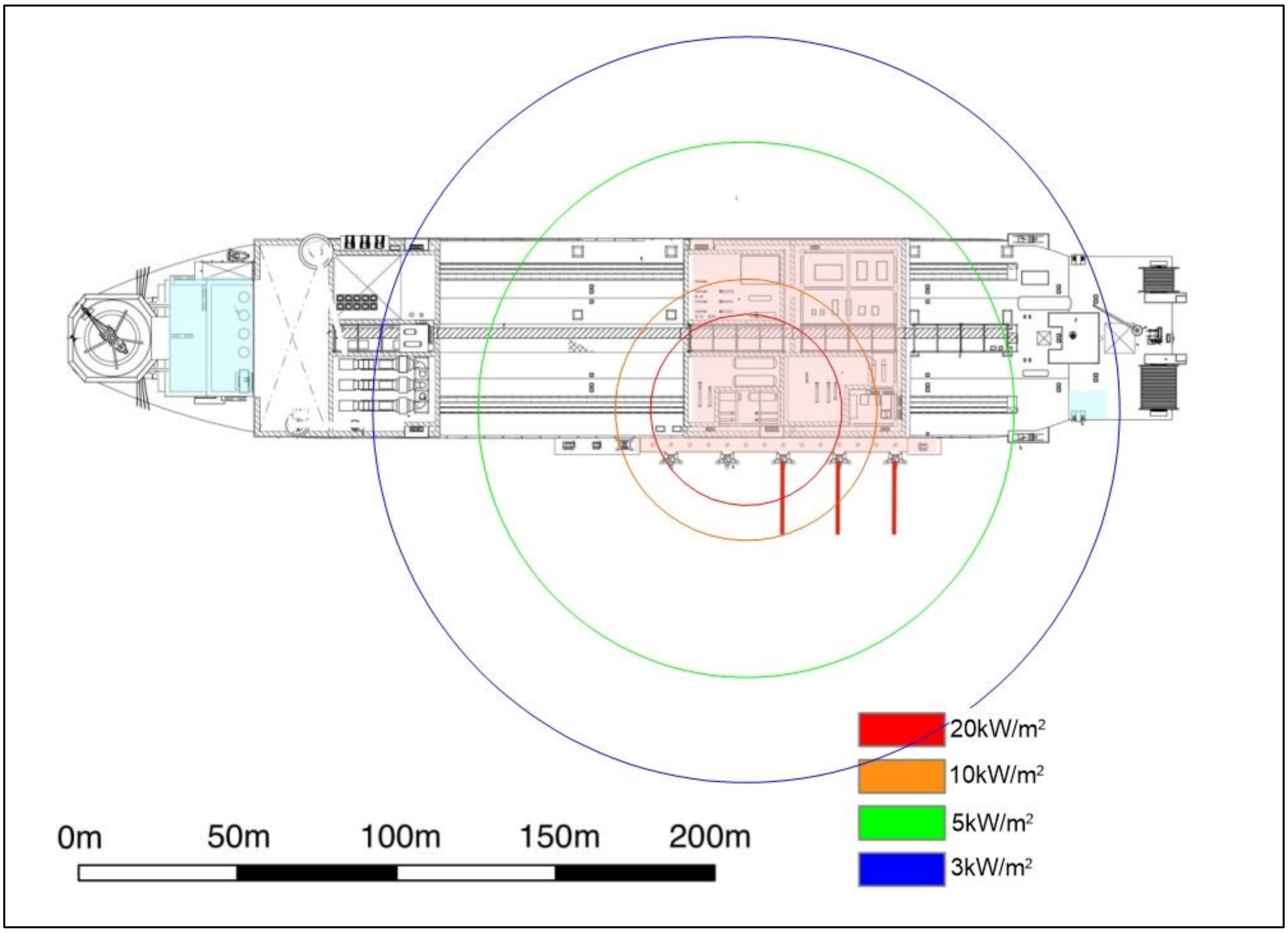


Figure 4-20 MAE F-07 Radiation Contours for Pool Fire from Catastrophic Failure (scale in m)

4.7.3. Explosion Results

Ignition of flammable gas dispersed into a congested region (Flash Gas Compression, Inlet Facilities, Condensate and Export Gas Metering and Vapour Recovery modules) following loss of containment for MAE F-07 will result in a vapour cloud explosion. Overpressure results are calculated for a VCE within these modules on the FPSO. The flammable mass involved in the explosion from a representative failure (50 mm) and a catastrophic failure (credible worst case) is limited to the total flammable inventory within the section. The contour plot and overpressures are shown in Figure 4-25 and Table 4-33 respectively.

Table 4-28 MAE F-07 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1123
0.05	491
0.14	200
0.35	89

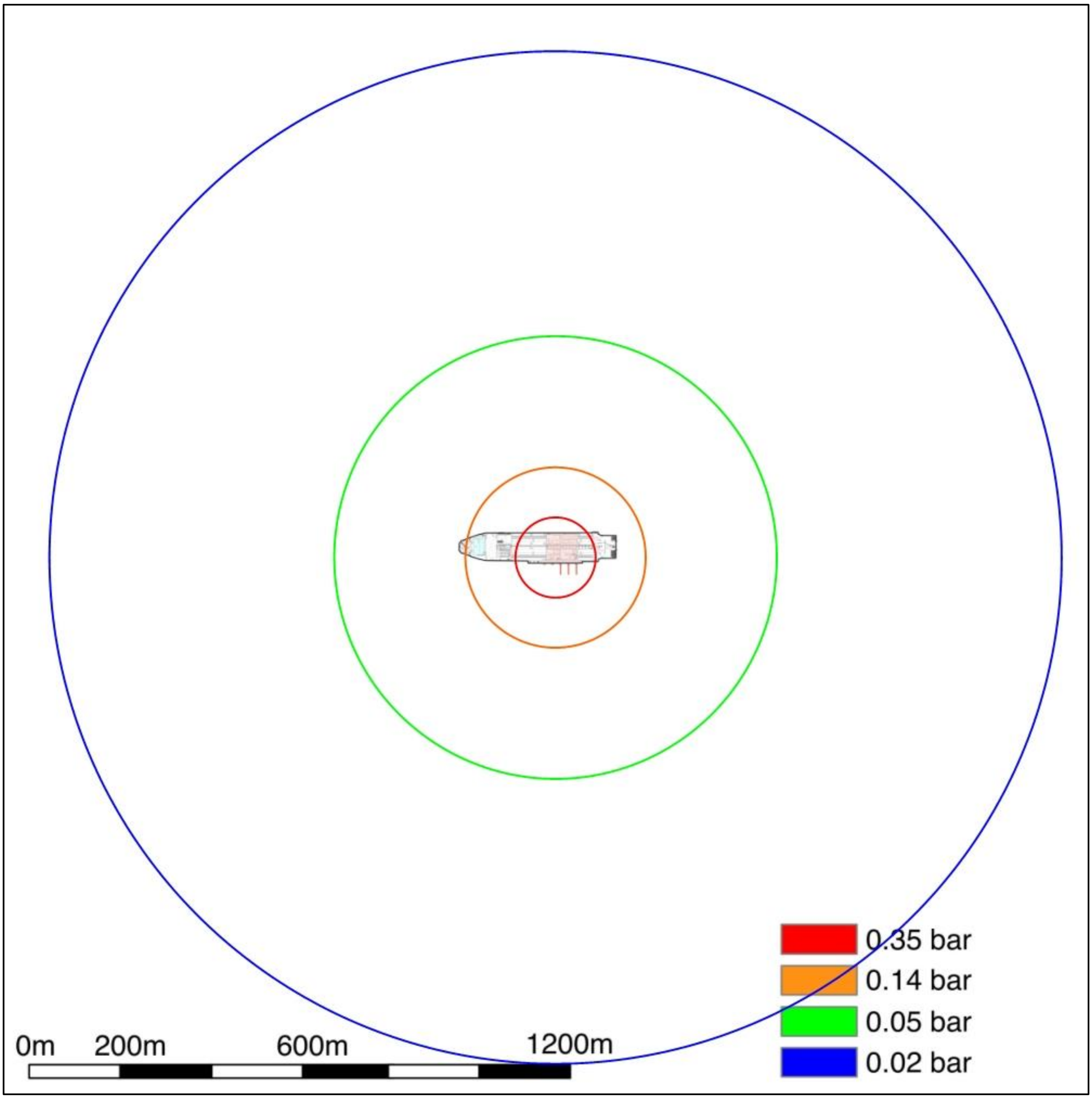


Figure 4-21 MAE F-07 Explosion Contours (scale in m)

4.8. MAE F-08: Liquid Release from LP Separator

4.8.1. Event Description

This MAE is for a loss of containment of the liquid side LP separator which is downstream of the MP separator. Modelling of fires and flammable gas dispersion for this MAE has been completed using the input data outlined in the table below and stream conditions taken from the FPSO Major Hazard Inventory (Appendix B.1.2).

Table 4-29 MAE F-08 Stream Parameters

Parameter	Input
Process Unit	Condensate Separation
Assumed Material	Condensate: (mol fraction) Water: 0.04 Propane: 0.19 i-Pentane: 0.05 Benzene: 0.04 Toluene: 0.02 Xylene: 0.03 C6: 0.05 C7: 0.09 C8: 0.11 C9: 0.04 C20: 0.32
Pressure (bara)	12
Temperature (deg C)	45
Phase	Liquid
Inventory (kg)	14,417
Outflow Rate for Representative Failure (50mm) (kg/s)	53.5
Estimated Release Duration for Representative (50mm) Failure	5-15mins
Congested Volume (m^3)	-

4.8.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) may result in a liquid jet / spray fire for MAE F-08 if the release is directed horizontally into open or uncongested space. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-22 and Table 4-30 respectively.

Table 4-30 MAE F-08 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	138	227
	5	119	175
	10	99	123
	20	84	89
5/D	3	119	196
	5	101	152
	10	83	106
	20	70	76

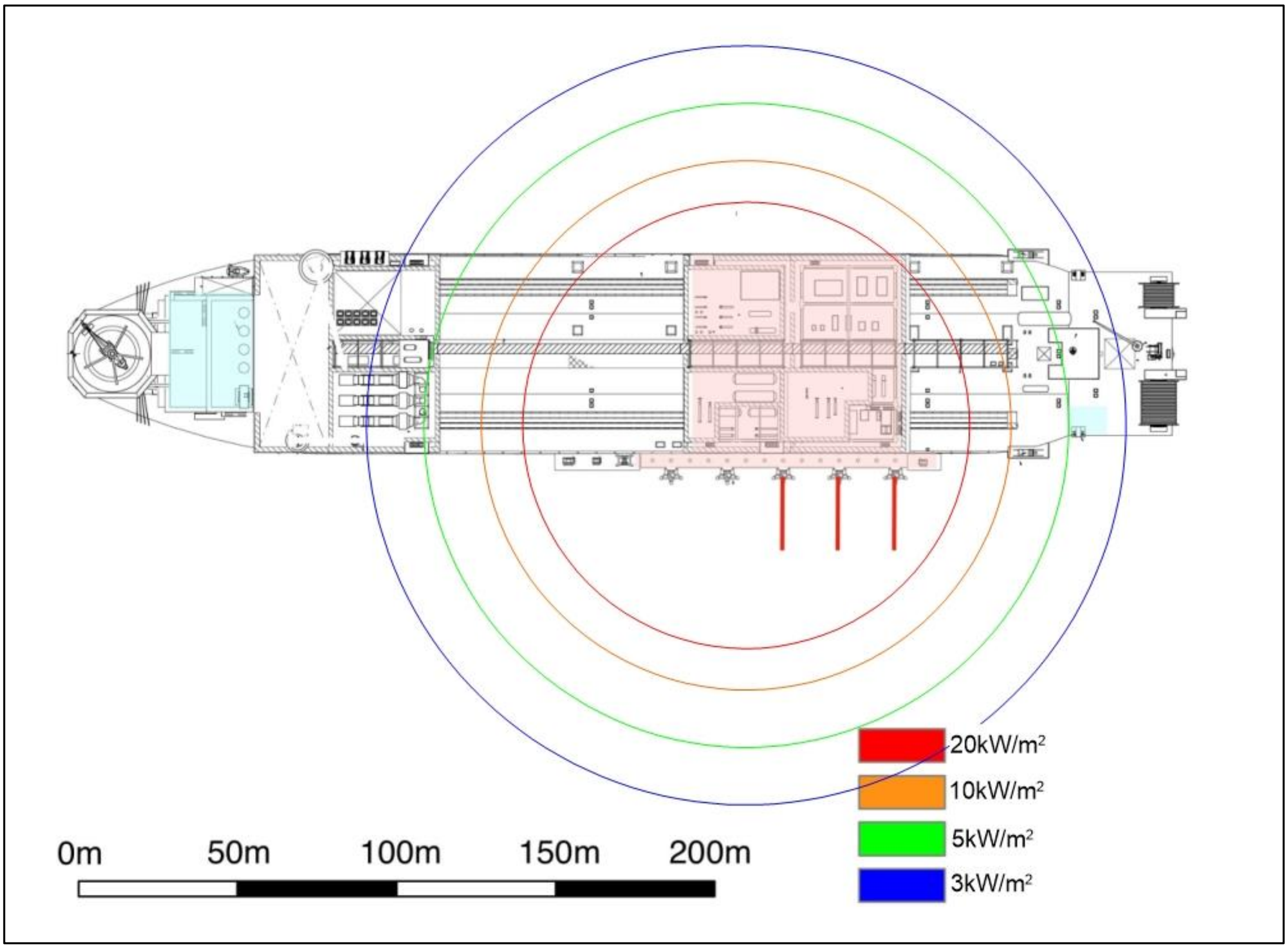


Figure 4-22 MAE F-08 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following loss of containment from a representative failure (50 mm) may also result in a liquid pool fire for MAE F-08 if the release is directed downwards and the momentum removed. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-23 and Table 4-31 respectively.

Table 4-31 MAE F-08 50mm Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	54	77
	5	40	53
	10	22	32
	20	12	22
5/D	3	61	80
	5	50	58
	10	27	35
	20	13	23

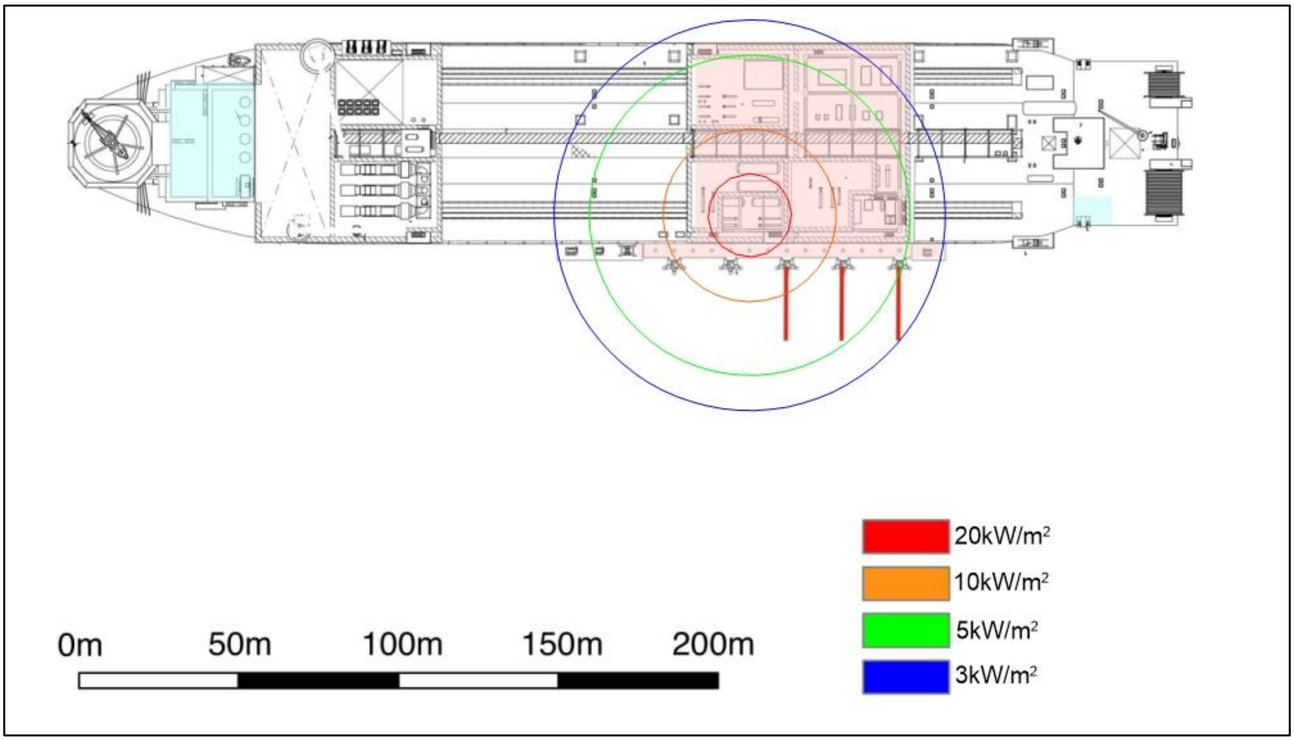


Figure 4-23 MAE F-08 Radiation Contours for Pool Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a liquid pool fire for MAE F-08. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-24 and Table 4-32 respectively.

Table 4-32 MAE F-08 Catastrophic Failure Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	89	131
	5	60	90
	10	33	59
	20	26	52
5/D	3	110	142
	5	76	99
	10	37	63
	20	27	52

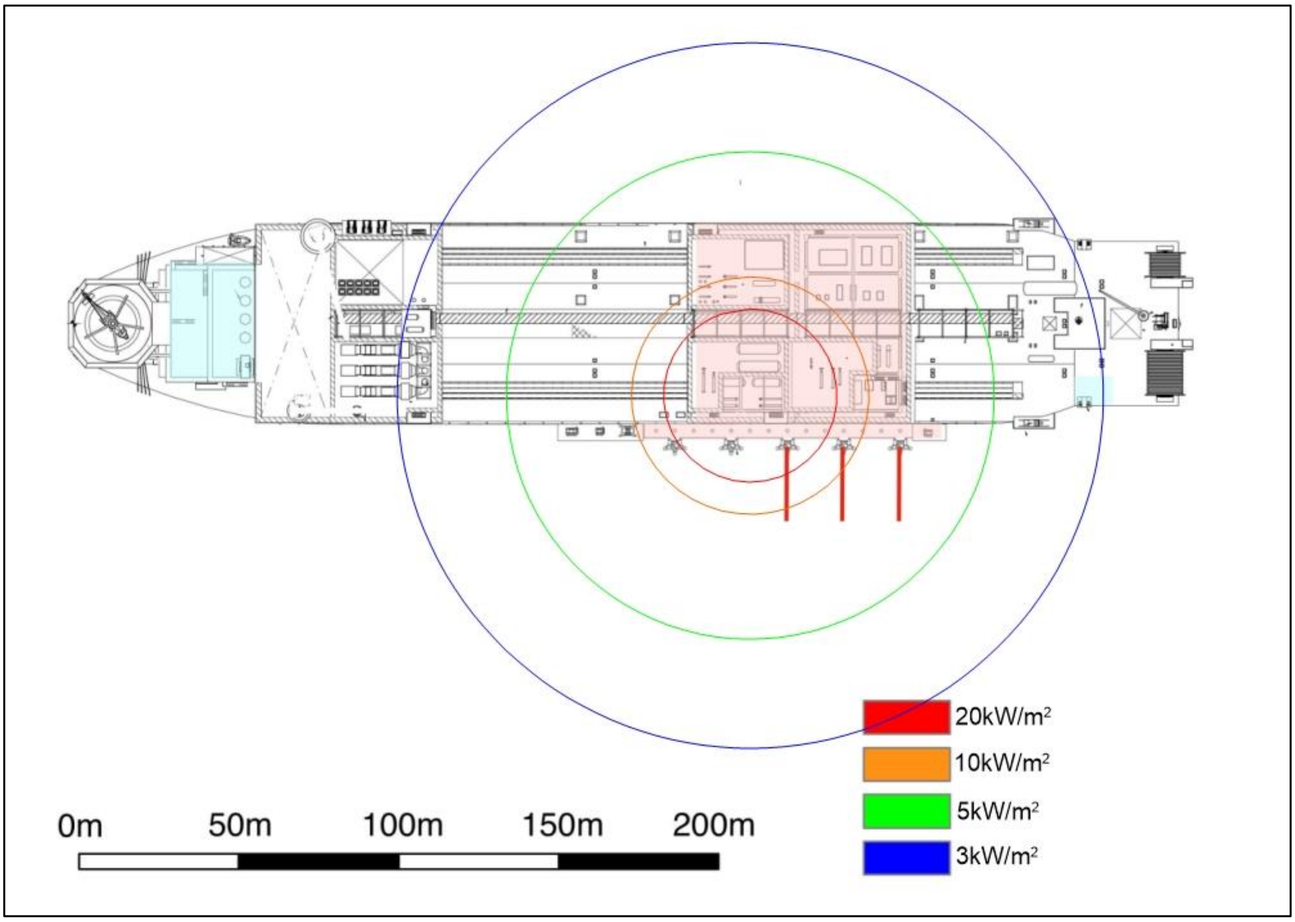


Figure 4-24 MAE F-08 Radiation Contours for Pool Fire from Catastrophic Failure (scale in m)

4.8.3. Explosion Results

Ignition of flammable vapour dispersed into a congested region (Flash Gas Compression, Inlet Facilities, Condensate and Export Gas Metering and Vapour Recovery modules) following loss of containment for MAE F-08 will result in a vapour cloud explosion. Overpressure results are calculated for a VCE within these modules on the FPSO. The flammable mass involved in the explosion from a representative failure (50 mm) and a catastrophic failure (credible worst case) is limited to the total flammable inventory within the section. The contour plot and overpressures are shown in Figure 4-25 and Table 4-33 respectively.

Table 4-33 MAE F-08 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1154
0.05	504
0.14	206
0.35	92

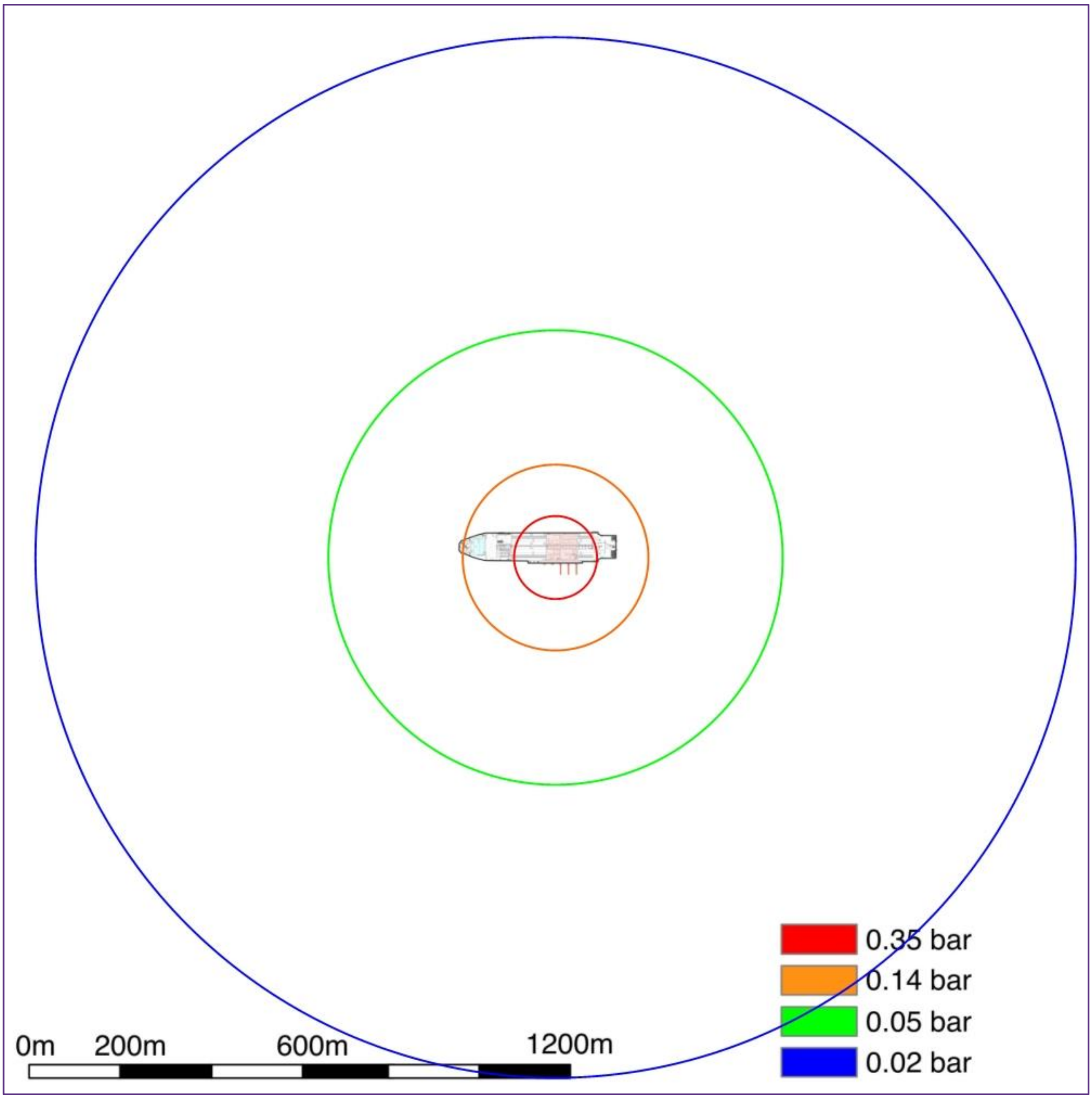


Figure 4-25 MAE F-08 Explosion Contours (scale in m)

4.9. MAE F-09: Liquid Release from LLP Separator

4.9.1. Event Description

This MAE is located on the FPSO downstream of the LLP Separator, leading to the MEG Regeneration and Storage and Condensate Storage.

The stream conditions for this MAE was obtained from the FPSO Major Hazard Inventory (Appendix B.1.2), and are shown below.

Table 4-34 MAE F-09 Stream Parameters

Parameter	Input
MAR Inventory	Condensate Separation - LLP (Liquid)
Process Unit	Condensate Separation
Assumed Material	Condensate: (mol fraction) Water: 0.02 Propane: 0.06 i-Pentane: 0.05 Benzene: 0.04 Toluene: 0.02 Xylene: 0.03 C6: 0.05 C7: 0.11 C8: 0.14 C9: 0.05 C20: 0.40
Pressure (bara)	1.6
Temperature (deg C)	65
Phase	Liquid
Inventory (kg)	20,267
Outflow Rate for Representative Failure (50mm) (kg/s)	12.5
Estimated Release Duration for Representative (50mm) Failure	15-30mins
Congested Volume (m^3)	-

4.9.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a liquid pool fire for MAE F-09. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-26 and Table 4-35 respectively.

Table 4-35 MAE F-09 50mm Pool Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	42	64
	5	34	47
	10	22	29
	20	12	18
5/D	3	46	65
	5	38	49
	10	29	31
	20	15	19

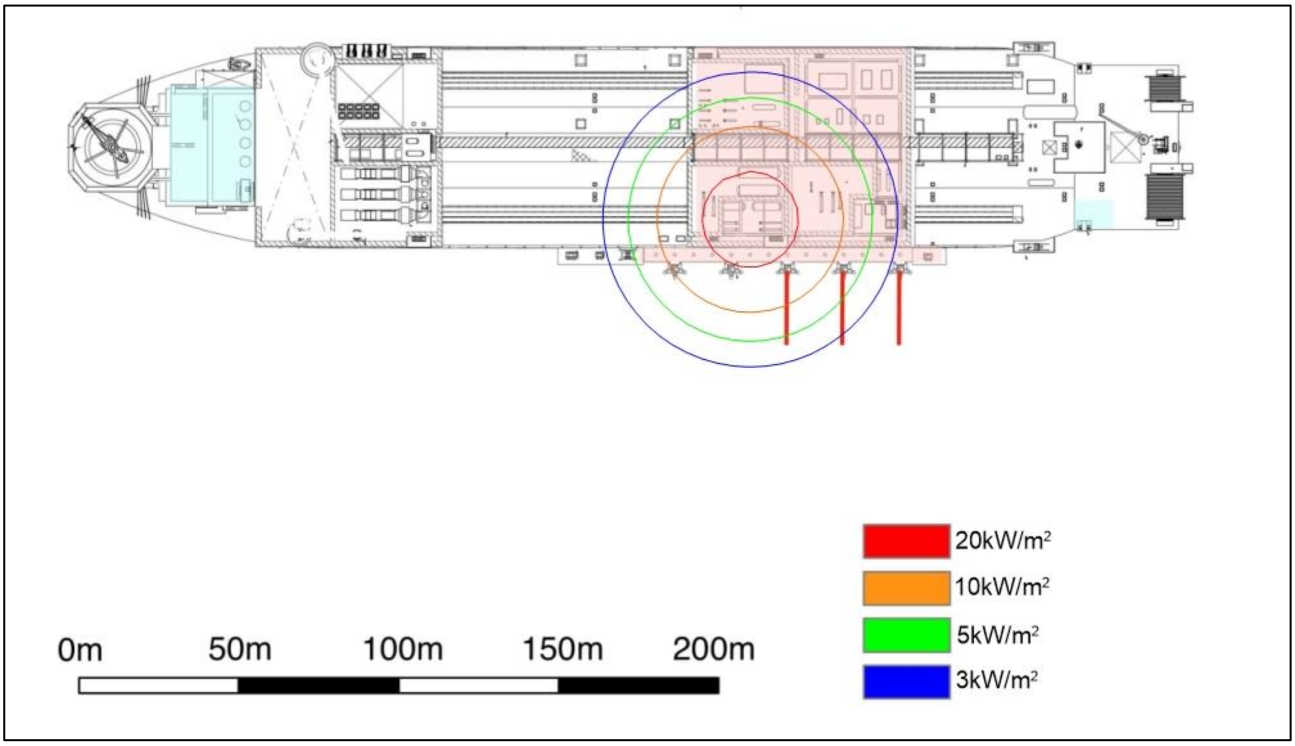


Figure 4-26 MAE F-09 Radiation Extent for Pool Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a liquid pool fire for MAE F-09. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-27 and Table 4-36 respectively.

Table 4-36 MAE F-09 Catastrophic Failure Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	93	139
	5	64	96
	10	35	63
	20	28	56
5/D	3	112	149
	5	81	106
	10	39	68
	20	29	56

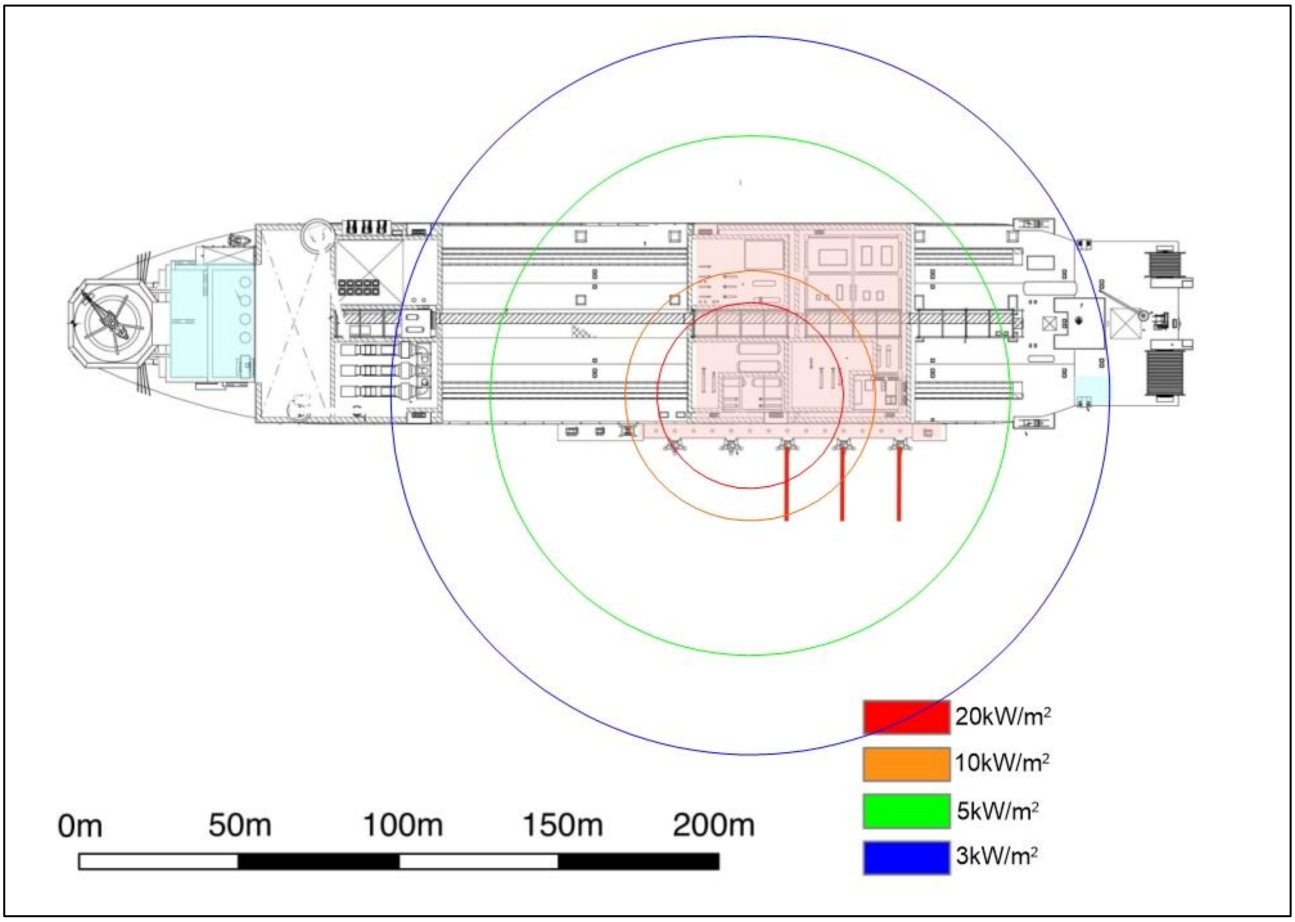


Figure 4-27 MAE F-09 Radiation Contours for Pool Fire from Catastrophic Failure (scale in m)

4.10. MAE F-10: Gas Release from Flash Gas Compression

4.10.1. Event Description

This MAE is a release of flammable gas due to loss of containment within the flash gas compression train, downstream of the turbo expander and taking vapour from the MP, LP and LLP separators. The section includes the following major equipment items:

- MP Separator (vapour space)
- LP Separator (vapour space)
- LLP Separator (vapour space)
- Fuel Gas MP Compression Discharge Drum
- Fuel Gas MP Compressor
- Fuel Gas MP Compression Suction Scrubber
- Fuel Gas LP Compressor
- Fuel Gas LP Compression Suction Scrubber
- Fuel Gas LLP Compressor
- Fuel Gas LLP Compression Suction Scrubber

The input data and stream conditions for this MAE are taken from the FPSO Major Hazard Inventory (Appendix B.1.2) and are shown below.

Table 4-37 MAE F-10 Stream Parameters

Parameter	Input
Process Unit	Flash Gas Compression
Assumed Material	Methane
Pressure (bara)	39
Temperature (deg C)	46
Phase	Gas
Inventory (kg)	154
Outflow Rate for Representative Failure (50mm) (kg/s)	11.3
Estimated Release Duration for Representative (50mm) Failure	<1min
Congested Volume (m^3)	21,000

4.10.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE F-10. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-28 and Table 4-38 respectively.

Table 4-38 MAE F-10 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	64	92
	5	57	71
	10	49	50
	20	42	34
5/D	3	64	92
	5	57	71
	10	50	50
	20	45	33

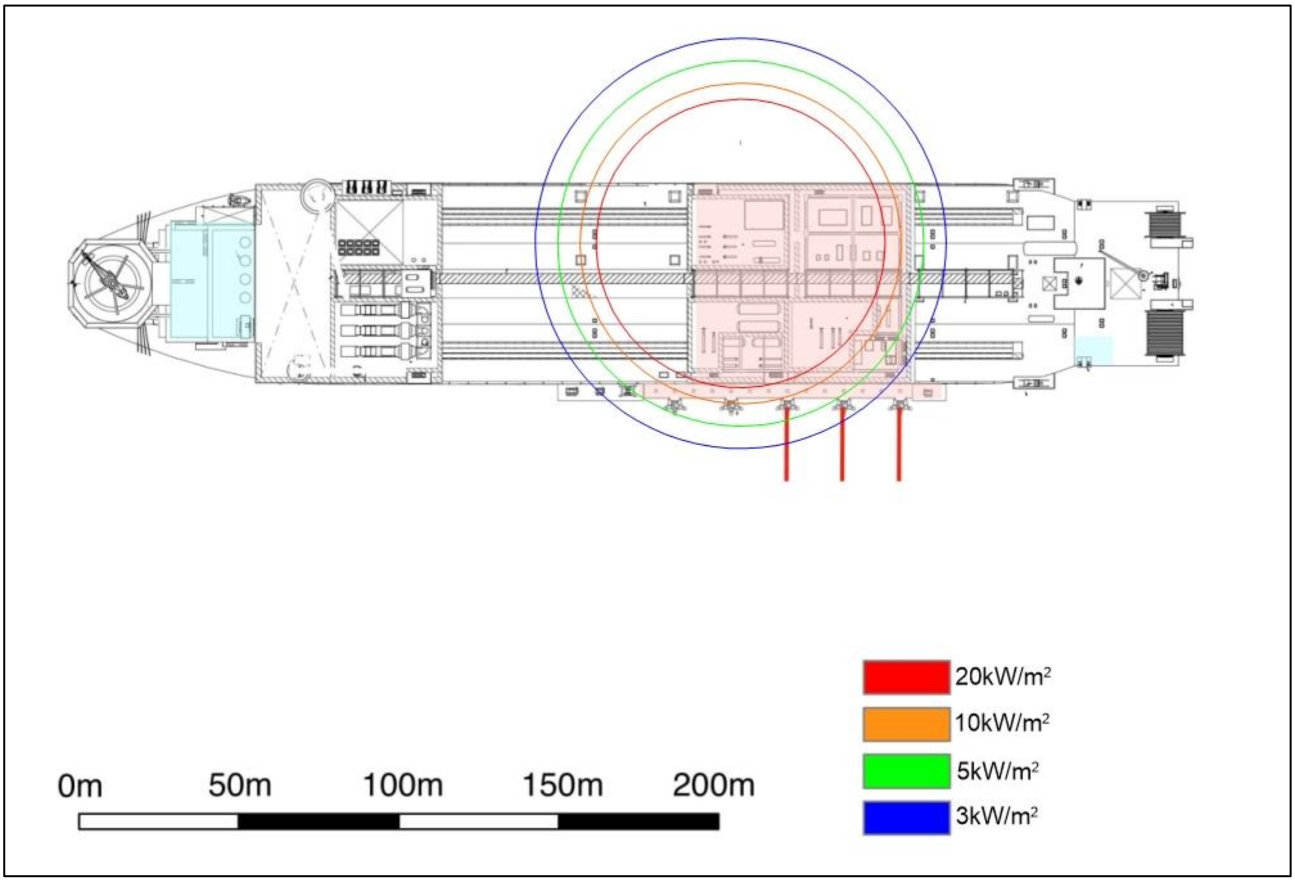
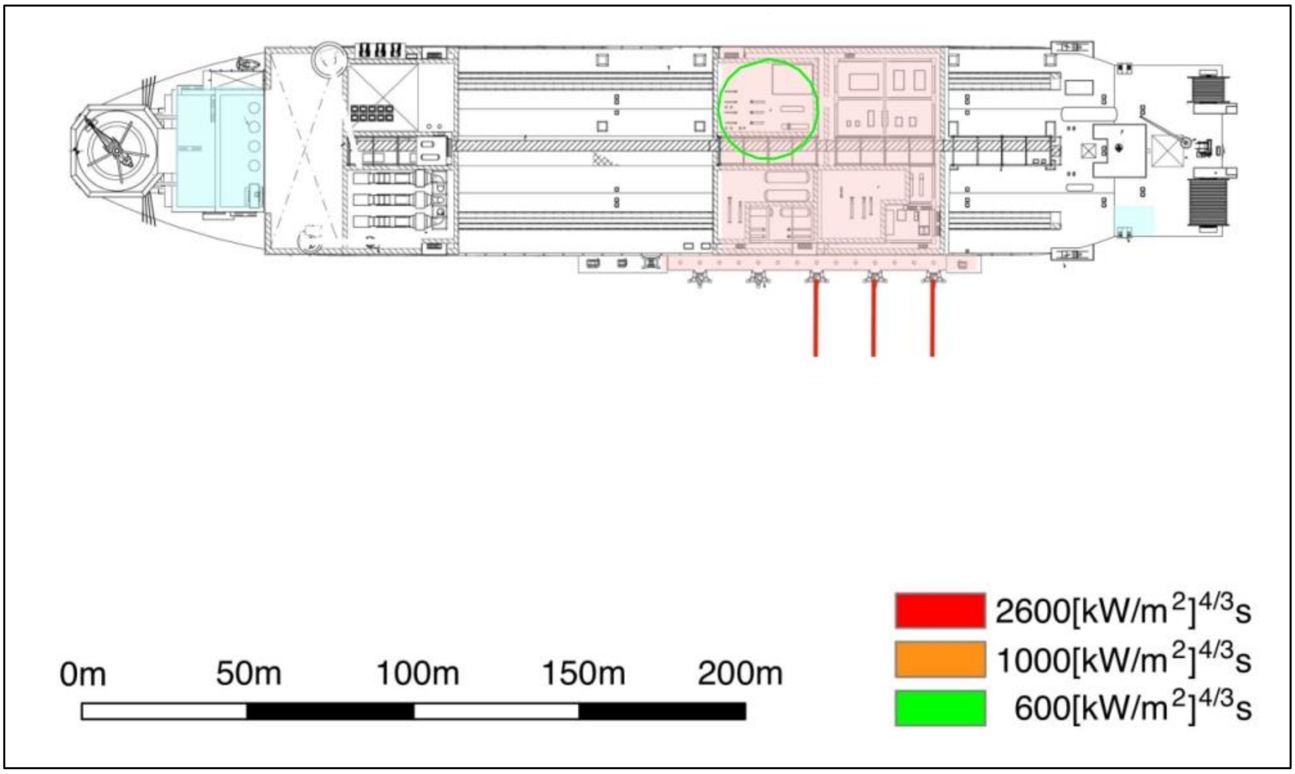


Figure 4-28 MAE F-10 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE F-10. The contour plot and hazard ranges due to the thermal dose from the fireball are shown in Figure 4-29 and Table 4-39 respectively.

Table 4-39 MAE F-10 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
17	600	15
	1000	Not Reached
	2600	Not Reached



NOTE: The higher thermal dose levels were not reached.

Figure 4-29 MAE F-10 Fireball Contour for Catastrophic Failure (scale in m)

4.10.3. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (Flash Gas Compression, Inlet Facilities, Condensate and Export Gas Metering and Vapour Recovery modules) following loss of containment for MAE F-10 will result in a vapour cloud explosion. Overpressure results are calculated for a VCE within the forward modules of the FPSO. The flammable mass involved in the explosion from a representative failure (50 mm) and a catastrophic failure (credible worst case) is limited to the total flammable inventory within the section. The contour plot and overpressures are shown in Figure 4-30 and Table 4-40 respectively.

Table 4-40 MAE F-10 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	496
0.05	217
0.14	88
0.35	39

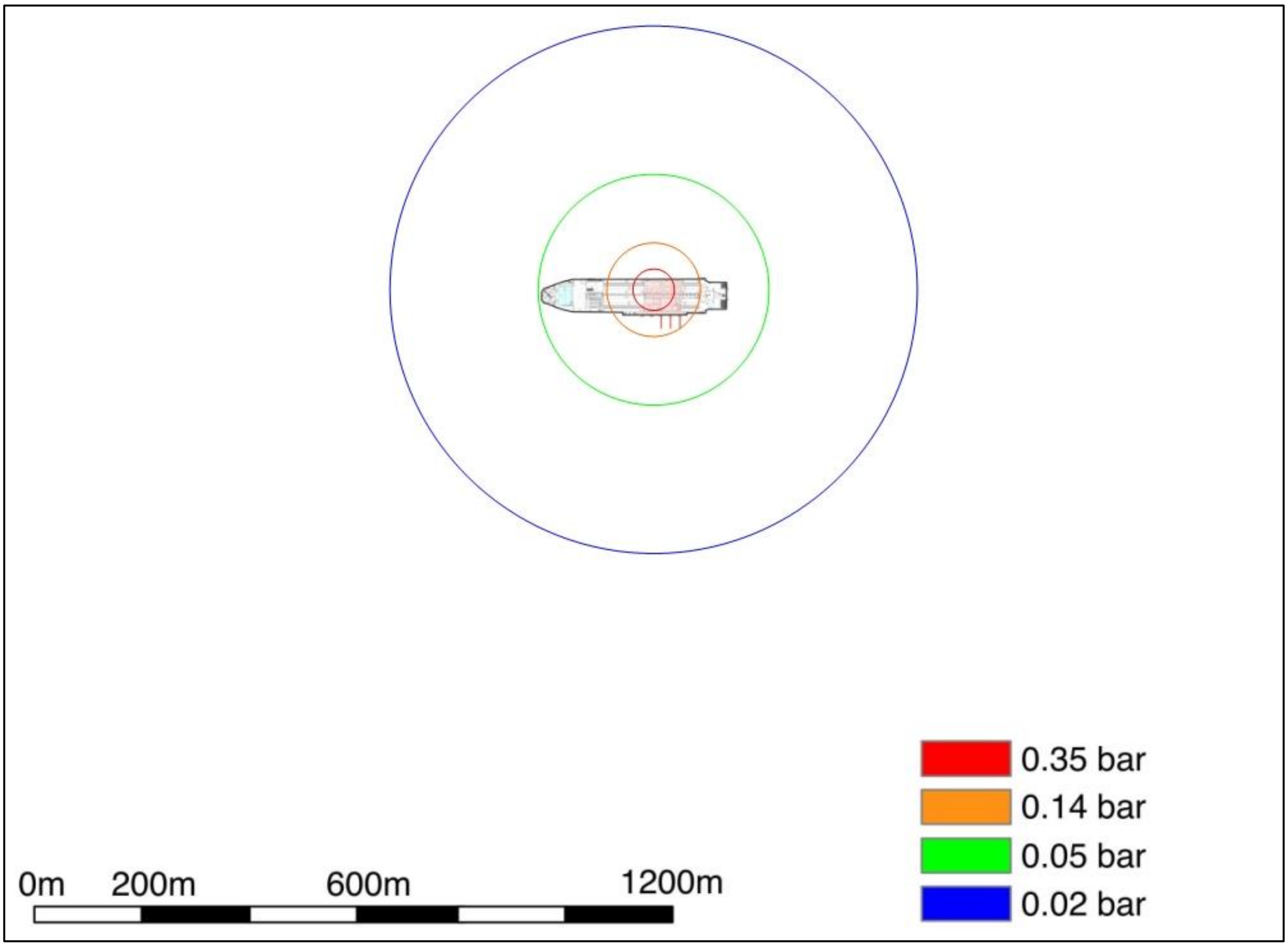


Figure 4-30 MAE F-10 Explosion Contours (scale in m)

4.11. MAE F-11: Gas Release from Fuel Gas System\

4.11.1. Event Description

This MAE is a loss of flammable gas from the fuel gas system. The section is located downstream of the flash gas compression train. The section includes the following major equipment item:

- Fuel Gas KO Drum

The stream conditions for this MAE was obtained from the FPSO Major Hazard Inventory (Appendix B.1.2) and are shown below.

Table 4-41 MAE F-11 Stream Parameters

Parameter	Input
Process Unit	Fuel Gas
Assumed Material	Methane
Pressure (bara)	38
Temperature (deg C)	45
Phase	Gas
Inventory (kg)	95
Outflow Rate for Representative Failure (50mm) (kg/s)	11.0
Estimated Release Duration for Representative (50mm) Failure	<1min
Congested Volume (m^3)	21,000

4.11.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE F-11. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-31 and Table 4-42 respectively.

Table 4-42 MAE F-11 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	63	91
	5	56	71
	10	48	49
	20	42	33
5/D	3	63	91
	5	56	70
	10	49	49
	20	44	33

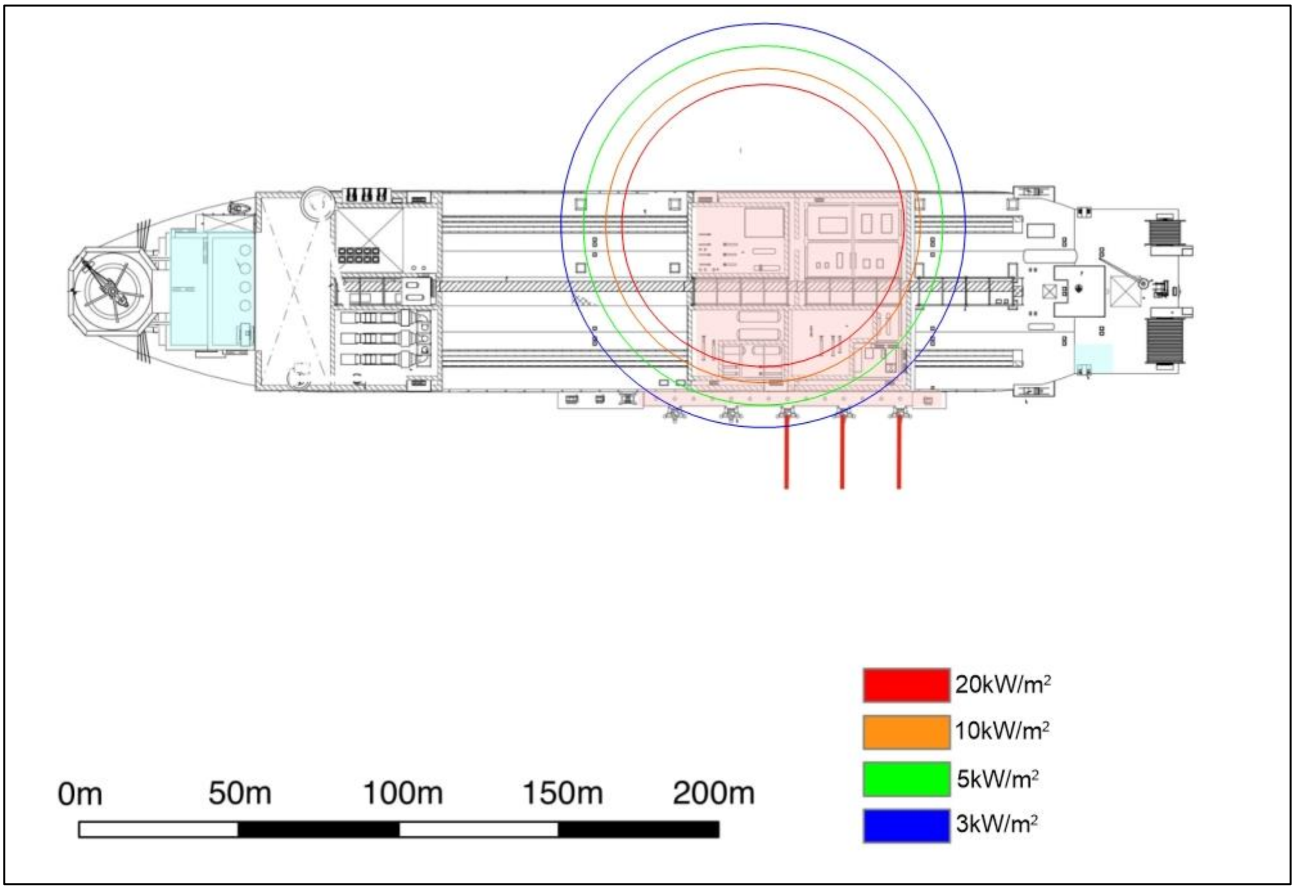


Figure 4-31 MAE F-11 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE F-11, however, only the lowest of the three thermal dose levels were reached with a range of 8m – this is due to the small inventory within the section resulting in a short duration fireball.

4.11.3. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (Flash Gas Compression, Inlet Facilities, Condensate and Export Gas Metering and Vapour Recovery modules) following loss of containment for MAE F-11 will result in a vapour cloud explosion. Overpressure results are calculated for a VCE within these modules of the FPSO. The flammable mass involved in the explosion from a representative failure (50 mm) and a catastrophic failure (credible worst case) is limited to the total flammable inventory within the section. The contour plot and overpressures are shown in Figure 4-32 and Table 4-43 respectively.

Table 4-43 MAE F-11 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	422
0.05	185
0.14	75
0.35	34

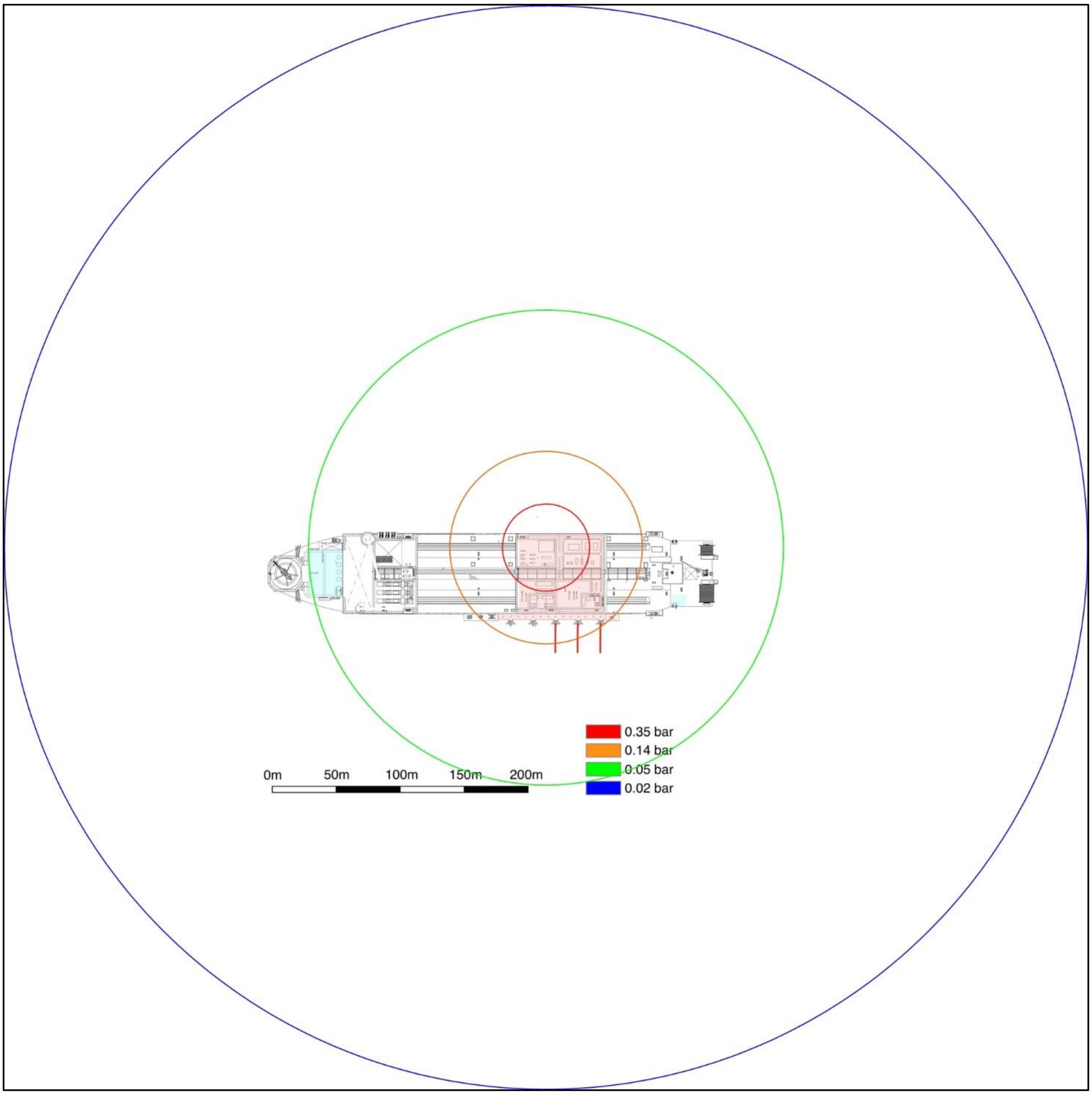


Figure 4-32 MAE F-11 Explosion Contours (scale in m)

4.12. MAE F-12: Injection Chemical Release Topsides

4.12.1. Event Description

This MAE is a loss of containment on the FPSO topsides chemical corrosion inhibitor. The input data for this MAE are shown below. Loss of containment is modelled as a release from the corrosion inhibitor storage vessel at atmospheric pressure, resulting in a liquid spill.

It is noted that corrosion inhibitor downstream of the storage vessel will be at a high pressure to allow injection to the production fluids / process. A loss of containment from this section of the inventory would result in an initial high momentum jet / liquid spray. However, pumps for the section would trip shortly after the initial failure and a liquid spray would be short-lived – the release would quickly transition to a low momentum spill forming a liquid pool.

Table 4-44 MAE F-12 Input Parameters

Parameter	Input
Process Unit	Chemical Injection
Assumed Material	Methanol
Pressure (bara)	1
Temperature (deg C)	20
Phase	Liquid
Inventory (kg)	7,326
Outflow Rate for Representative Failure (50mm) (kg/s)	121.1
Estimated Release Duration for Representative (50mm) Failure	1-5mins

4.12.2. Fire Results

Ignition following loss of containment from a representative failure (50 mm) will result in a pool fire for MAE F-12. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 4-33 and Table 4-45 respectively.

Table 4-45 MAE F-12 50mm Pool Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	54	99
	5	45	80
	10	35	59
	20	25	43
5/D	3	54	99
	5	46	80
	10	37	61
	20	28	46

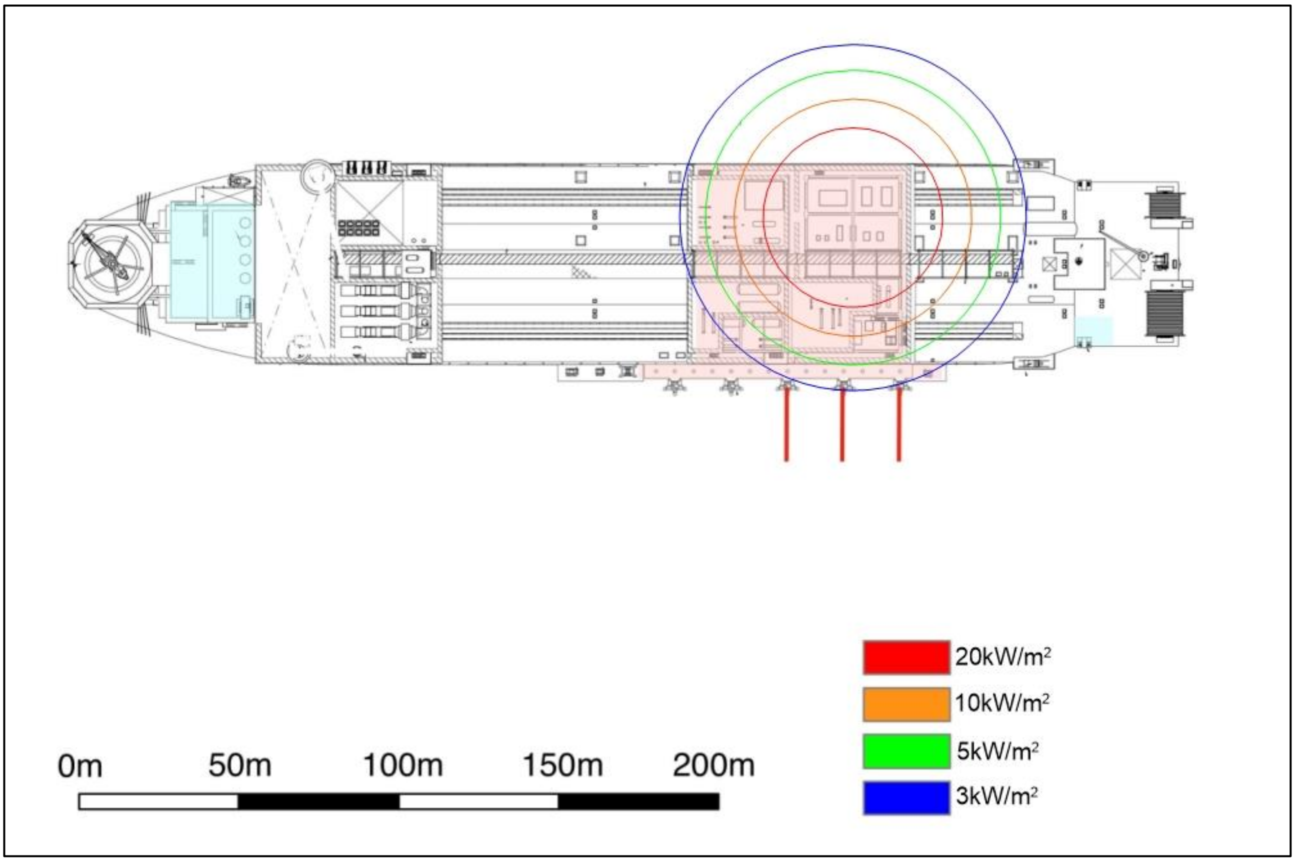


Figure 4-33 MAE F-12 Radiation Extent for Pool Fire from 50mm Failure (scale in m)

Ignition following loss of containment from a catastrophic failure will result in a pool fire for MAE F-12. The size of a fire from a catastrophic failure is the same as for a 50mm release and the contour plots and hazard ranges for thermal radiation impact are the same as those shown in Figure 4-33 and Table 4-45.

4.13. MAE F-14: Condensate Storage Tank Fire

4.13.1. Event Description

This MAE is a fire associated with the largest of the condensate storage tanks. Input data for the MAE is taken from the FPSO Major Hazard Inventory (Appendix B.1.2) and shown below.

Table 4-46 MAE F-14 Input Parameters

Parameter	Input
Process Unit	Condensate Storage
Assumed Material	Condensate: (mol fraction) Water: 0.02 Propane: 0.06 i-Pentane: 0.05 Benzene: 0.04 Toluene: 0.02 Xylene: 0.03 C6: 0.05 C7: 0.11 C8: 0.14 C9: 0.05 C20: 0.40
Pressure (bara)	1
Temperature (deg C)	20
Phase	Liquid
Inventory (kg)	26,405,852

4.13.2. Fire Results

The contour plots and hazard ranges due to thermal radiation impact from a single cargo tank fire on the FPSO are shown in Figure 4-34 and Table 4-47.

Table 4-47 MAE F-14 Cargo Tank Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	96	143
	5	65	97
	10	34	59
	20	29	58
5/D	3	116	155
	5	83	108
	10	39	66
	20	29	58

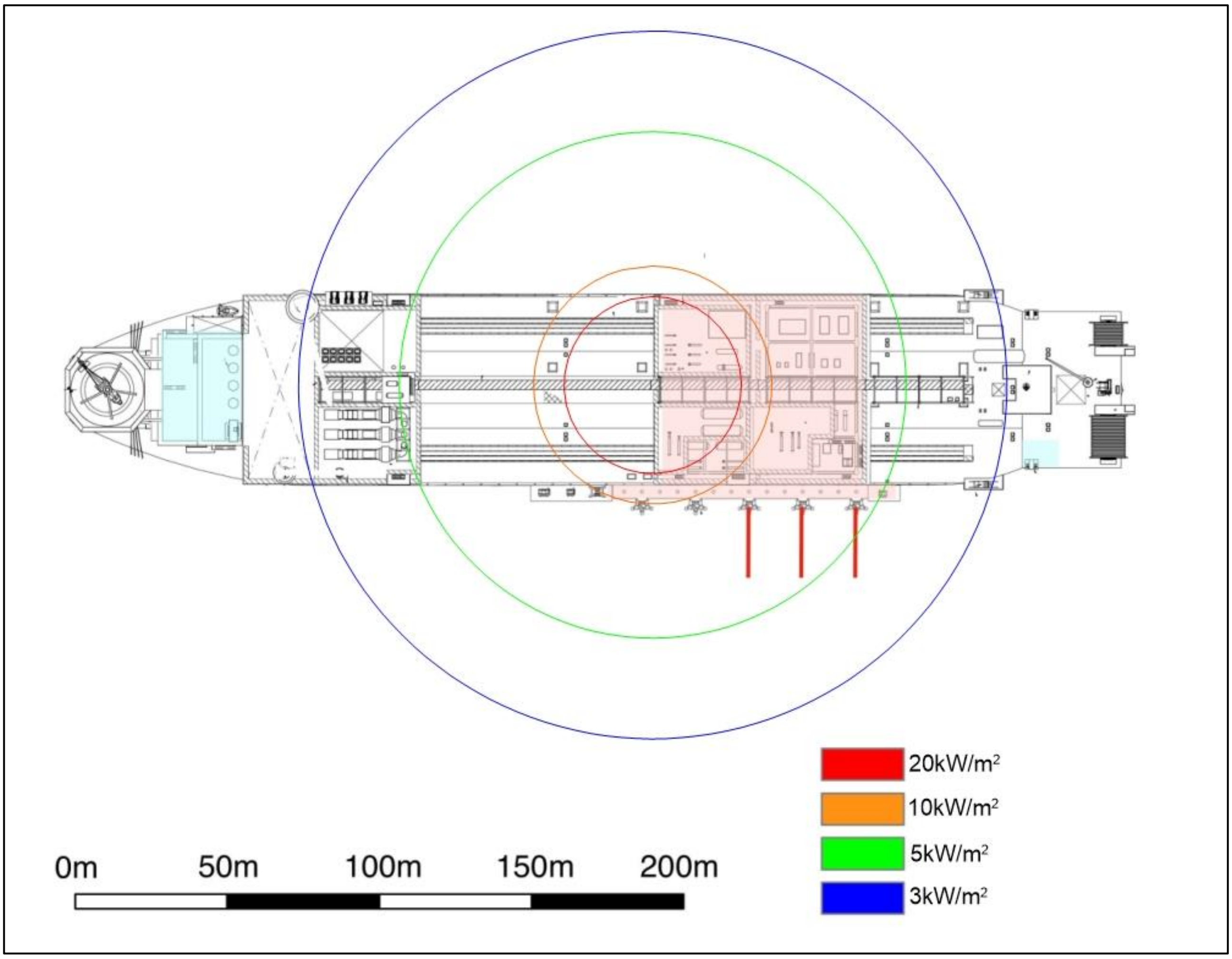


Figure 4-34 MAE F-14 Radiation Contours for Cargo Tank Fire (scale in m)

4.14. FPSO and Subsea Failure Scenario Summary Tables

This section summarises the impairment potential of the key EER facilities on the FPSO, i.e. the primary escape routes along the starboard and portside of the FPSO, the TR and the evacuation facilities. It also considers potential for impact of hazardous effects beyond the 500m safety zone around the FPSO.

The following assumptions have also been made whilst determining impairment potential:

Escape routes impairment

- Escape routes are assumed to be impaired after exposure to levels of thermal radiation of 5kW/m^2 or higher for 5 minutes or longer;
- Explosions overpressures of 0.35bar or higher will impair escape routes;

TR impairment

Fire and explosion protection (PFP, blast walls etc) is expected to be provided for the TR and hence only long duration fires or very high overpressures are considered to cause impairment.

Evacuation impairment

Evacuation facilities for the FPSO are assumed to be at the aft of the FPSO, within vicinity of the LQ/TR. Impairment of the evacuation facilities is only considered if the TR is impaired or there is significant likelihood of large-scale escalation. Impairment is assumed to be at low overpressures and thermal radiation.

Safety zone impairment

Impairment potential of the safety zone has been assessed by considering impact at any of the criteria presented in Table 3-1 to Table 3-5 for fires and explosions.

Where a ✓ is shown in the tables below, impairment of the EER provisions / the safety zone is possible based on the criteria and assumptions listed above.

Event ID: **F-01 Hydrocarbon Release from Production Riser**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet/Spray/Pool Fire	✓	×	×	×
Fireball	×	×	×	×
Discussion	A jet fire for this event is expected to be around 20 minutes and, depending on release direction, could cause impairment of the starboard and portside escape routes. Personnel who survive the initial jet fire and are forward of the riser balcony would be unable to seek shelter in the TR but could instead use the Alternate Safe Muster Area (ASMA) – see Figure 1-3. High thermal radiation levels from a fireball (and subsequent jet fire) could reach the TR, however, the provision of PFP should provide protection from the short duration impact allowing personnel who survive the initial event to safely shelter in the TR. Impairment of the evacuation facilities and safety zone is discounted.			

Event ID: **F-02 Gas Release from Export Gas Risers**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet/Spray/Pool Fire	✓	×	×	×
Fireball	×	×	×	×
Discussion	A jet fire for this event is expected to be around 20 minutes and, depending on release direction, could cause impairment of the starboard and portside escape routes. Personnel who survive the initial event and are forward of the riser balcony would be unable to seek shelter in the TR but could instead use the ASMA. High thermal radiation levels from a fireball could reach the TR, however, the provision of PFP should provide protection from this impact allowing personnel who survive the initial event to shelter in the TR. Impairment of the evacuation facilities and safety zone is discounted.			

Event ID: **F-03 Gas Release from Reception Facilities (Slug Catchers)**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	✓	×	×	×
Fireball	×	×	N/A	×
Explosions	✓	×	✓	✓
Discussion	A jet fire or explosion could cause impairment of both the starboard and portside escape routes. Personnel who survive the initial event will be able to seek shelter in the TR or, if they were forward of the incident, muster at the ASMA. A fireball results in high thermal radiation impact but only for a short duration; impact to escape routes is only temporary and hence impairment is discounted. The provision of PFP should provide protection for the TR from fires from this short duration event. There is potential for escalation from jet fires however, the evacuation facilities would be unaffected and an orderly evacuation could be completed. Due to the short duration of a fireball there is no expected escalation and personnel will be able to wait out the event in the TR. Overpressure impact from the initial event can impair both primary escape routes to the TR – personnel forward of the explosion would need to muster at the ASMA. The explosion does not impair the TR although there is potential for escalation and the evacuation facilities may be impaired. Impact from lower level overpressures extends beyond the safety zone.			

Event ID: **F-04 Liquid Release from Reception Facilities (Slug Catchers)**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Spray Fire	✓	×	N/A	×
Pool Fire	✓	×	N/A	×
Explosions	✓	×	✓	✓
Discussion	Impact from a pool fire or due to overpressure impact from explosions is sufficient to impair both primary escape routes back to the TR. Personnel unaffected and forward of the event would need to muster at the ASMA. A spray fire (depending on release direction) could impact routes but due to the short duration of this event the impact would only be temporary. The TR is unlikely to be threatened by the initial event although explosion impact is significant and the event may result in escalation and require a precautionary evacuation. Evacuation facilities may be impaired by explosion damage while impact from lower level overpressures extends beyond the safety zone.			

Event ID: **F-05 Gas Release from Gas Processing**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	✓	×	✓	✓
Discussion	Due to the small inventory associated with this event, fire durations will be of short duration (<5 minutes). Any impact on escape routes will be temporary and personnel who survive the initial jet fire or fireball event will be able to seek shelter in the TR. Evacuation would not be required. Explosion damage is significant with both primary escape routes back to the TR impaired – unaffected personnel forward of the event would need to muster at the ASMA. Overpressures are not sufficient to threaten the TR however escalation is possible and evacuation facilities may also be impaired. Impact from lower level overpressures extends beyond the safety zone.			

Event ID: **F-06 Liquid Release from Gas Processing**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Spray Fire	×	×	N/A	×
Pool Fire	×	×	N/A	×
Explosions	✓	×	✓	✓
Discussion	Due to the small inventory for this event, pool fire durations and impact will be limited – potential for escape impairment is discounted. Spray fires have a large initial extent but will be very short duration – escape route TR impairment is also discounted. Personnel who survive the initial jet fire or pool fire event will be able to seek shelter in the TR. There is no requirement for evacuation. Explosion damage is significant with both primary escape routes back to the TR impaired – unaffected personnel forward of the event would need to muster at the ASMA. Escalation is possible due to explosion damage and evacuation facilities may also be impaired. Impact from lower level overpressures extends beyond the safety zone.			

Event ID: **F-07 Liquid Release from MP Separator**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Spray Fire	✓	×	×	×
Pool Fire	✓	×	×	×
Explosions	✓	×	✓	✓
Discussion	Impact from a jet fire (depending on release direction), a worst case pool fire, or overpressure impact from explosions is sufficient to impair both primary escape routes back to the TR. Personnel unaffected and forward of the event would need to muster at the ASMA. The TR is unlikely to be threatened by the initial event although, fire durations and explosion impact are significant and the event may result in escalation and require a precautionary evacuation. Evacuation facilities may be impaired by explosion damage while impact from lower level overpressures extends beyond the safety zone.			

Event ID: **F-08 Liquid Release from LP Separator**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Spray Fire	✓	×	×	×
Pool Fire	✓	×	×	×
Explosions	✓	×	✓	✓
Discussion	Thermal radiation impact from jet fires (depending on release direction) and pool fires, and overpressure impact from explosions is sufficient to impair both primary escape routes back to the TR. Personnel unaffected and forward of the event would need to muster at the ASMA. The TR is unlikely to be threatened by the initial event although, fire durations and explosion impact are significant and the event may result in significant escalation. Evacuation facilities may be impaired by explosion damage while impact from lower level overpressures extends beyond the safety zone.			

Event ID: **F-09 Liquid Release from LLP Separator**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Pool Fire	✓	×	×	×
Discussion	Due to the large liquid inventory, fire durations are expected to be significant and the event may have potential for significant escalation. Fire impact following a 50mm release is not sufficient to impair all escape routes back to the TR – personnel will be able to return via the portside. However, thermal radiation from a catastrophic pool fire would cause impairment of both of the main escape routes and personnel not affected and forward of the fire would need to muster at the ASMA. Thermal radiation is not sufficient to impact the TR or the evacuation facilities.			

Event ID: **F-10 Gas Release from Flash Gas Compression**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	✓	×	N/A	×
Discussion	Due to the limited inventory associated with this event, fire durations will be short (<1 minute) and high levels of thermal radiation impacting the escape routes will only be temporary. Personnel who survive the initial jet fire / fireball event will be able to seek shelter in the TR. There is no requirement for evacuation. High explosion overpressures can impact both starboard and portside escape routes and surviving personnel forward of the event will need to muster at the ASMA. Impact from explosions are not sufficient to impair the TR and there is expected to be limited escalation – requirement for evacuation is discounted.			

Event ID: **F-11 Gas Release from Fuel Gas System**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	×	×	N/A	×
Discussion	Due to the small inventory associated with this event, fire durations will be very short (<1 minute); high levels of thermal radiation causing escape route impairment will be limited to the vicinity of the release area. Personnel who survive the initial jet fire / fireball event will be able to seek shelter in the TR. High explosion overpressures will be limited to the release area with the potential for impairment of only the portside escape routes. Impairment of the TR due to fires and explosions is discounted and there is no expected requirement for evacuation.			

Event ID: **F-12 Injection Chemical Release Topsides**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Pool Fire	✓	×	N/A	×
Discussion	All primary escape routes would be impaired by thermal radiation from pool fires associated with the chemical injection storage and hence personnel at the fore and not affected by the initial event would need to muster at the ASMA. However, pool fires would not have sufficient duration and / or extent to threaten the TR and evacuation is not expected to be required.			

Event ID: **F-14 Condensate Storage Tank Fire**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Pool Fire	✓	✓	✓	×
Discussion	A cargo tank fire is a long duration event and is likely to present a significant threat to the integrity of the FPSO. Thermal radiation from a cargo tank fire towards the aft of the facility may threaten the TR and impact the evacuation facilities – depending on the PFP rating protecting the LQ / TR block. All primary escape routes would be impaired and hence personnel in the forward modules and not affected the initial event would need to evacuate from the ASMA.			

5. Near Shore Hub Failure Scenarios

This section outlines each of the Near Shore Hub MAEs for which fire, explosion and cryogenic spill modelling has been completed and presents the hazard effect distances for these scenarios.

5.1. MAE N-01: Gas Release from Import Gas Riser

5.1.1. Event Description

This MAE is a release of flammable gas from the gas import riser at the A1 Riser Platform. The gas riser begins at the FPSO and ends at the gas export riser ESDV. The inventory for N-01 is based on no SSIV provision on the import riser at the NSH. It is noted that this assumption does not make a significant impact on the fire sizes presented in the sections below but does impact the release duration.

Modelling of fires for this MAE has been completed using input data as outlined in Table 5-1 which are taken from MAR Inventory 1 [Appendix B.1.1].

Table 5-1 MAE N-01 Stream Parameters

Parameter	Input
MAR Inventory	-
Process Unit	Gas Riser
Assumed Material	Methane
Pressure (bara)	74
Temperature (deg C)	16
Phase	Gas
Inventory (kg)	1,101,329
Outflow Rate for Representative Failure (50mm) (kg/s)	23.9
Estimated Release Duration for Representative (50mm) Failure	>12hours
Congested Volume (m^3)	-

5.1.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-01. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-1 and Table 5-2 respectively.

Table 5-2 MAE N-01 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	93	135
	5	81	105
	10	69	74
	20	59	51
5/D	3	92	135
	5	81	105
	10	71	74
	20	62	50

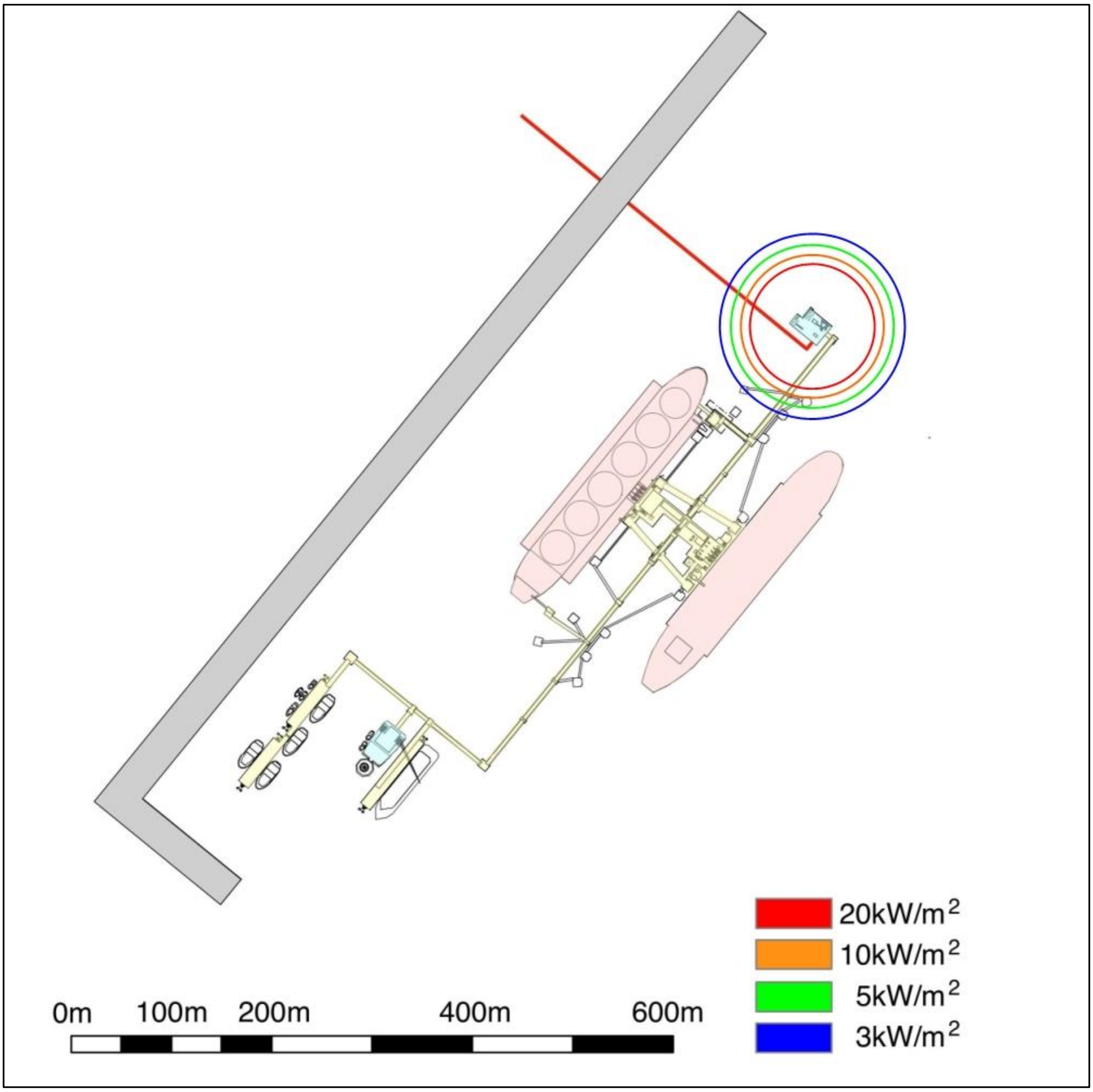


Figure 5-1 MAE N-01 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE N-01. The mass involved in the fireball is assumed to be the mass released in the first 30 seconds following rupture of the of the riser. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-2 and Table 5-3 respectively.

Table 5-3 MAE N-01 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
116	600	382
	1000	295
	2600	143

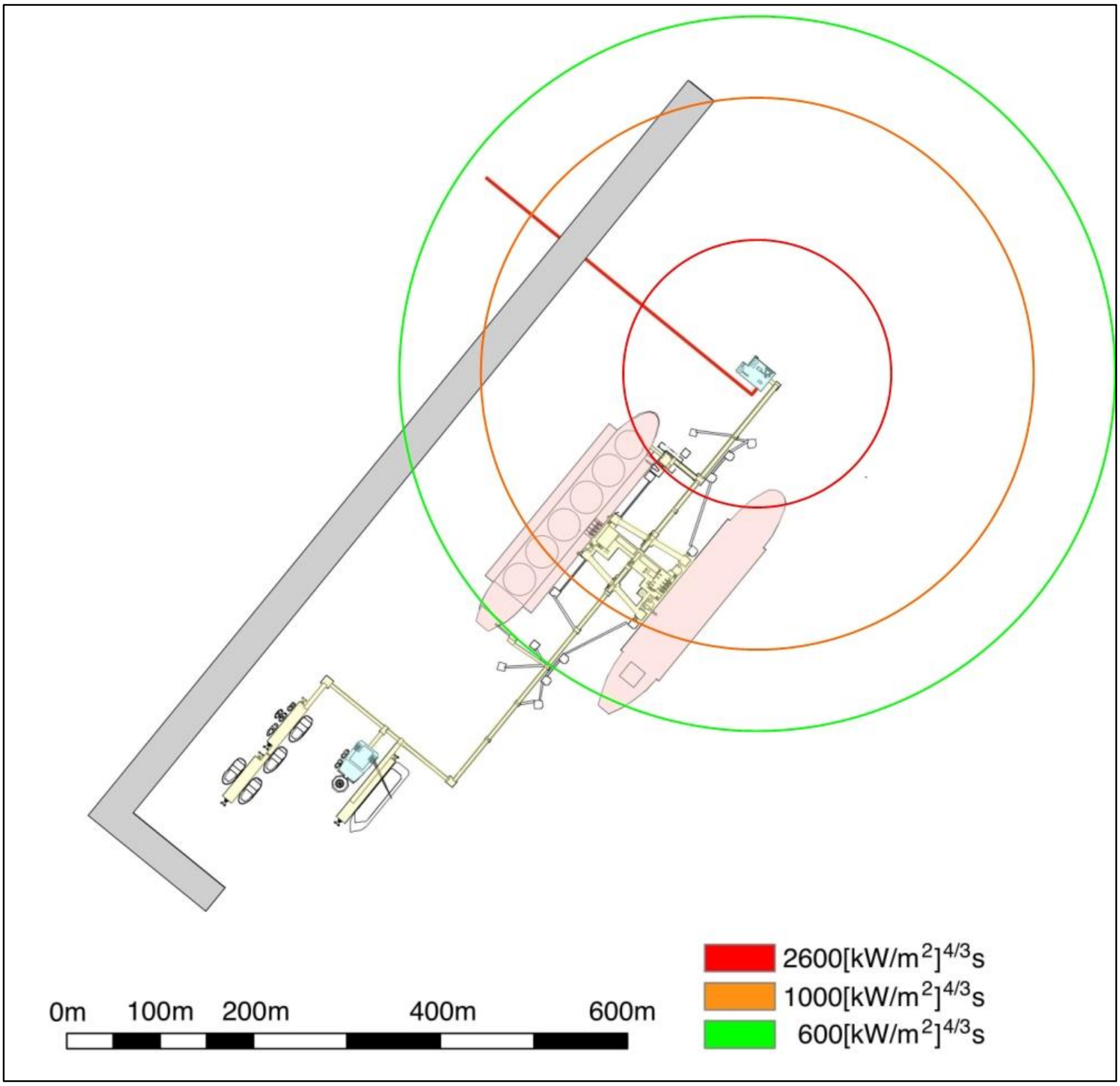


Figure 5-2 MAE N-01 Fireball Contour for Catastrophic Failure (scale in m)

5.2. MAE N-02: Gas Release from Trestle Feed Gas Flowline / Hose to FLNG

5.2.1. Event Description

This MAE begins on the A1 Riser Platform and extends to the FLNG including the two import hoses and pig launcher. Modelling of fires for this MAE has been completed using input data as outlined in Table 5-4, which are taken from MAR study [Appendix B.1.1].

Table 5-4 MAE N-02 Input Parameters

Parameter	Input
MAR Inventory	Trestle Feed Gas Flowline
Process Unit	Trestle
Assumed Material	Methane
Pressure (bara)	74
Temperature (deg C)	16
Phase	Gas
Inventory (kg)	2,919
Outflow Rate for Representative Failure (50mm) (kg/s)	23.9
Estimated Release Duration for Representative (50mm) Failure	1-5mins

5.2.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-02. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-3 and Table 5-5 respectively.

Table 5-5 MAE N-02 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	93	135
	5	81	105
	10	69	74
	20	59	51
5/D	3	92	135
	5	81	105
	10	71	74
	20	62	50

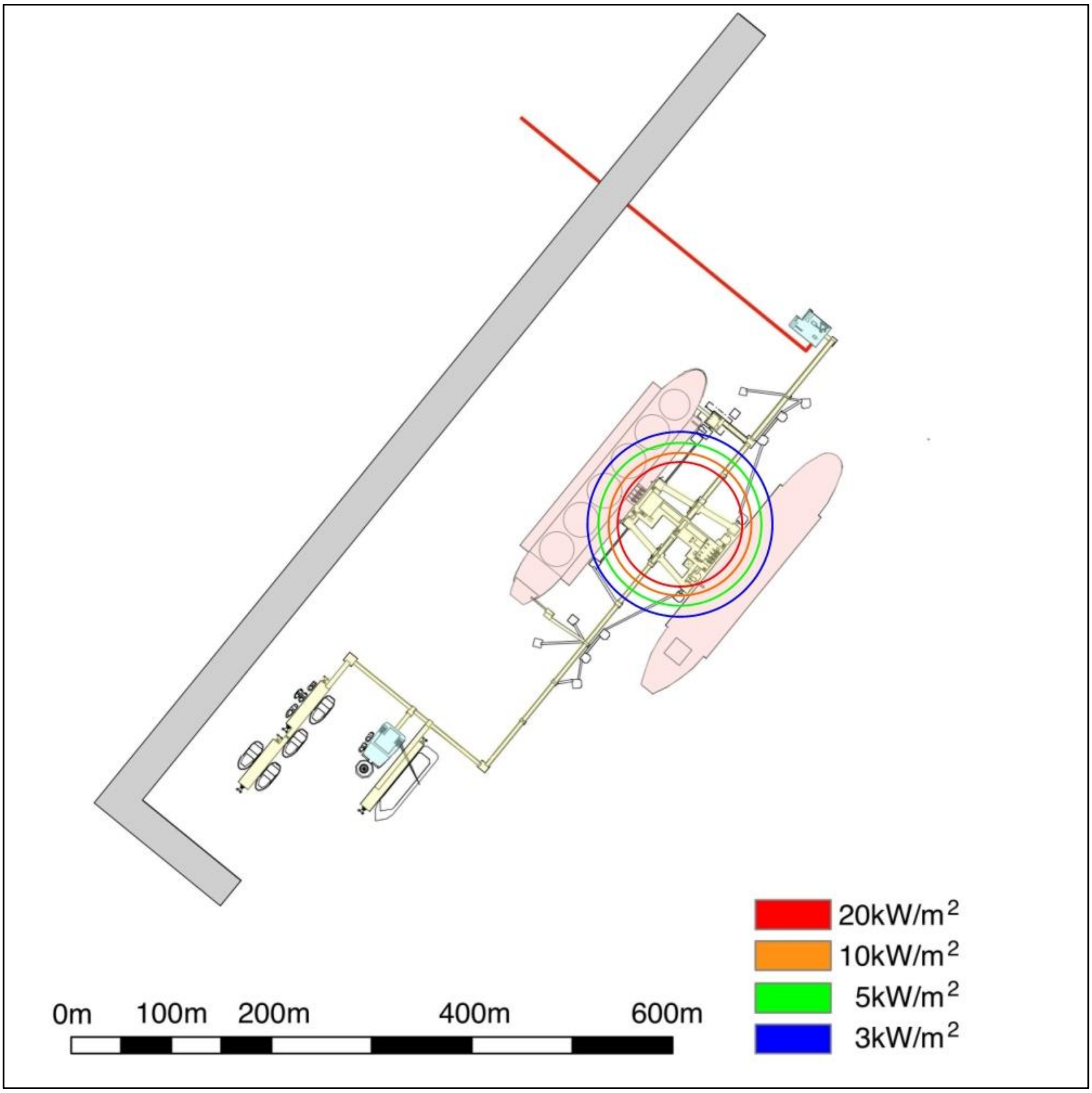


Figure 5-3 MAE N-02 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE N-02. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-4 and Table 5-6 respectively.

Table 5-6 MAE N-02 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ($[kW/m^2]^{4/3}$ s)	Distance from Release Point (m)
43	600	102
	1000	72
	2600	Not Reached

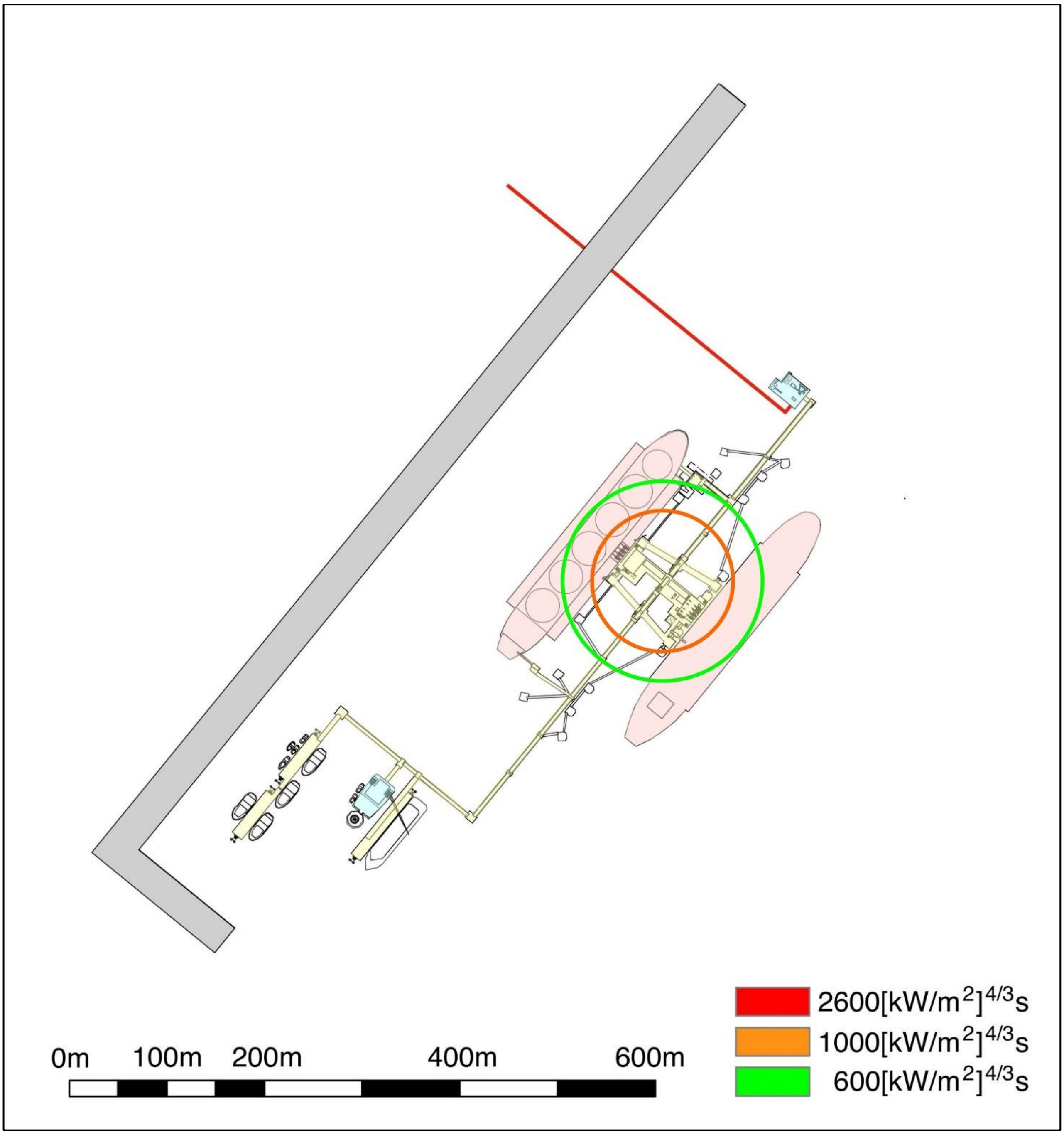


Figure 5-4 MAE N-02 Fireball Contour for Catastrophic Failure (scale in m)

5.3. MAE N-03: Gas Release from Trestle Fuel Gas Flowline to QU Platform

5.3.1. Event Description

This MAE is a loss of containment of flammable gas from the trestle fuel gas flowline between the A1 Riser Platform and the QU Platform.

Modelling of fires for this MAE has been completed using input data as outlined in Table 5-7, which are taken from MAR study (Appendix B.1.1).

Table 5-7 MAE N-03 Input Parameters

Parameter	Input
MAR Inventory	Fuel Gas
Process Unit / Area	Trestle
Assumed Material	Methane
Pressure (bara)	74
Temperature (deg C)	16
Phase	Gas
Inventory (kg)	95
Outflow Rate for Representative Failure (50mm) (kg/s)	23.9
Estimated Release Duration for Representative (50mm) Failure	<1min

5.3.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-03. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-5 and Table 5-8 respectively.

Table 5-8 MAE N-03 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	93	135
	5	81	105
	10	69	74
	20	59	51
5/D	3	92	135
	5	81	105
	10	71	74
	20	62	50

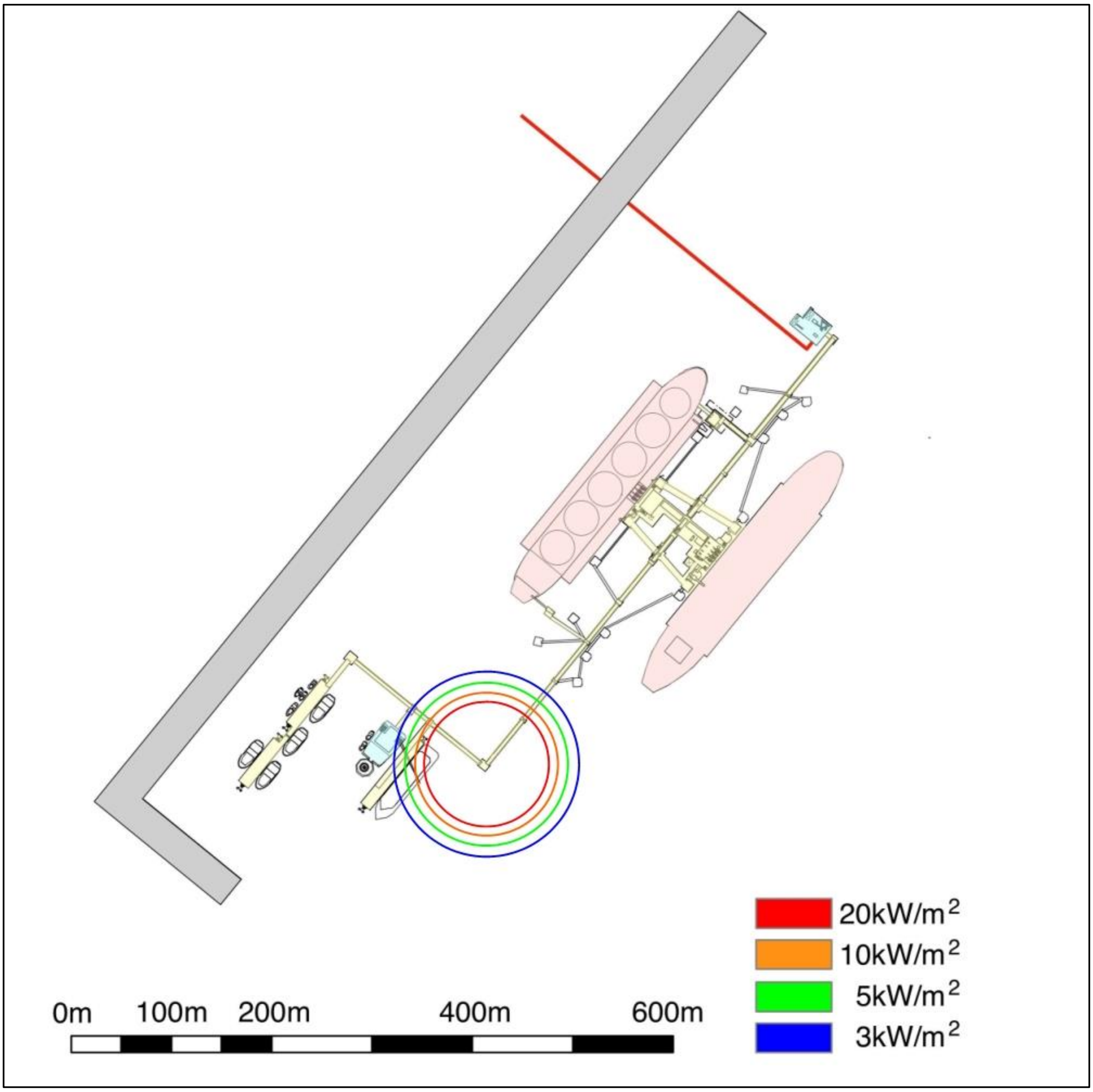
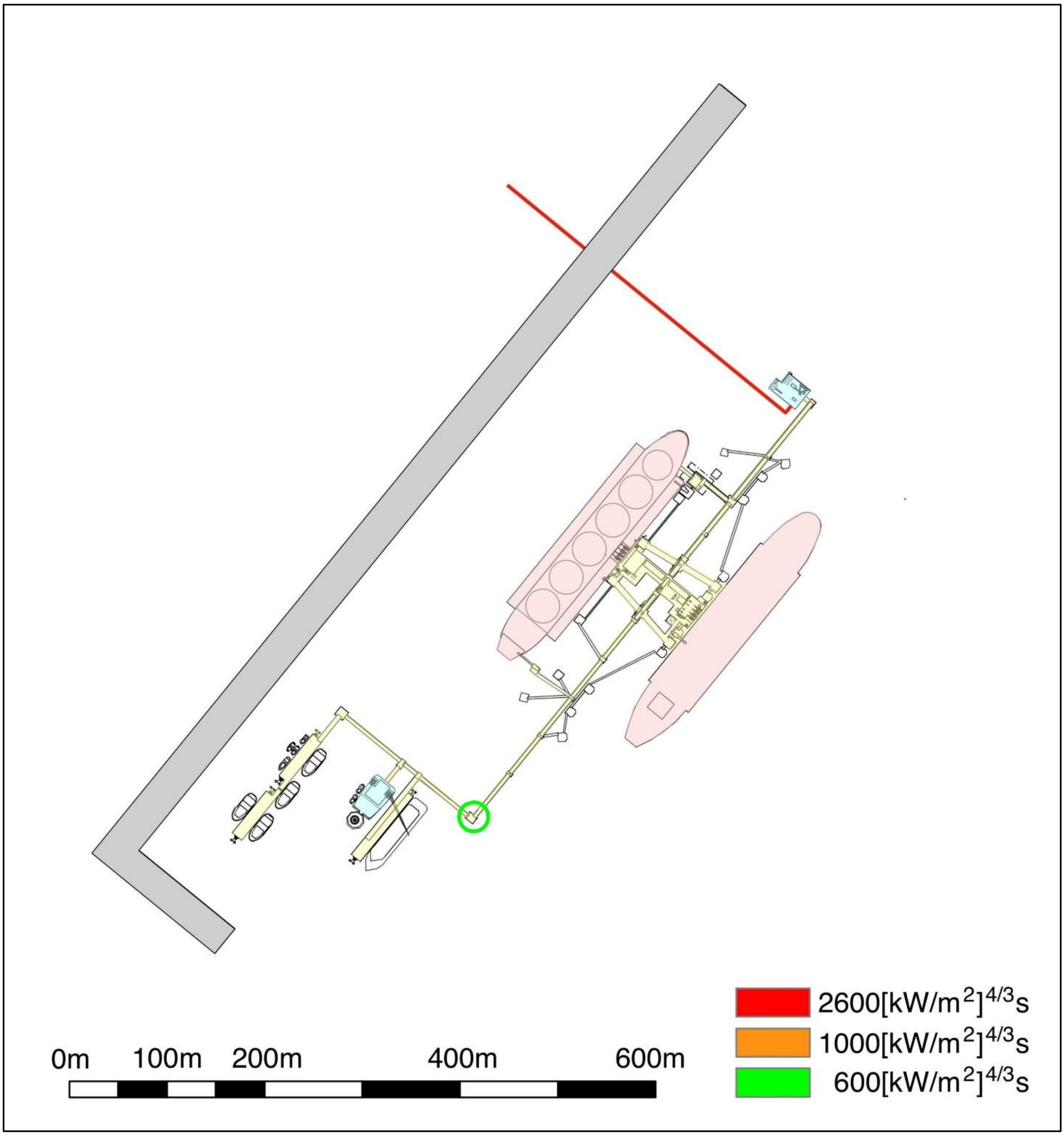


Figure 5-5 MAE N-03 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE N-03. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-6 and Table 5-9 respectively.

Table 5-9 MAE N-03 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
15	600	8
	1000	Not Reached
	2600	Not Reached



NB: The higher thermal dose levels are not reached.

Figure 5-6 MAE N-03 Fireball Contour for Catastrophic Failure (scale in m)

5.4. MAE N-04: Gas Release from FLNG Inlet Metering and Amine Treatment

5.4.1. Event Description

This MAE begins at the ESDVs downstream of the Import Hoses (x2) between the A1 Riser Platform and the FLNG and extends to the ESDVs upstream of the Mol Sieve Inlet Scrubber and Fuel Gas Heater. The section includes the following major equipment items:

- Gas Metering
- HP Separator
- Inlet Gas Filter
- Contact Feed Exchanger
- Amine Contractor

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-10, which are taken from the MAR study (Appendix B.1.1).

Table 5-10 MAE N-04 Stream Parameters

Parameter	Input
MAR Inventory	Metering and Amine Treatment
Process Unit	Amine Treatment
Assumed Material	Methane
Pressure (bara)	60
Temperature (deg C)	44
Phase	Gas
Inventory (kg)	28,670
Outflow Rate for Representative Failure (50mm) (kg/s)	17.8
Estimated Release Duration for Representative (50mm) Failure	15-30mins
Congested Volume (m^3)	20,300

5.4.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-04. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-7 and Table 5-11 respectively.

Table 5-11 MAE N-04 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	80	117
	5	71	91
	10	60	64
	20	52	43
5/D	3	80	117
	5	71	91
	10	62	64
	20	55	43

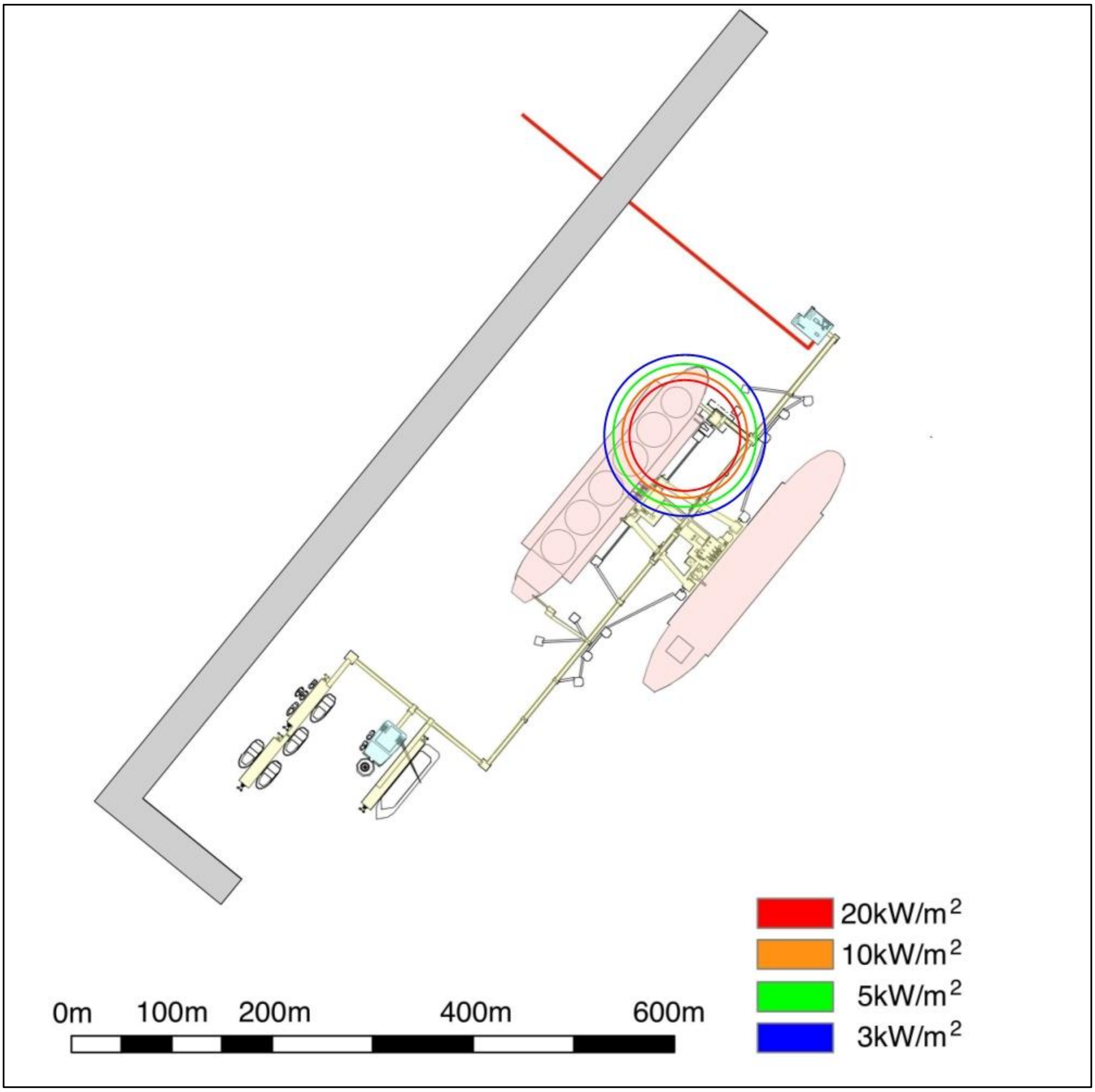


Figure 5-7 MAE N-04 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE N-04. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-8 and Table 5-12 respectively.

Table 5-12 MAE N-04 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
91	600	280
	1000	214
	2600	91

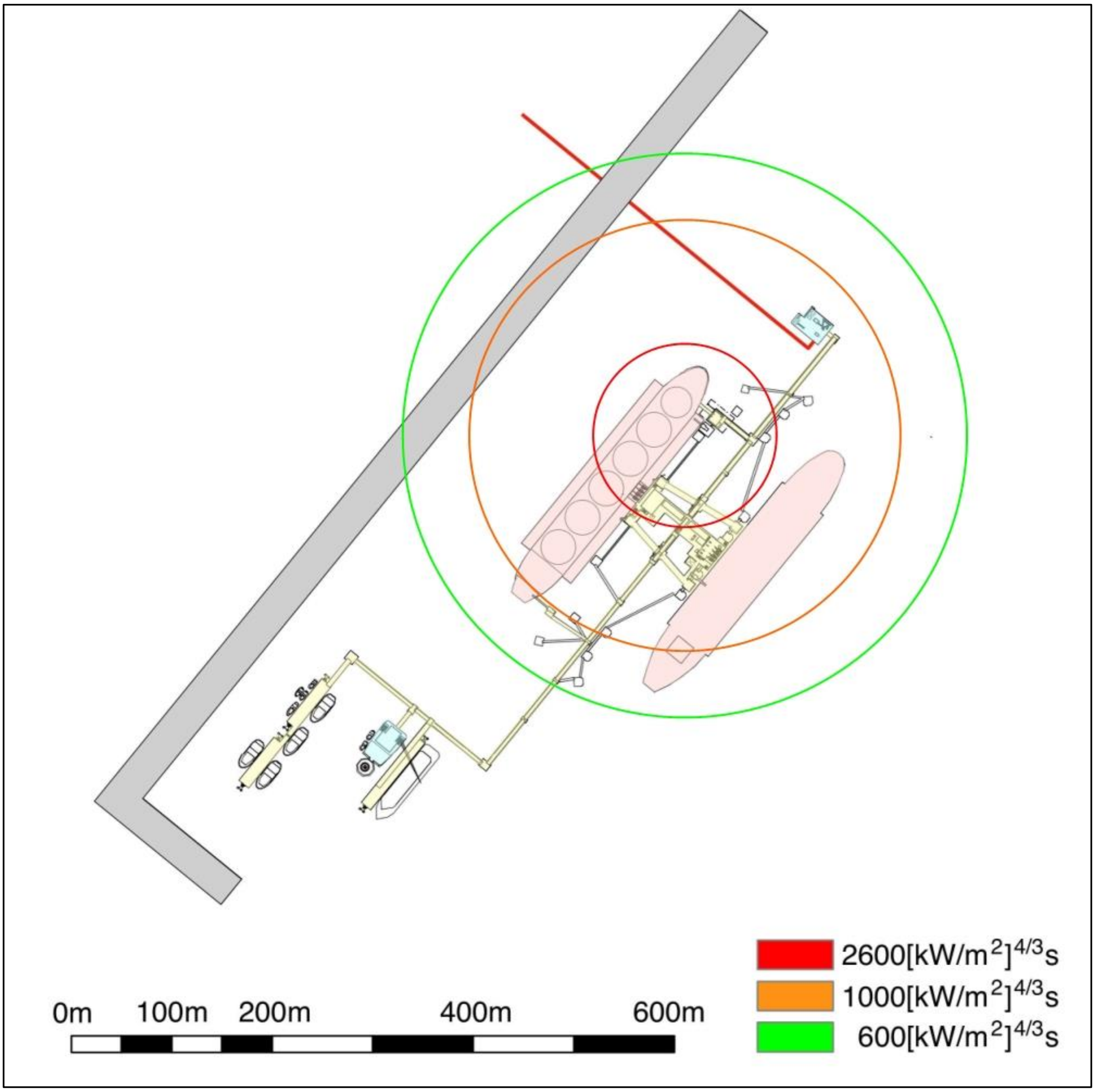


Figure 5-8 MAE N-04 Fireball Contour for Catastrophic Failure (scale in m)

5.4.3. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (starboard sponson) following loss of containment for MAE N-04 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) completely fills the module. The contour plot and overpressures associated with 100% fill of the region are shown in Figure 5-9 and Table 5-13 respectively.

Table 5-13 MAE N-04 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1013
0.05	443
0.14	189
0.35	103

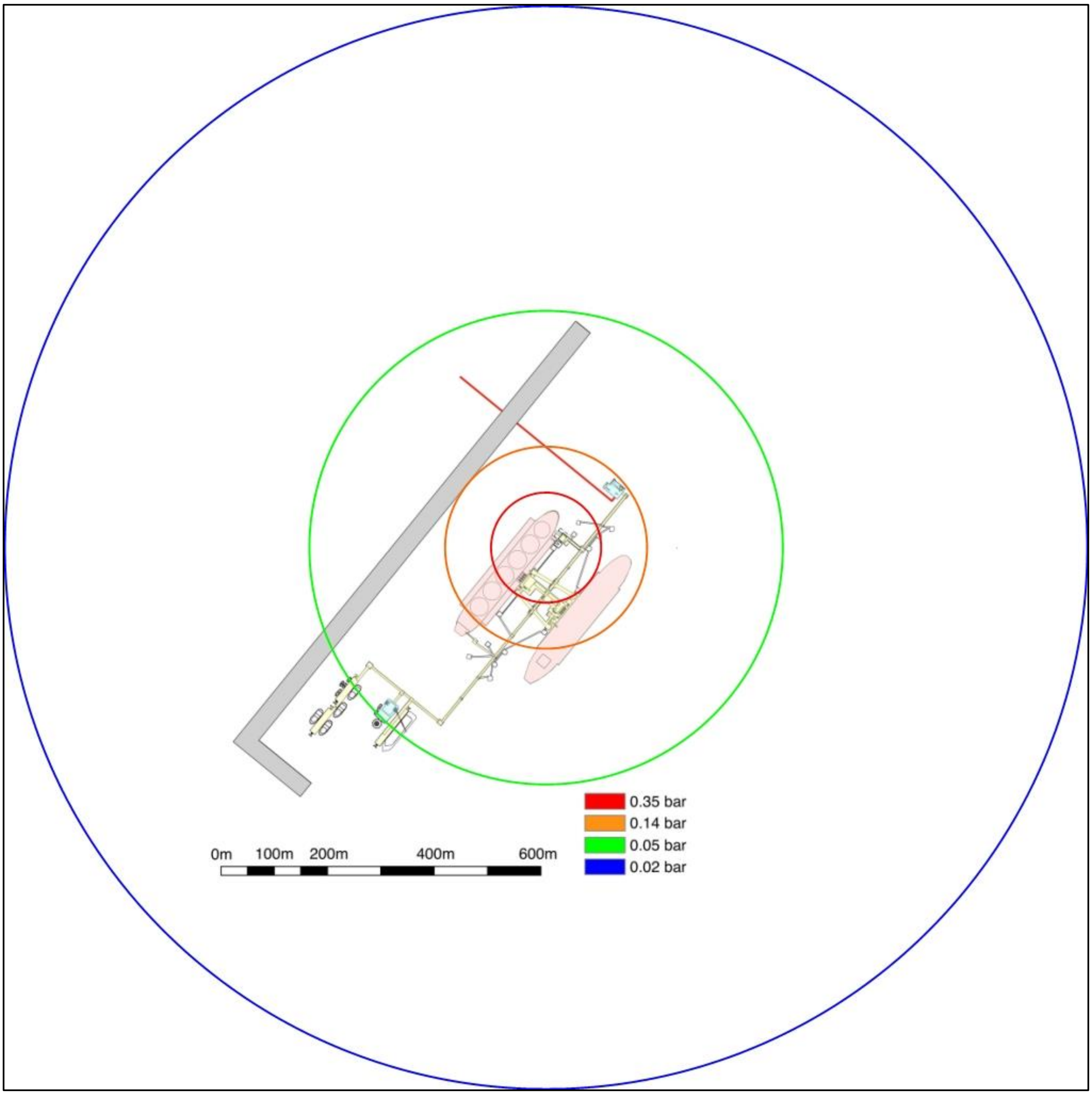


Figure 5-9 MAE N-04 Explosion Contours (scale in m)

5.5. MAE N-05: Gas Release from FLNG Dehydration and Regeneration

5.5.1. Event Description

This MAE is a release of flammable gas from gas dehydration and regeneration unit on the FLNG. The section begins downstream of the Amine Contractor and extends to the Boil Off Gas Compression System and the Liquefaction package. The section includes the following major equipment items:

- Recycler Gas Cooler
- Regeneration Cooler (x4)
- Recycle Compressor (x4)
- Regeneration Gas Separator
- Regeneration Gas Cooler
- Dehydrator (In Regeneration)
- Regeneration Gas Heater
- Mol Sieve Scrubber
- Mol Sieve Filter
- Dehydrator (x2)
- HG Removal Vessel

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-14, which are taken from the MAR study (Appendix B.1.1).

Table 5-14 MAE N-05 Stream Parameters

Parameter	Input
MAR Inventory	Dehydration and Regen Compression
Process Unit	Dehydration
Assumed Material	Methane
Pressure (bara)	60
Temperature (deg C)	40
Phase	Gas
Inventory (kg)	19,962
Outflow Rate for Representative Failure (50mm) (kg/s)	17.9
Estimated Release Duration for Representative (50mm) Failure	15-30mins
Congested Volume (m^3)	20,300

5.5.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-05. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-10 and Table 5-15 respectively.

Table 5-15 MAE N-05 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	81	117
	5	71	91
	10	60	64
	20	52	43
5/D	3	80	117
	5	71	91
	10	62	64
	20	55	43

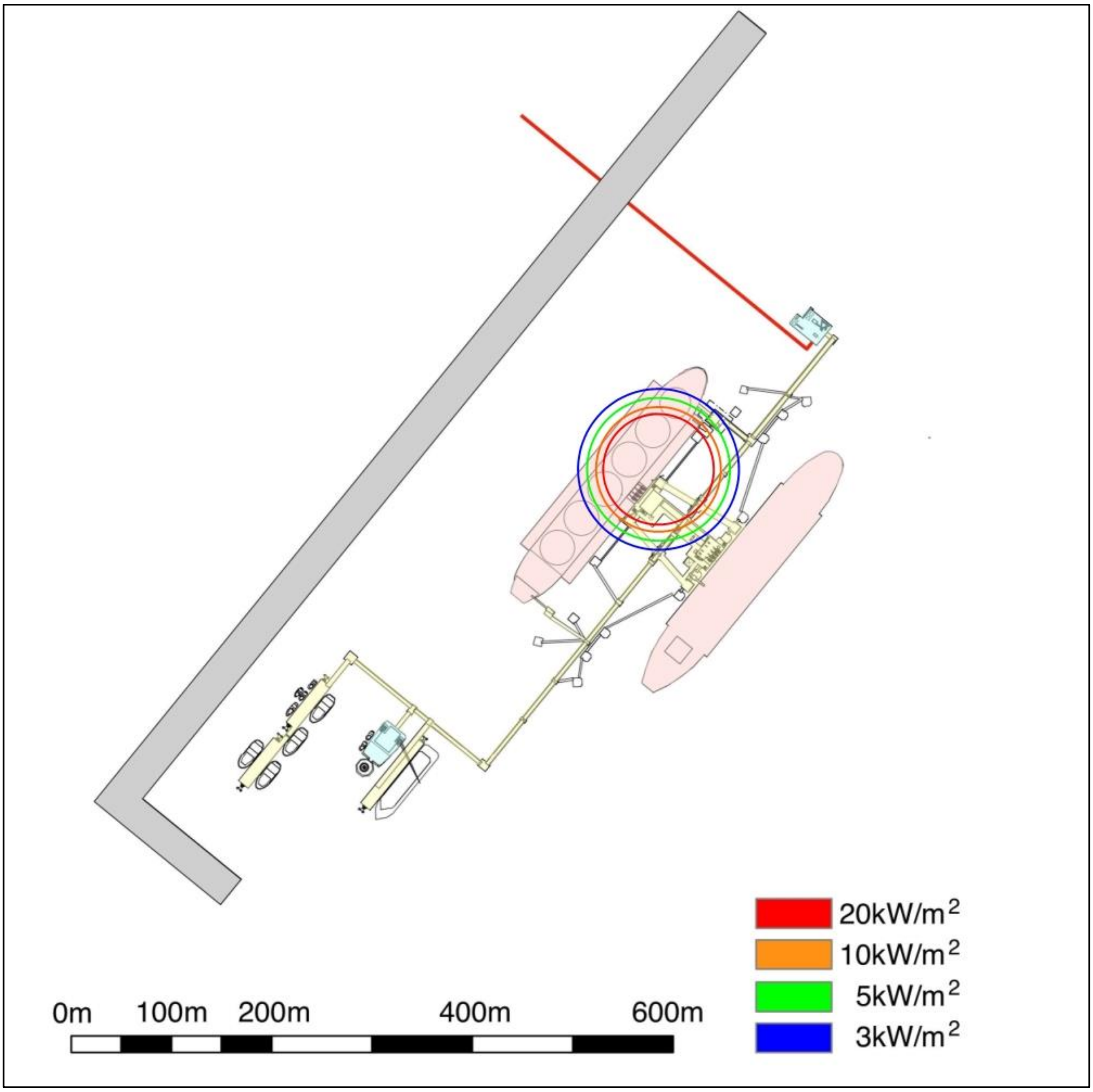


Figure 5-10 MAE N-05 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE N-05. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-11 and Table 5-16 respectively.

Table 5-16 MAE N-05 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ($[kW/m^2]^{4/3}$ s)	Distance from Release Point (m)
81	600	241
	1000	182
	2600	68

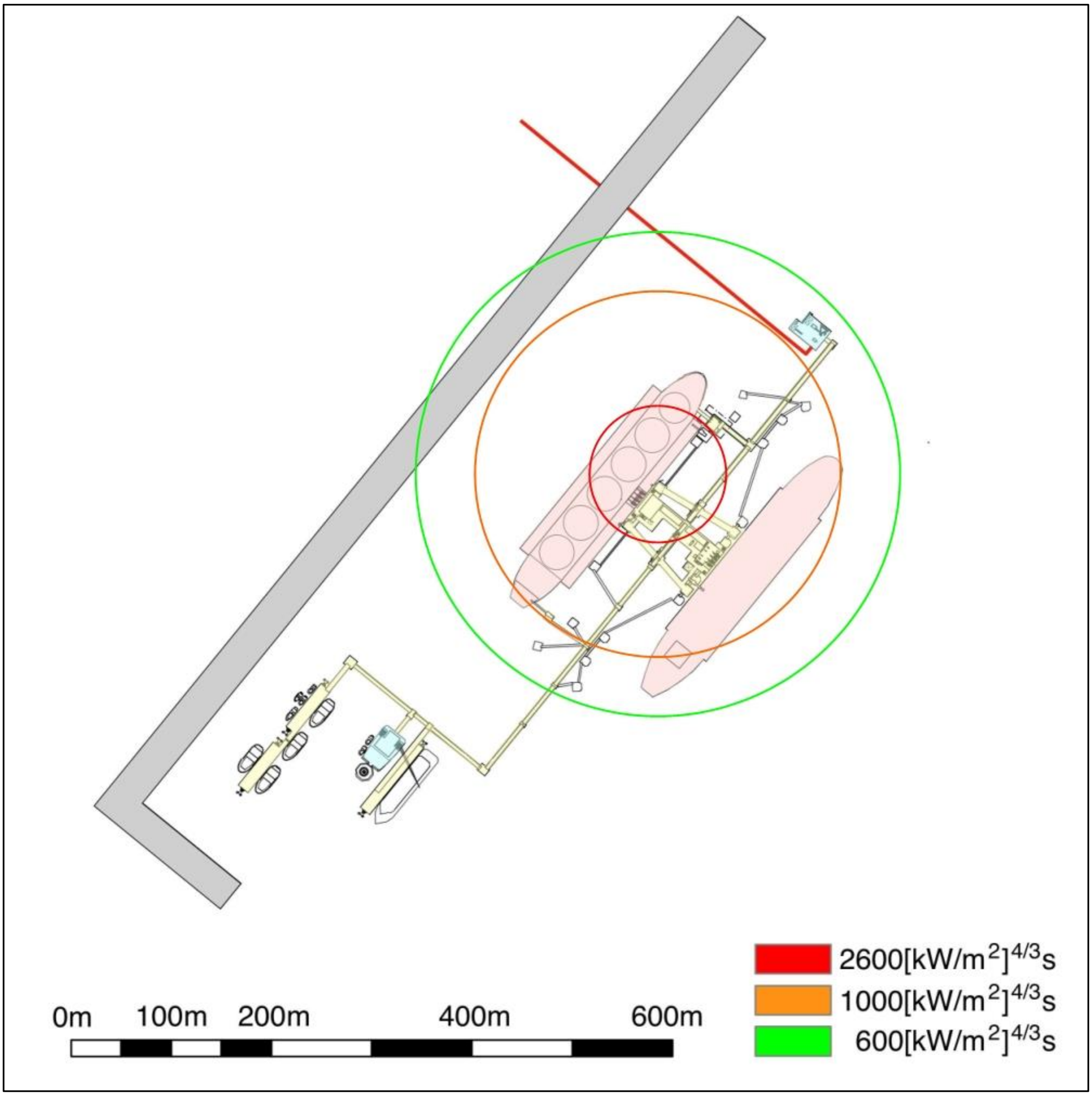


Figure 5-11 MAE N-05 Fireball Contour for Catastrophic Failure (scale in m)

5.5.3. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (starboard sponson) following loss of containment for MAE N-05 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) completely fills the congested region. The contour plot and overpressures associated with 100% fill of the congested region is shown in Figure 5-12 and Table 5-17 respectively.

Table 5-17 MAE N-05 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1013
0.05	443
0.14	189
0.35	103

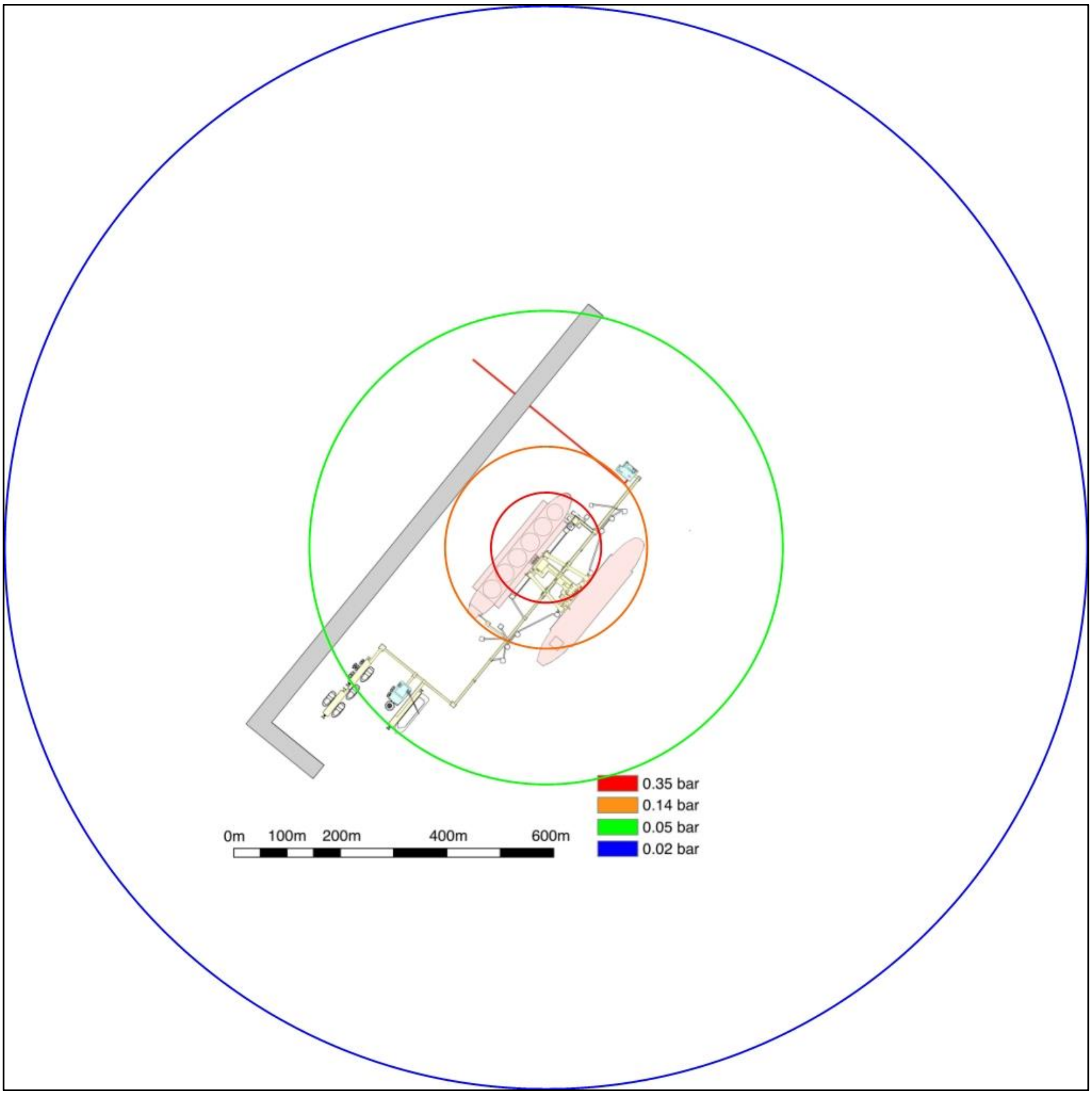


Figure 5-12 MAE N-05 Explosion Contours (scale in m)

5.6. MAE N-06: Gas Release from FLNG Boil Off Gas / Flash Gas Compression

5.6.1. Event Description

This MAE is a release of flammable gas from the boil off gas / flash gas compression unit on the FLNG. The section takes boil off gas from the LNG flash drum and links to the fuel gas unit at a higher pressure. The section includes the following major equipment items:

- BOG Discharge Cooler
- BOG Compressor Oil Separator (x2)
- BOG Compressor (x3)
- BOG Exchanger (x2)
- BOG Compressor Discharge Cooler
- LNG Flash Drum (Vapour Space)
- LNG Storage Tank (x6) (Vapour Space)

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-18, which are taken from the MAR study (Appendix B.1.1).

Table 5-18 MAE N-06 Stream Parameters

Parameter	Input
MAR Inventory	Boil Off Gas Compression
Process Unit	Boil Off Gas
Assumed Material	Methane
Pressure (bara)	60
Temperature (deg C)	36
Phase	Gas
Inventory (kg)	131
Outflow Rate for Representative Failure (50mm) (kg/s)	18.1
Estimated Release Duration	<1min
Congested Volume (m^3)	10,150

5.6.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-06. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-13 and Table 5-19 respectively.

Table 5-19 MAE N-06 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	81	118
	5	71	92
	10	61	64
	20	52	44
5/D	3	80	118
	5	72	91
	10	62	64
	20	55	43

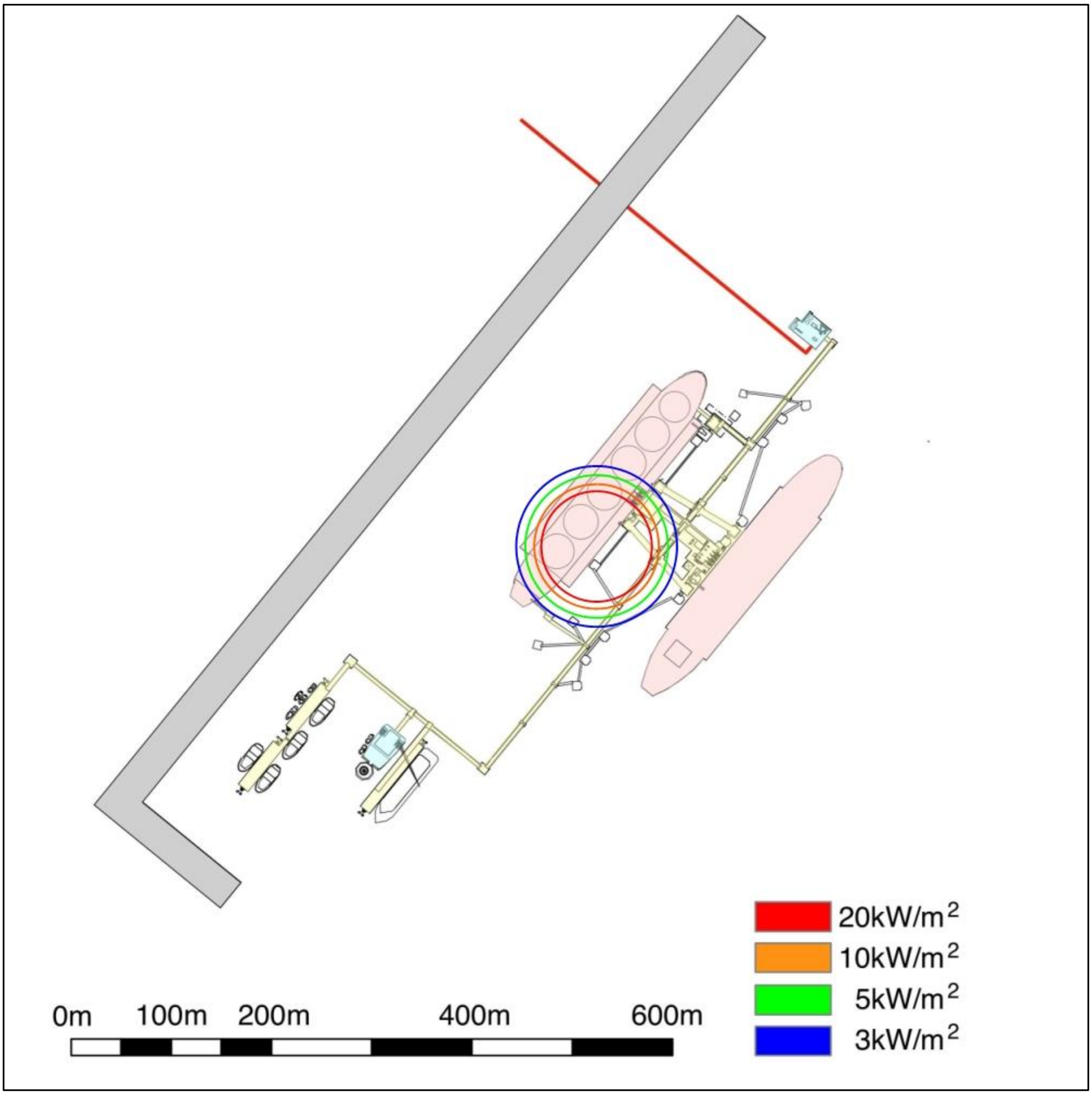
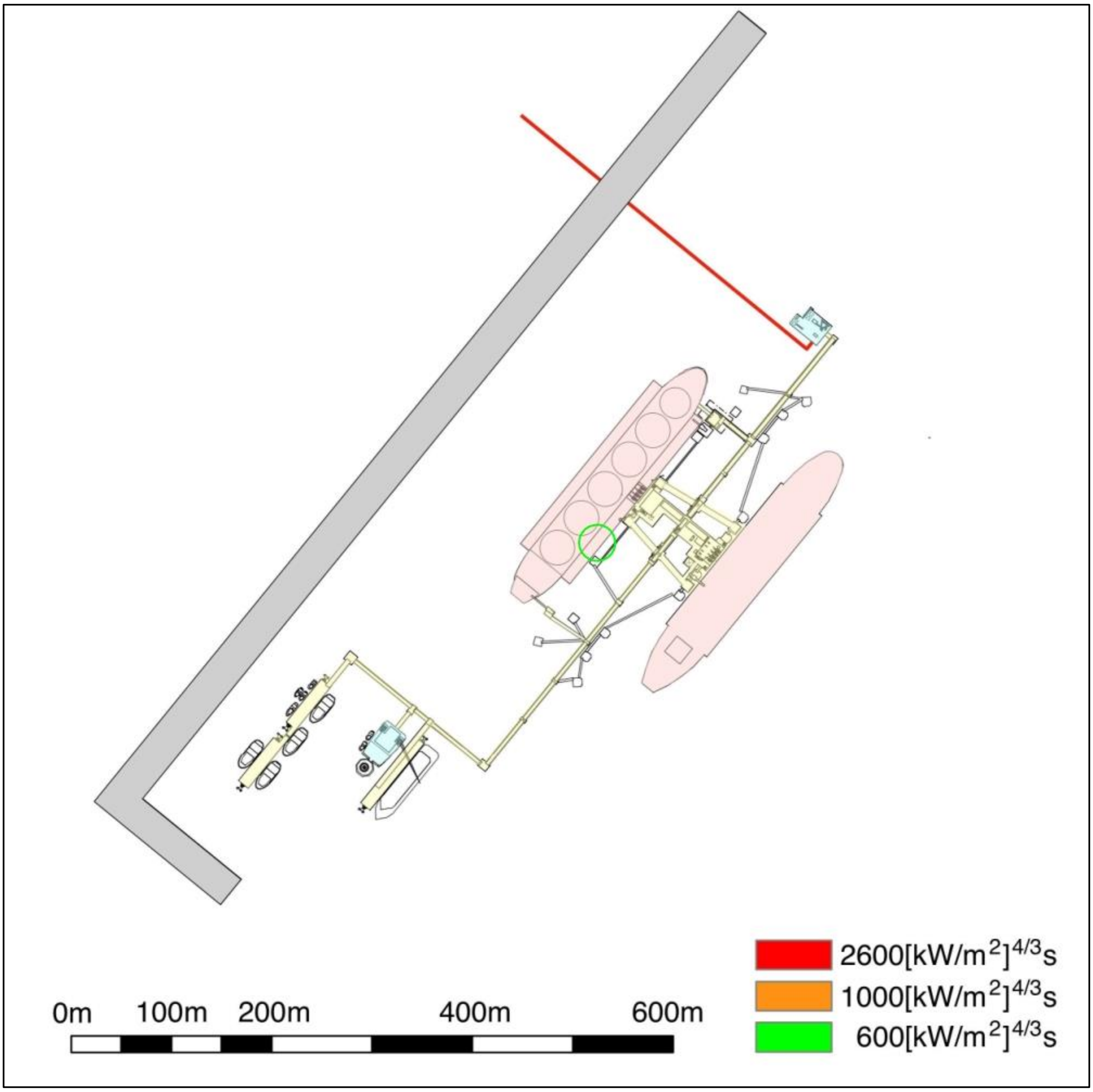


Figure 5-13 MAE N-06 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE N-06. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-14 and Table 5-20 respectively.

Table 5-20 MAE N-06 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
16	600	18
	1000	Not Reached
	2600	Not Reached



NOTE: The higher thermal dose levels were not reached.

Figure 5-14 MAE N-06 Fireball Contour for Catastrophic Failure (scale in m)

5.6.3. Explosion Results

Ignition of flammable gas dispersed into a congested region (starboard sponson) following loss of containment for MAE N-06 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) is limited to the total flammable inventory within the section. The contour plot and overpressures associated with an explosion in this region are shown in Figure 5-15 and Table 5-21 respectively.

Table 5-21 MAE N-06 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	470
0.05	205
0.14	88
0.35	48

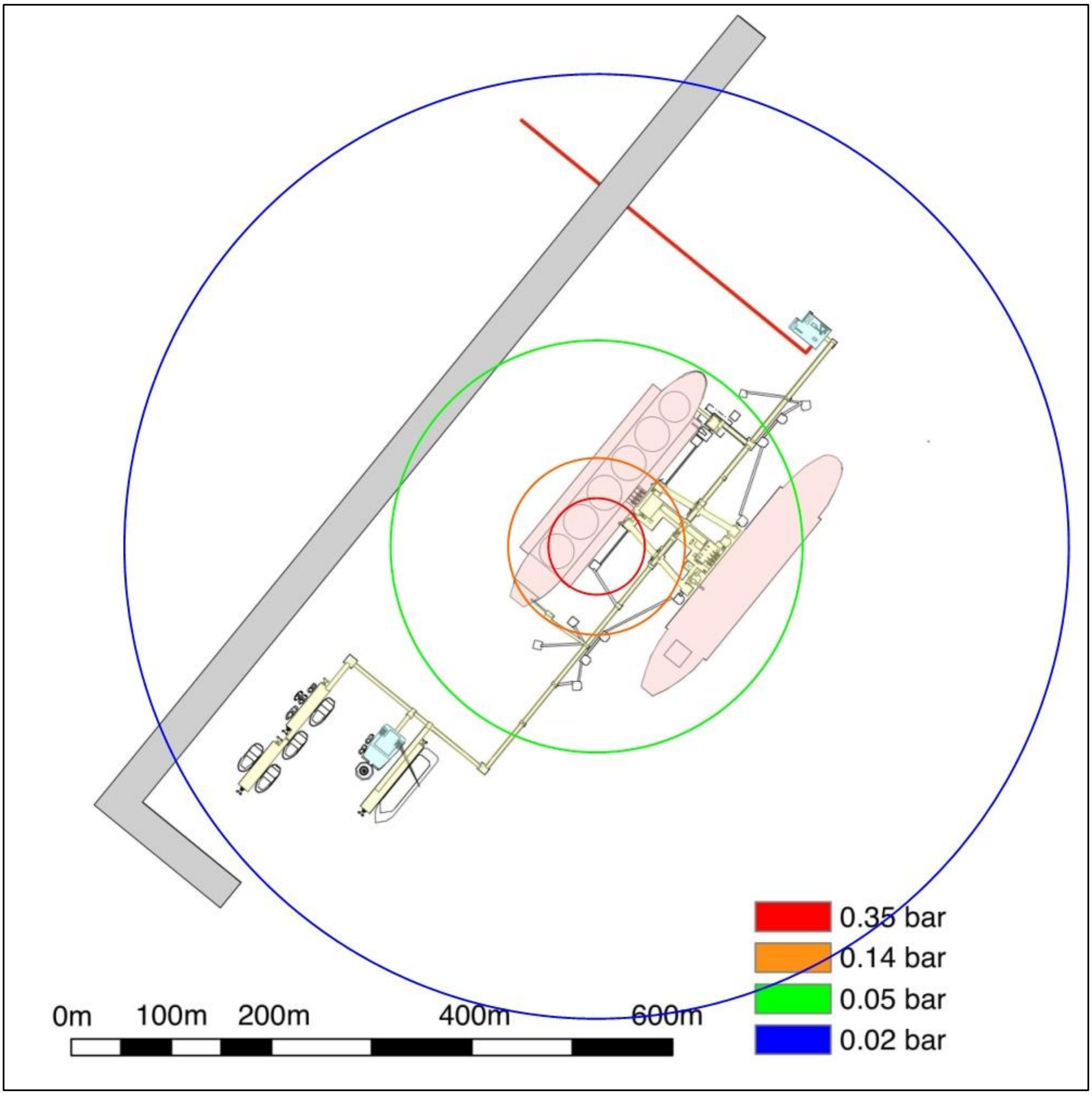


Figure 5-15 MAE N-06 Explosion Contours (scale in m)

5.7. MAE N-07: Fuel Gas Release from FLNG HP Fuel Gas System

5.7.1. Event Description

This MAE is a release of flammable gas from the fuel gas unit on the FLNG. This section begins downstream of the HP Separator and leads to the HP/LP Fuel Gas users. The section includes the following major equipment items:

- Fuel Gas Heater
- Fuel Gas Super Heater
- Fuel Gas KO Drum
- Fuel Gas Scrubber

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-22, which are taken from MAR Inventory 1 (Appendix B.1.1).

Table 5-22 MAE N-07 Stream Parameters

Parameter	Input
MAR Inventory	Fuel Gas System
Process Unit	Fuel Gas
Assumed Material	Methane
Pressure (bara)	38
Temperature (deg C)	45
Phase	Gas
Inventory (kg)	191
Outflow Rate for Representative Failure (50mm) (kg/s)	11.3
Estimated Release Duration for Representative (50mm) Failure	<1min
Congested Volume (m^3)	10,150

5.7.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-07. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-16 and Table 5-23 respectively.

Table 5-23 MAE N-07 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	64	92
	5	57	72
	10	49	50
	20	42	34
5/D	3	64	92
	5	57	71
	10	50	50
	20	45	33

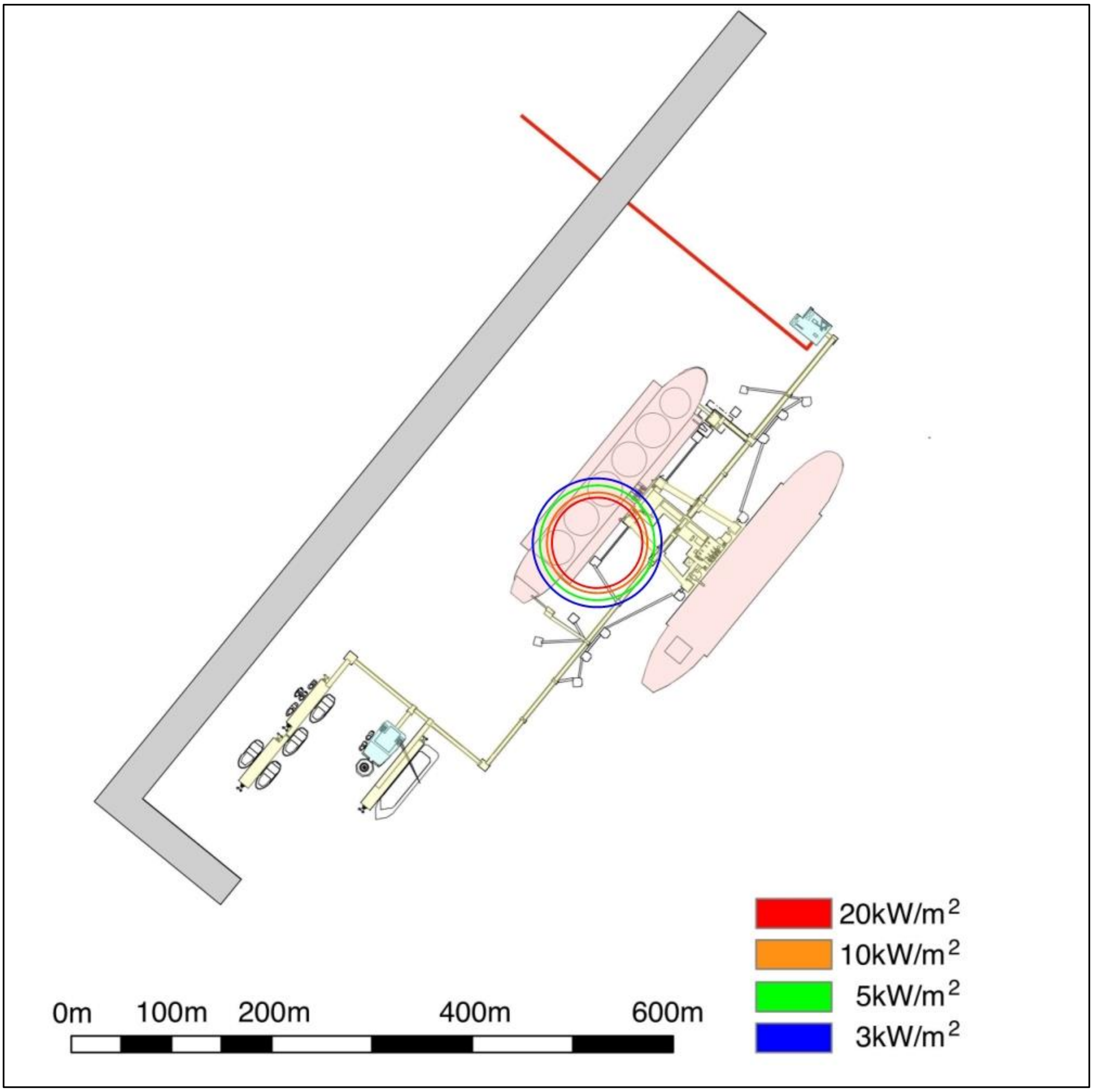
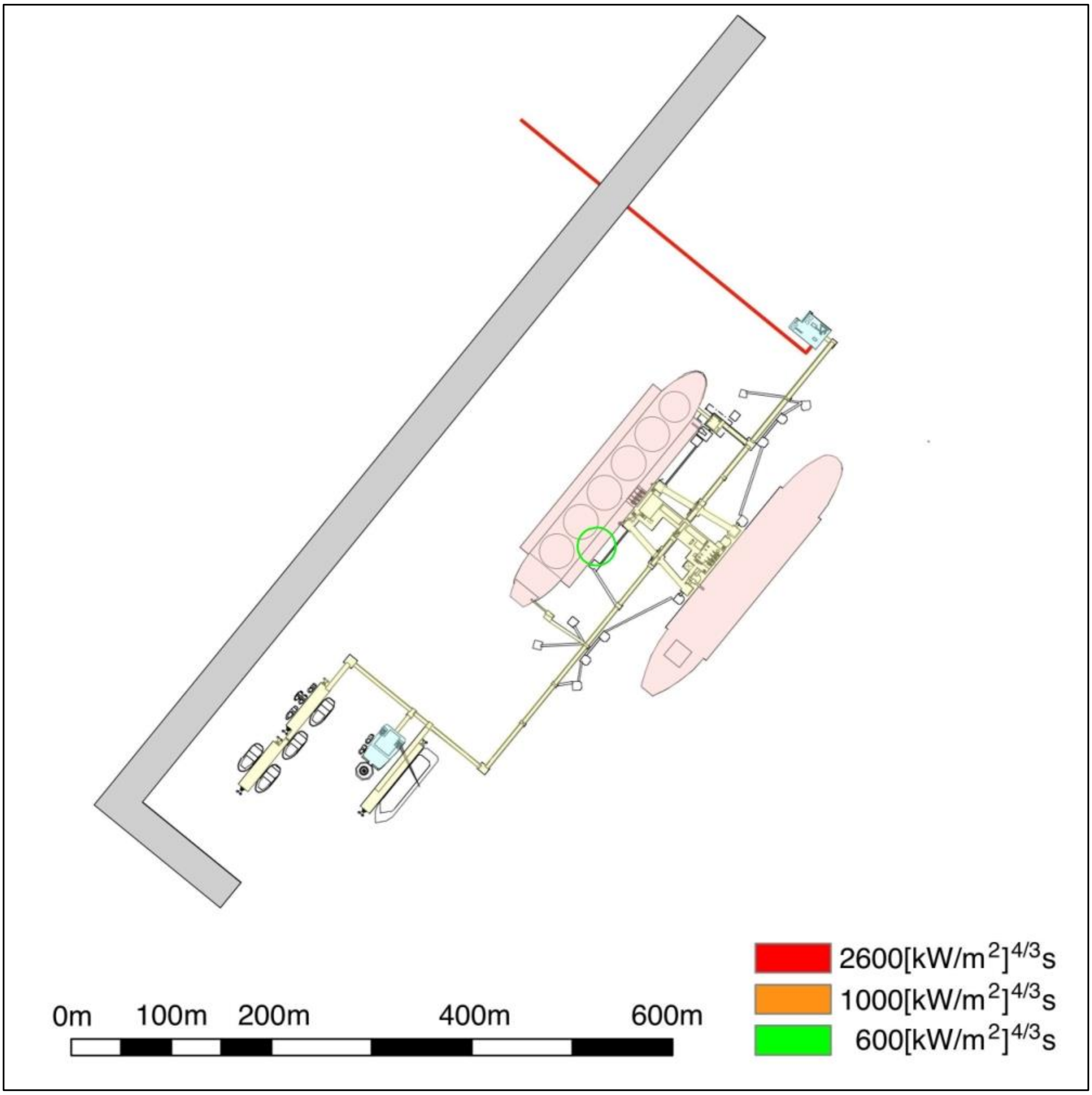


Figure 5-16 MAE N-07 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE N-07. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-17 and Table 5-24 respectively.

Table 5-24 MAE N-07 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
18	600	19
	1000	Not Reached
	2600	Not Reached



NOTE: The higher thermal dose levels were not reached.

Figure 5-17 MAE N-07 Fireball Contour for Catastrophic Failure (scale in m)

5.7.3. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (starboard sponson) following loss of containment for MAE N-07 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) is capped by the total mass in the section. The contour plot and overpressures associated with an explosion in this region is shown in Figure 5-18 and Table 5-25 respectively.

Table 5-25 MAE N-07 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	533
0.05	233
0.14	99
0.35	54

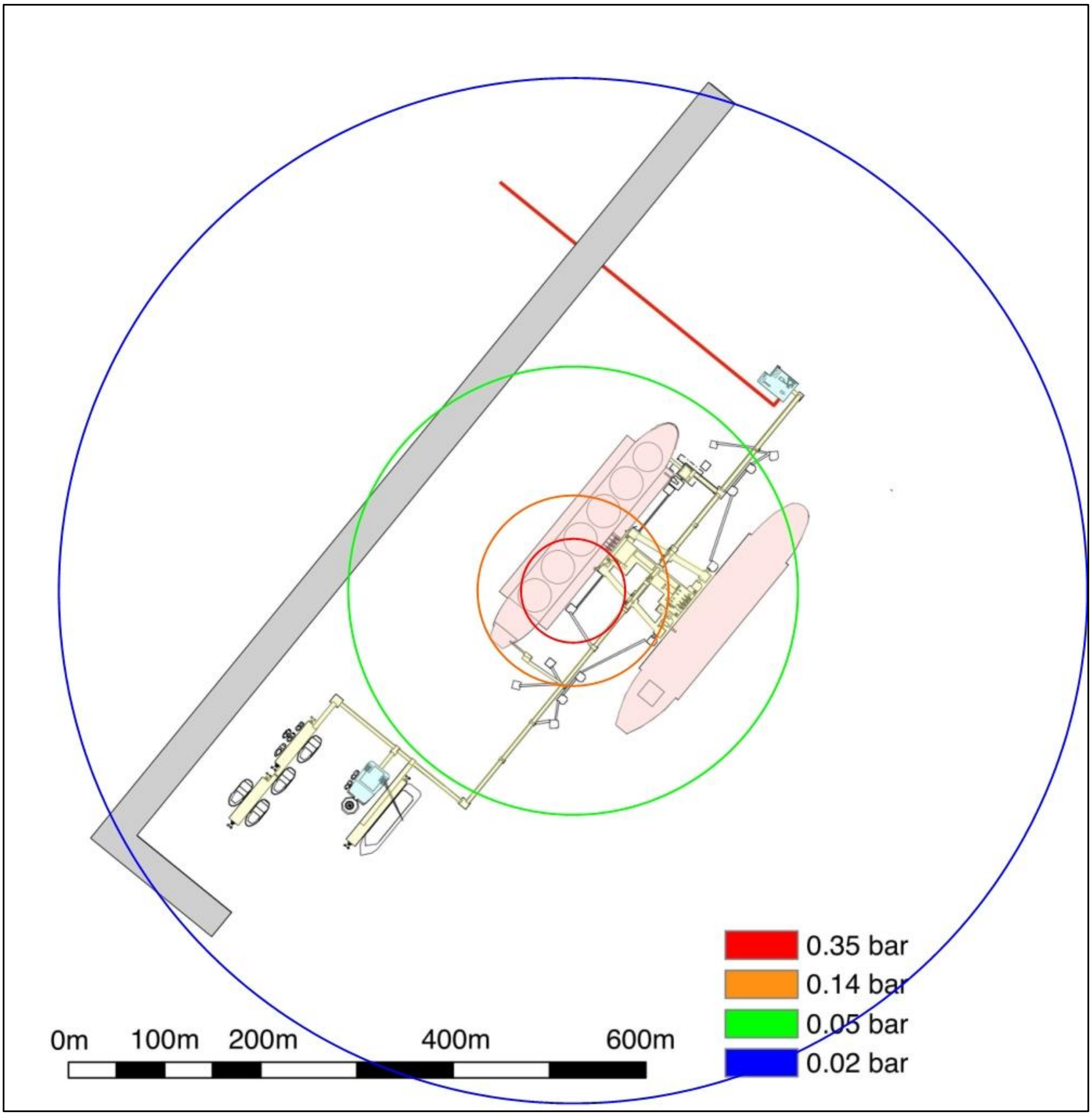


Figure 5-18 MAE N-07 Explosion Contour for 100% Fill of Fuel Gas Module (scale in m)

5.8. MAE N-08: Gas Release from FLNG Fractionation

5.8.1. Event Description

This MAE is a release of flammable gas from the fractionation system on the FLNG. The section includes the following major equipment items:

- Fractionator (vapour space)
- Fractionation Reflux Conditioner
- Fractionation Reflux Drum (vapour space)
- HP Heavy Separator (vapour space)

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-26.

Table 5-26 MAE N-08 Stream Parameters

Parameter	Input
MAR Inventory	-
Process Unit	Fractionation
Assumed Material	Methane
Pressure (bara)	30
Temperature (deg C)	-40
Phase	Gas
Inventory (kg)	7,250
Outflow Rate for Representative Failure (50mm) (kg/s)	11.0
Estimated Release Duration for Representative (50mm) Failure	5-15mins
Congested Volume (m^3)	20,300

5.8.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-08. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-19 and Table 5-27 respectively.

Table 5-27 MAE N-08 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	63	91
	5	56	71
	10	48	49
	20	42	33
5/D	3	63	90
	5	56	70
	10	49	49
	20	44	33

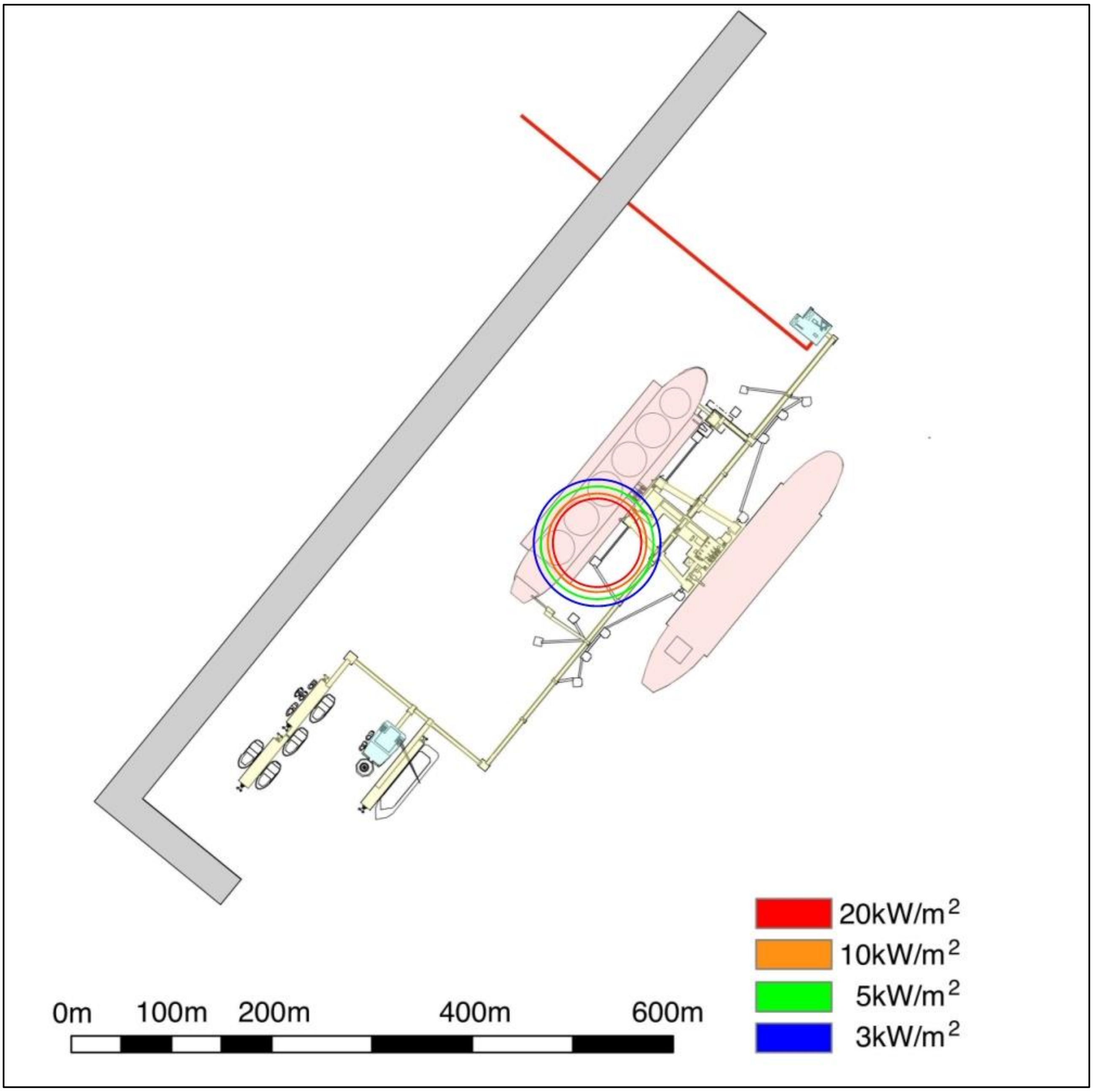
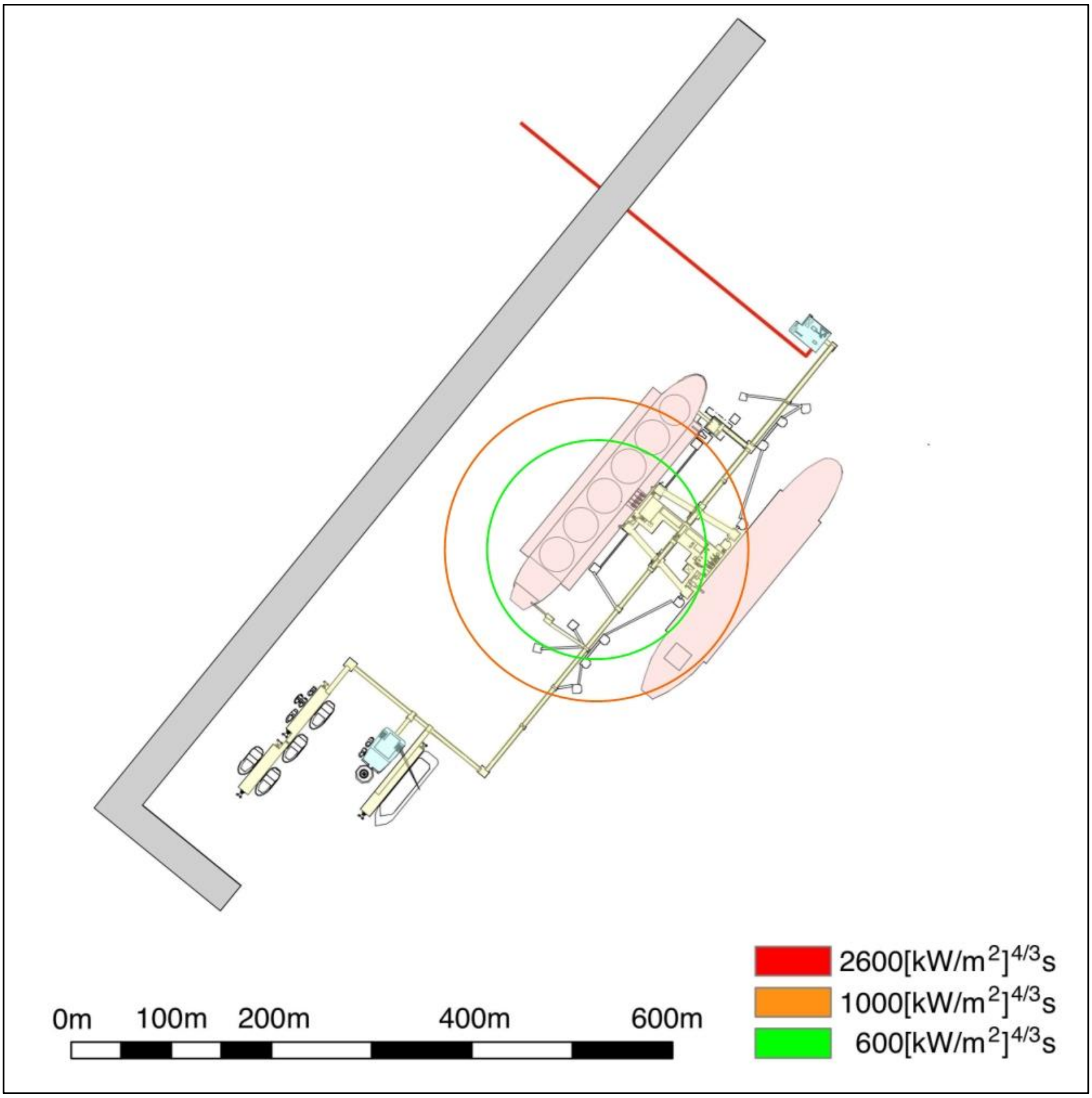


Figure 5-19 MAE N-08 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE N-08. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-20 and Table 5-28 respectively.

Table 5-28 MAE N-08 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
58	600	151
	1000	109
	2600	Not Reached



NOTE: The higher thermal dose level was not reached.

Figure 5-20 MAE N-08 Fireball Contour for Catastrophic Failure (scale in m)

5.8.3. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (portside sponson) following loss of containment for MAE N-08 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) completely fills the region. The contour plot and overpressures associated with an explosion are shown in Figure 5-21 and Table 5-29 respectively.

Table 5-29 MAE N-08 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1013
0.05	443
0.14	189
0.35	103

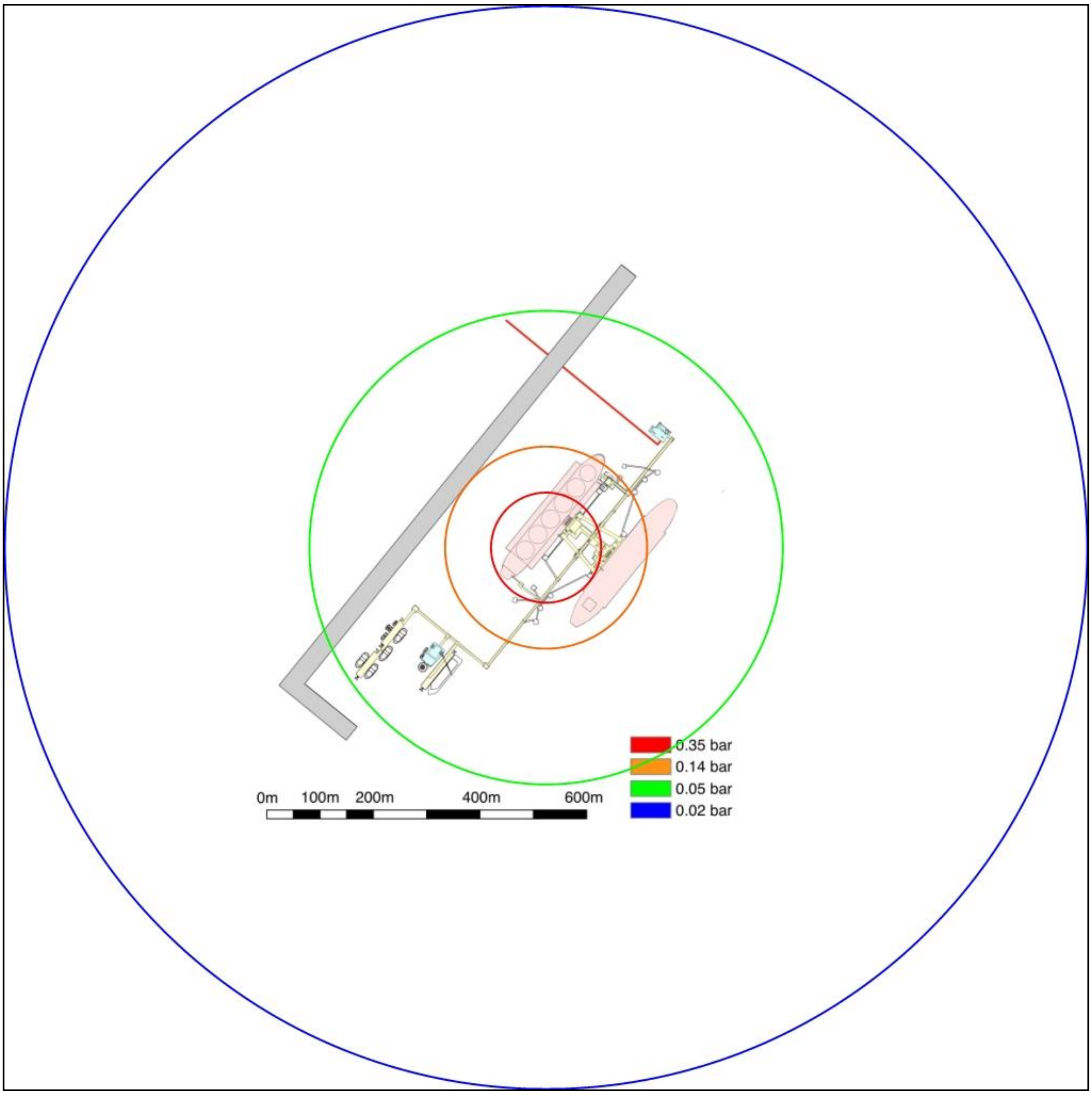


Figure 5-21 MAE N-08 Explosion Contours (scale in m)

5.9. MAE N-09: Light Hydrocarbon Liquid Releases from FLNG Fractionation

5.9.1. Event Description

This MAE is a release of hydrocarbon liquid from the fractionation system on the FLNG. The section includes the following major equipment items:

- HP Heavy Separator
- Heavies Heat Exchanger
- Fractionator
- Fractionation Reboiler
- Heavies Booster Pump (x2)
- Fractionation Reflux Drum
- Fractionation Reflux Pump

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-30.

Table 5-30 MAE N-09 Stream Parameters

Parameter	Input
MAR Inventory	-
Process Unit	Fractionation
Assumed Material	Propane
Pressure (bara)	30
Temperature (deg C)	-40
Phase	Liquid
Inventory (kg)	12,000
Outflow Rate for Representative Failure (50mm) (kg/s)	67.2
Estimated Release Duration for Representative (50mm) Failure	1-5mins
Congested Volume (m^3)	20,300

5.9.2. Fire Results

Light hydrocarbon liquid released from MAE N-09 is expected to flash on release from a representative failure (50 mm) or form a liquid spray. Immediate ignition of this release will result in a jet / liquid spray fire for MAE N-09. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-22 and Table 5-31 respectively.

Table 5-31 MAE N-09 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	182	263
	5	160	203
	10	139	148
	20	122	107
5/D	3	168	265
	5	146	204
	10	123	144
	20	106	106

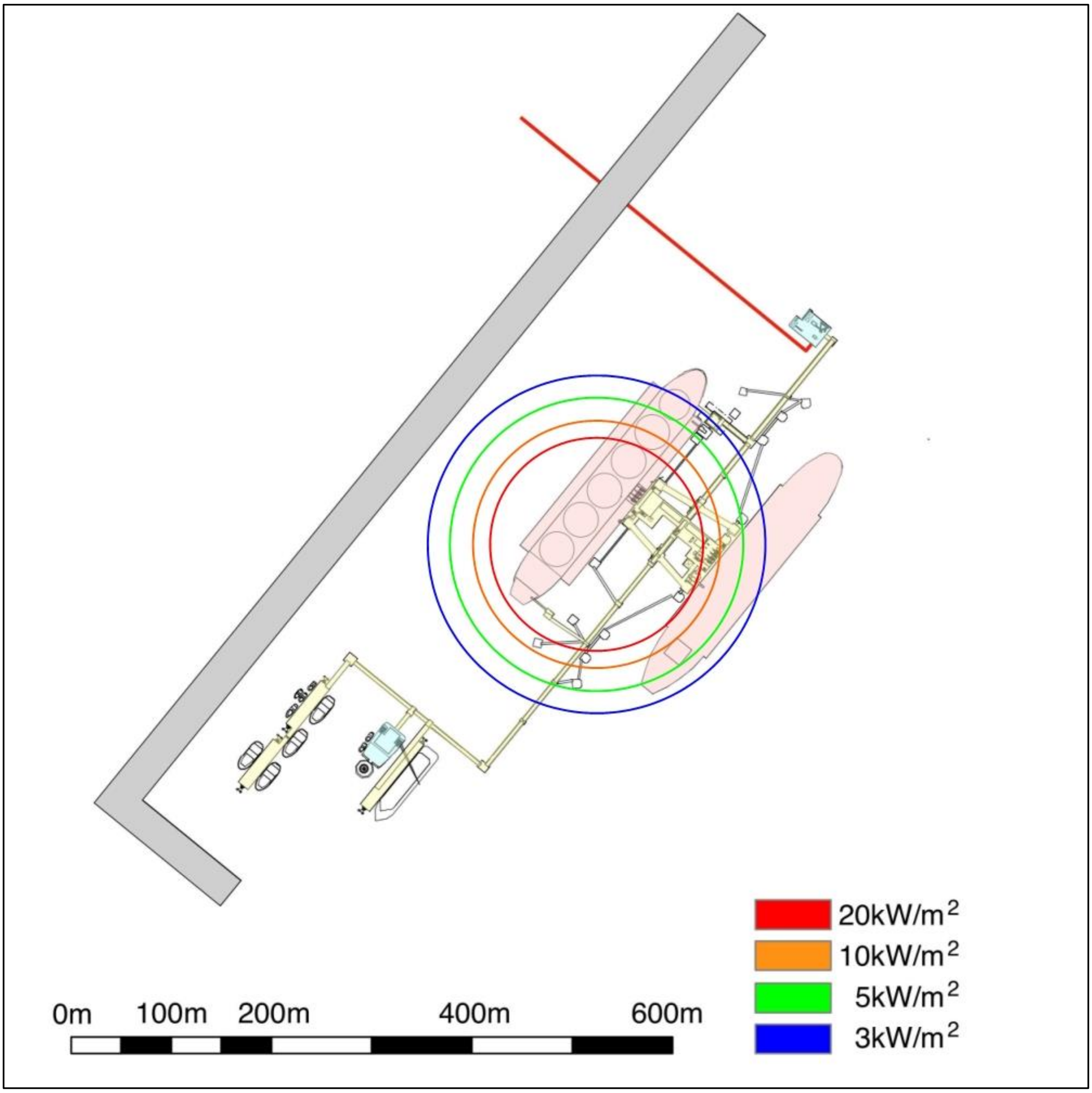


Figure 5-22 MAE N-09 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Light hydrocarbon liquid released from MAE N-09 is expected to mostly flash on release following a catastrophic failure (credible worst case), or to form small airborne liquid droplets. Ignition of a catastrophic failure for MAE N-09 is best represented by a fireball. The contour plot and hazard ranges due to the thermal dose from a fireball are shown in Figure 5-23 and Table 5-32 respectively.

Table 5-32 MAE N-09 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ($[kW/m^2]^{4/3}$ s)	Distance from Release Point (m)
67	600	175
	1000	128
	2600	8

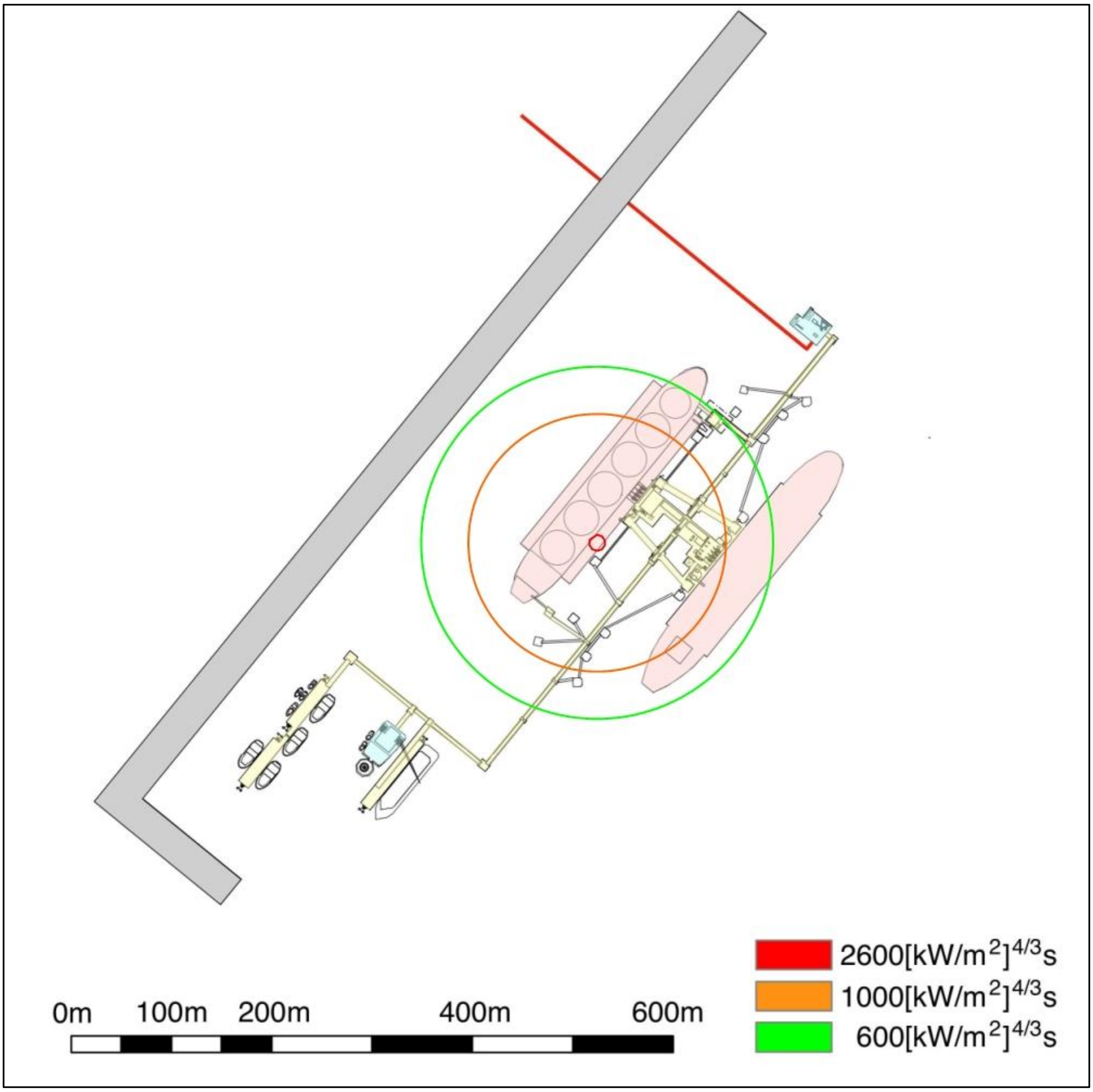


Figure 5-23 MAE N-09 Fireball Contour for Catastrophic Failure (scale in m)

5.9.3. Flash Fire Results

Delayed ignition of flammable vapour released into an open or uncongested area following loss of containment will result in a flash fire for MAE N-09. The distances to 100% LFL are presented in Table 5-33 and Table 5-34 for a representative failure (50 mm) and catastrophic failure (credible worst case) respectively. The contour plots to 100% LFL are presented in Figure 5-24 and Figure 5-25 for a representative failure (50 mm) and catastrophic failure (credible worst case) respectively.

Table 5-33 MAE N-09 50mm 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	204
5/D	117

Table 5-34 MAE N-09 Catastrophic Failure 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	352
5/D	186

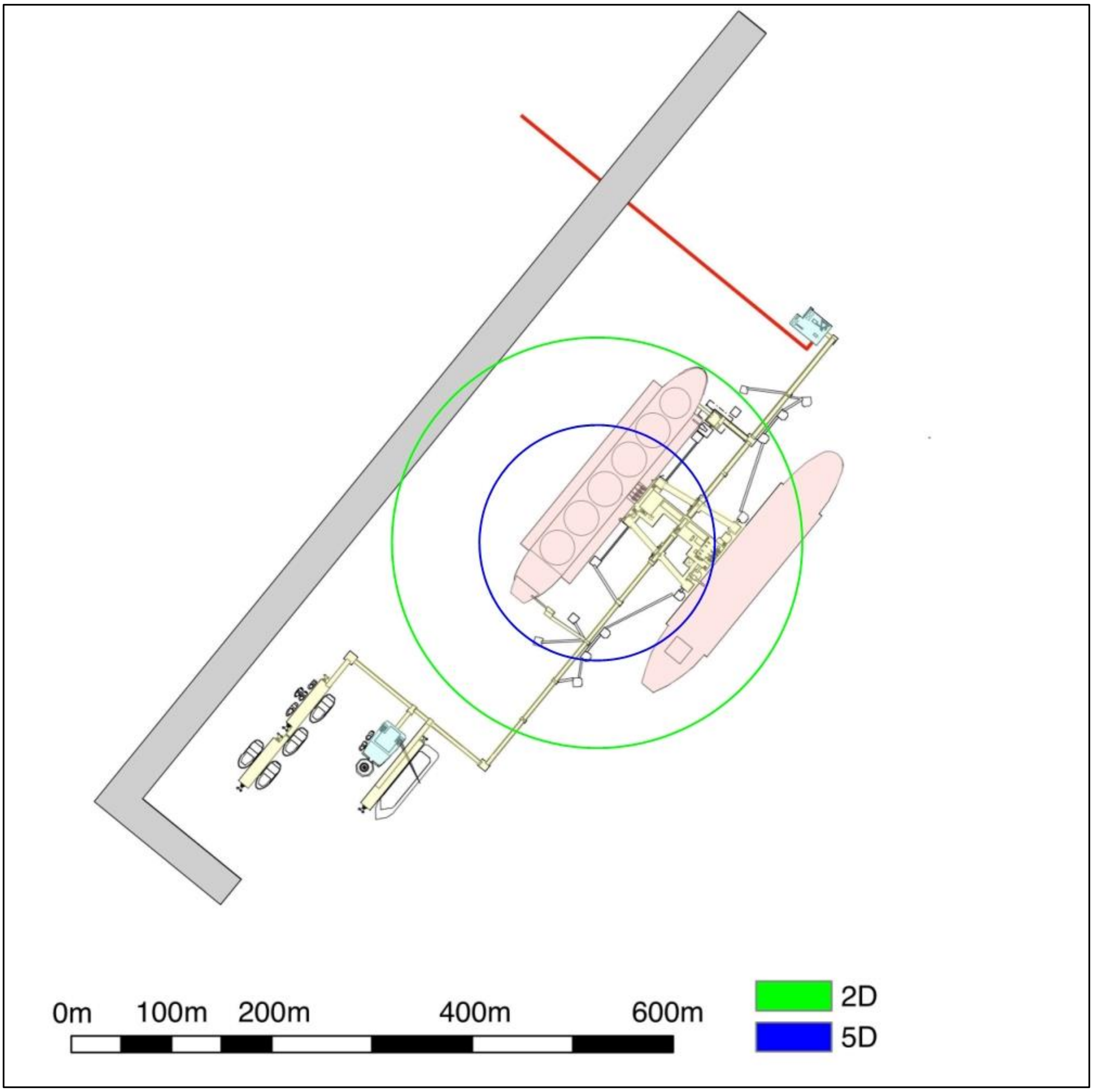


Figure 5-24 MAE N-09 Flashfire Extent to 100% LFL for 50mm Failures (scale in m)

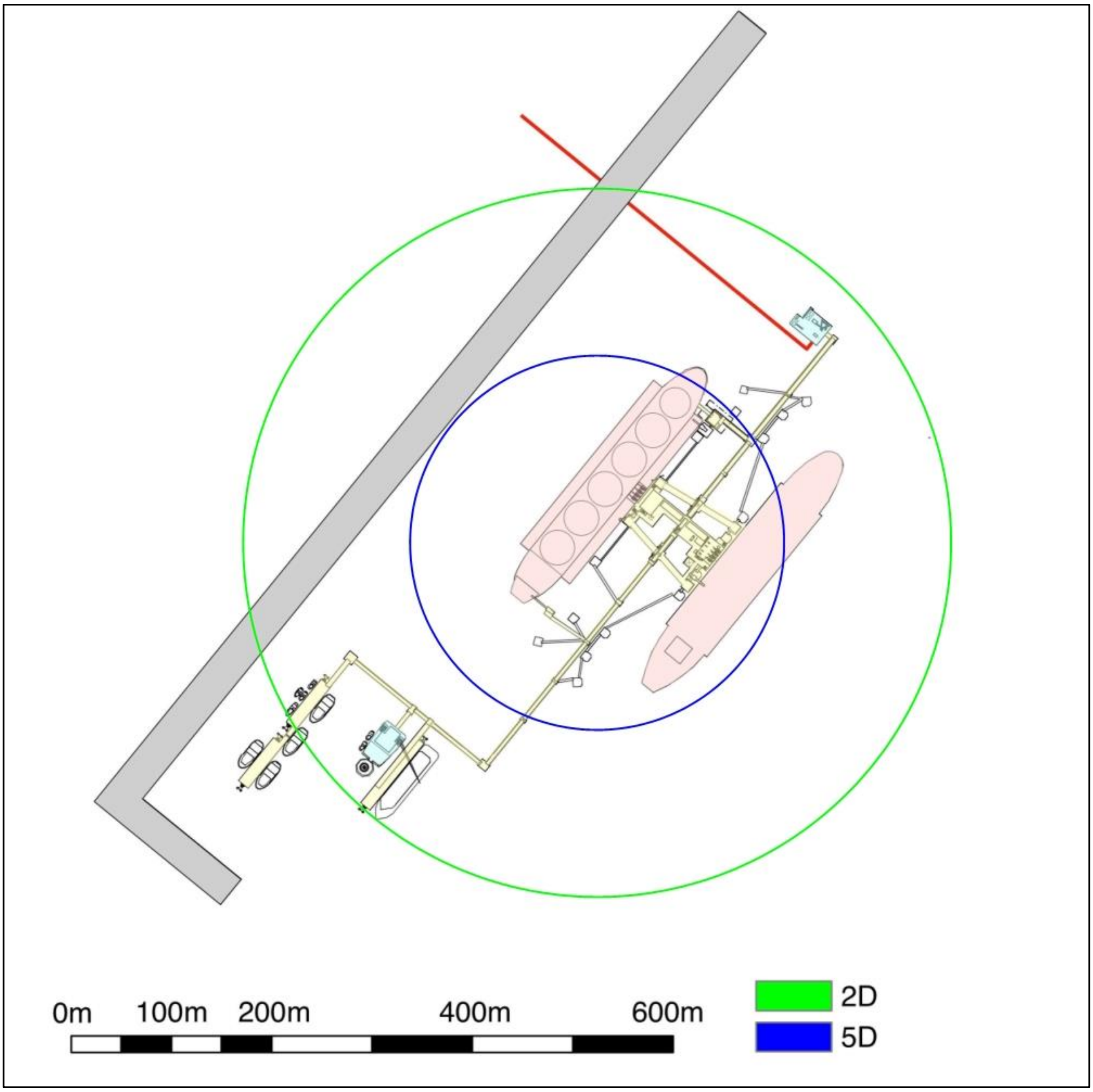


Figure 5-25 MAE N-09 Flashfire Extent to 100% LFL for Catastrophic Failures (scale in m)

5.9.4. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (portside sponson) following loss of containment for MAE N-09 will result in a vapour cloud explosion. Flammable gas in an explosion from a representative failure (50 mm) and a catastrophic failure (credible worst case) completely fills the congested region. The contour plot and overpressure associated with an explosion are shown in Figure 5-26 and Table 5-35 respectively.

Table 5-35 MAE N-09 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1045
0.05	457
0.14	195
0.35	106

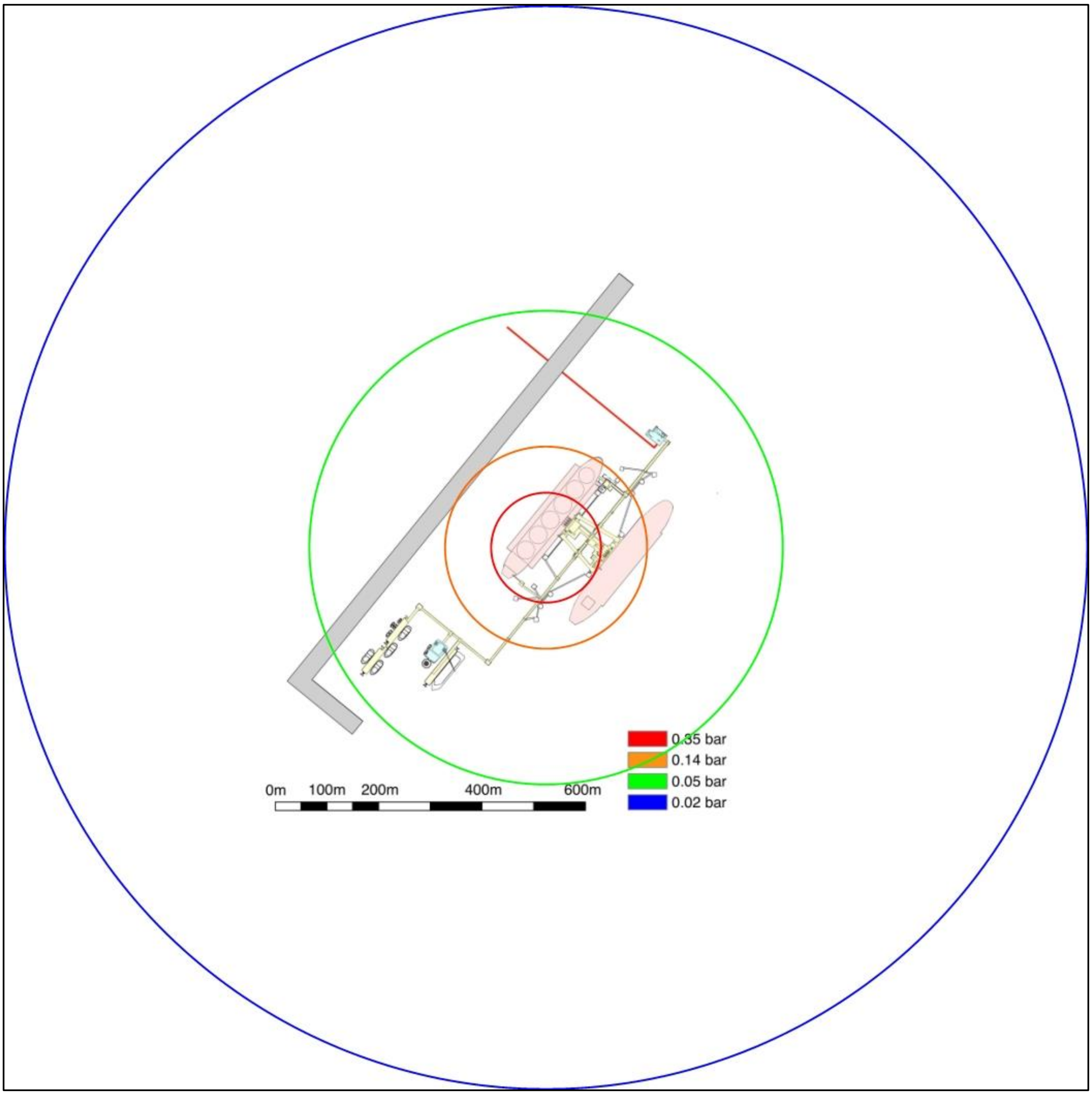


Figure 5-26 MAE N-09 Explosion Contours (scale in m)

5.10. MAE N-10: LNG Release from FLNG Liquefaction Process

5.10.1. Event Description

This MAE is a release of LNG from the Main Liquefaction Exchanger and connecting pipework. The section is downstream of the Fractionation Reflux Drum and upstream of the Expander/Flash Drum.

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-36.

Table 5-36 MAE N-10 Stream Parameters

Parameter	Input
MAR Inventory	-
Process Unit	Liquefication
Assumed Material	Methane
Pressure (bara)	18
Temperature (deg C)	-109
Phase	Liquid
Inventory (kg)	11,750
Outflow Rate for Representative Failure (50mm) (kg/s)	42.8
Estimated Release Duration for Representative (50mm) Failure	1-5mins
Congested Volume (m^3)	20,300

5.10.2. Fire Results

LNG released from MAE N-10 is expected to flash on release from a representative failure (50 mm) or form a liquid spray. Immediate ignition of this release will result in a jet / liquid spray fire for MAE N-10. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-27 and Table 5-37 respectively.

Table 5-37 MAE N-10 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	52	73
	5	46	57
	10	40	40
	20	35	27
5/D	3	52	73
	5	46	56
	10	41	39
	20	37	26

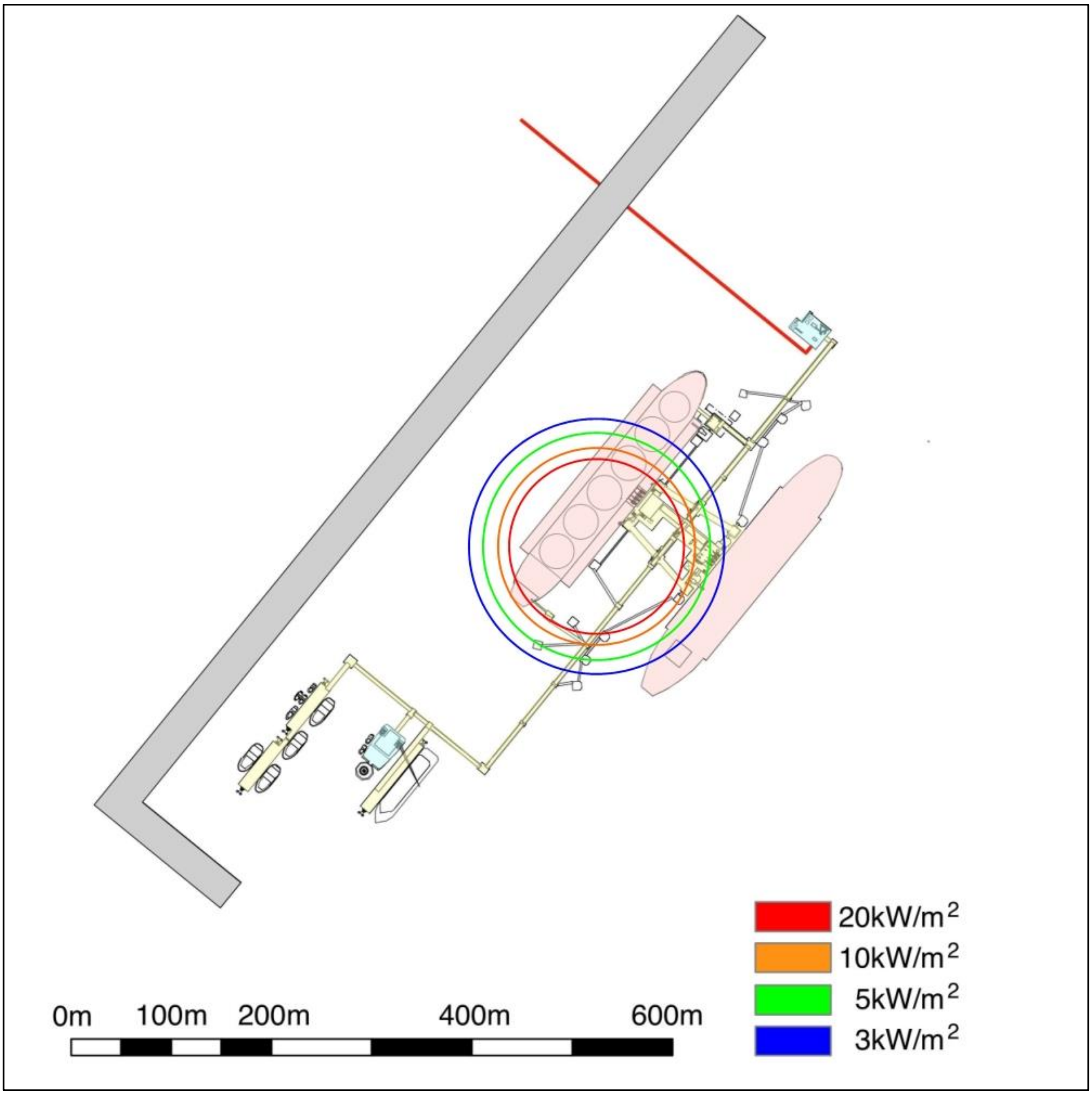
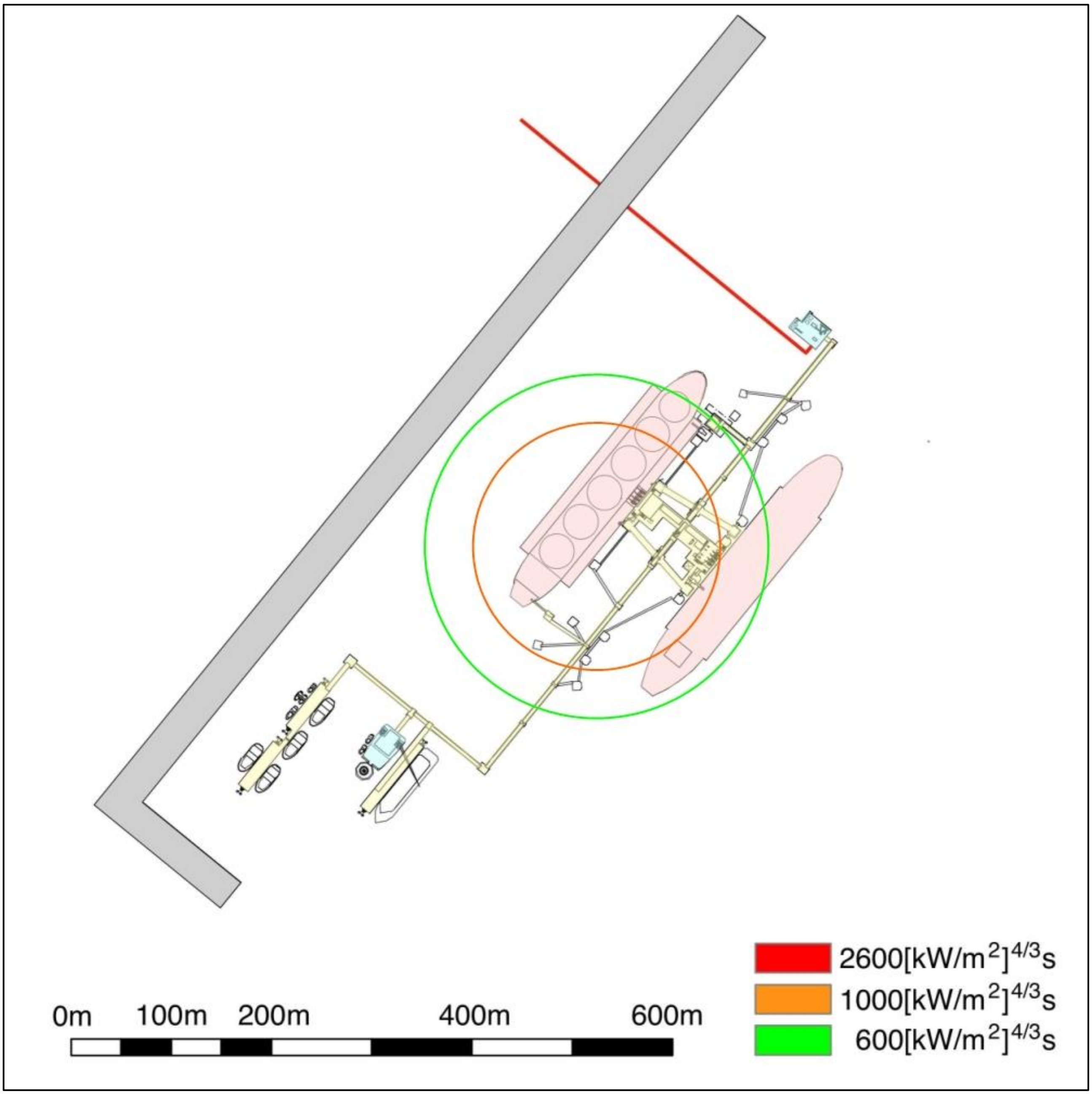


Figure 5-27 MAE N-10 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

LNG released from MAE N-10 is expected to mostly flash on release following a catastrophic failure (credible worst case), or to form small airborne liquid droplets. Ignition of a catastrophic failure for MAE N-10 is considered to be best represented by a fireball. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-28 and Table 5-38 respectively.

Table 5-38 MAE N-10 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ($[kW/m^2]^{4/3}$ s)	Distance from Release Point (m)
68	600	171
	1000	123
	2600	Not Reached



NOTE: The higher thermal dose level was not reached.

Figure 5-28 MAE N-10 Fireball Contour for Catastrophic Failure (scale in m)

5.10.3. Flash Fire Results

Delayed ignition of flammable vapour released into an open or uncongested area will result in a flash fire for MAE N-10. The distances to 100% LFL are presented in Table 5-39 and Table 5-40 for a representative failure (50 mm) and catastrophic failure (credible worst case) respectively. The contour plots to 100% LFL are presented in Figure 5-29 and Figure 5-30 for a representative failure (50 mm) and catastrophic failure (credible worst case) respectively.

Table 5-39 MAE N-10 50mm 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	97
5/D	66

Table 5-40 MAE N-10 Catastrophic Failure 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	196
5/D	220

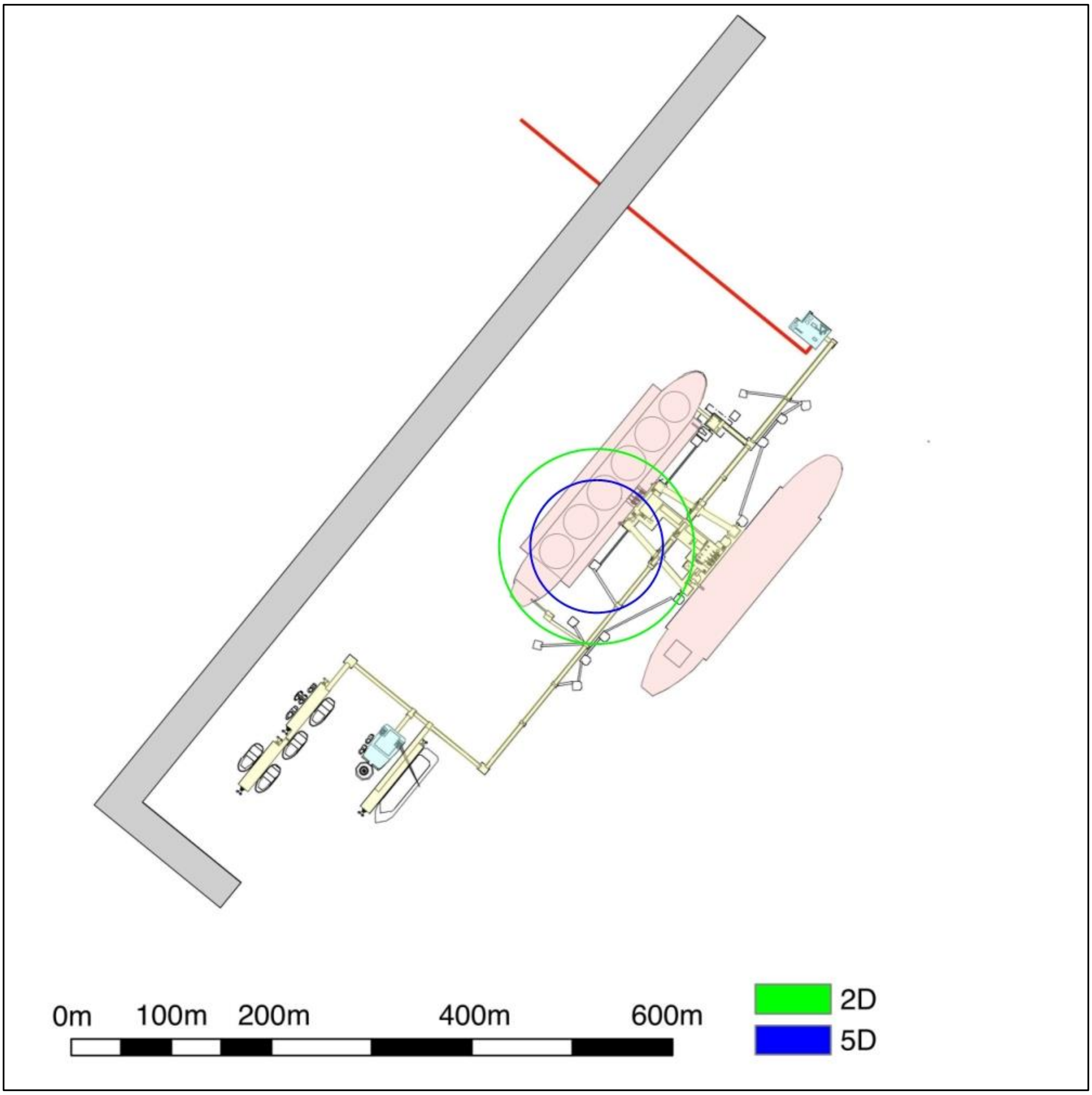


Figure 5-29 MAE N-10 Flashfire Extent to 100% LFL for 50mm Failures (scale in m)

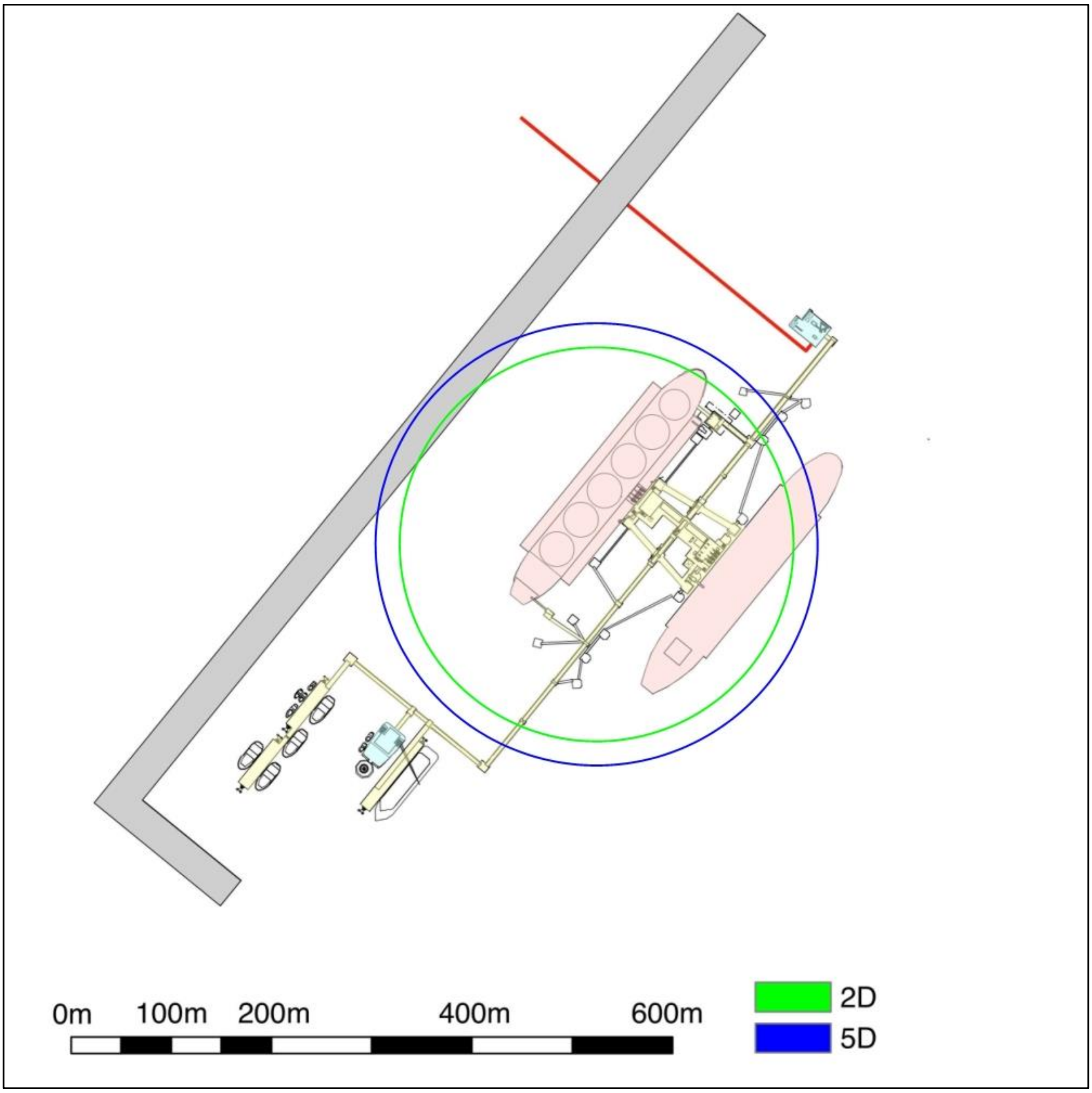


Figure 5-30 MAE N-10 Flashfire Extent to 100% LFL for Catastrophic Failures (scale in m)

5.10.4. Explosion Results

Delayed ignition of flammable vapour dispersed into a congested region (portside sponson) following loss of containment for MAE N-10 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) is completely fills the module. The contour plot and overpressures associated with an explosion are shown in Figure 5-31 and Table 5-41 respectively.

Table 5-41 MAE N-10 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1013
0.05	443
0.14	189
0.35	103

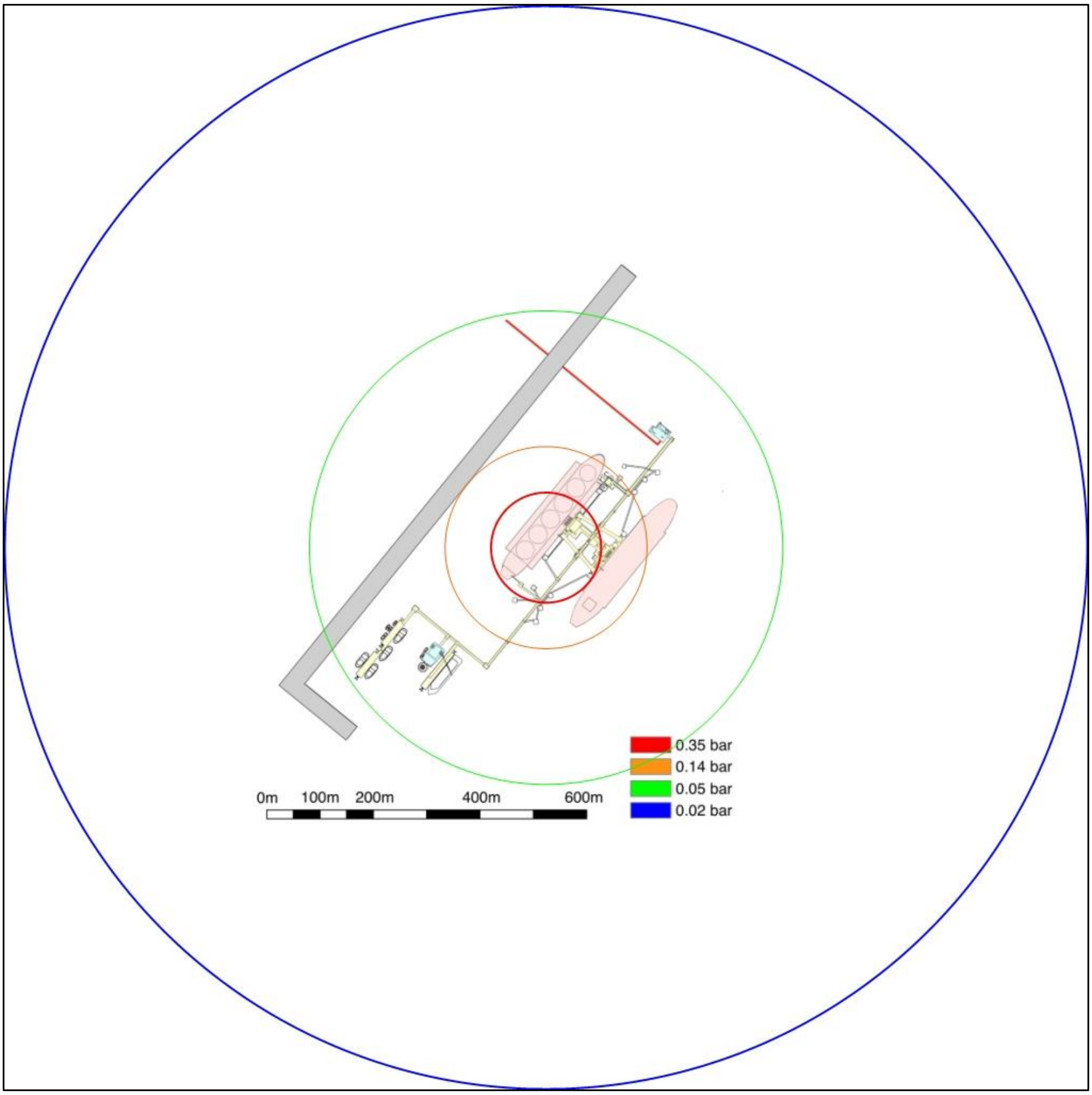


Figure 5-31 MAE N-10 Explosion Contours (scale in m)

5.10.5. Cryogenic Spill Results

The extent of a cryogenic pool has been determined for a representative and credible worst case release associated with MAE N-10. For a representative failure (50 mm) the pool spreads to a radius of 15m while for a catastrophic vessel failure the pool extends to 22m.

Table 5-42 MAE N-10 Cryogenic Spill Results

Release Scenario	Pool Radius (m)
Representative failure (50 mm)	15
Catastrophic failure (credible worst case)	21

5.11. MAE N-11: LNG Release from FLNG Flash Gas Drum

5.11.1. Event Description

This MAE is a release of LNG from the Flash Gas Drum and connecting pipework. The section is downstream of the Liquefaction unit and upstream of the LNG storage tanks. The section includes the following major equipment items:

- LNG Expander
- LNG Flash Drum
- LNG Transfer Pump (x2)

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-43, which are taken from the MAR study (Appendix B.1.1).

Table 5-43 MAE N-11 Stream Parameters

Parameter	Input
MAR Inventory	Liquefaction and LNG Flash Drum Train 1
Process Unit	Liquefaction
Assumed Material	Methane
Pressure (bara)	6
Temperature (deg C)	-158
Phase	Liquid
Inventory (kg)	30,143
Outflow Rate for Representative Failure (50mm) (kg/s)	26.4
Estimated Release Duration for Representative (50mm) Failure	15-30mins
Congested Volume (m^3)	20,300

5.11.2. Fire Results

Part of the LNG released from MAE N-11 is expected to flash on release from a representative failure (50 mm) or form a liquid spray. If the release from a representative failure (50 mm) is into an open or uncongested area then ignition of the released vapour / spray failure will result in a jet / liquid spray fire for MAE N-11. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-32 and Table 5-44 respectively.

Table 5-44 MAE N-11 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	145	162
	5	130	130
	10	114	94
	20	102	60
5/D	3	130	161
	5	115	126
	10	99	93
	20	86	66

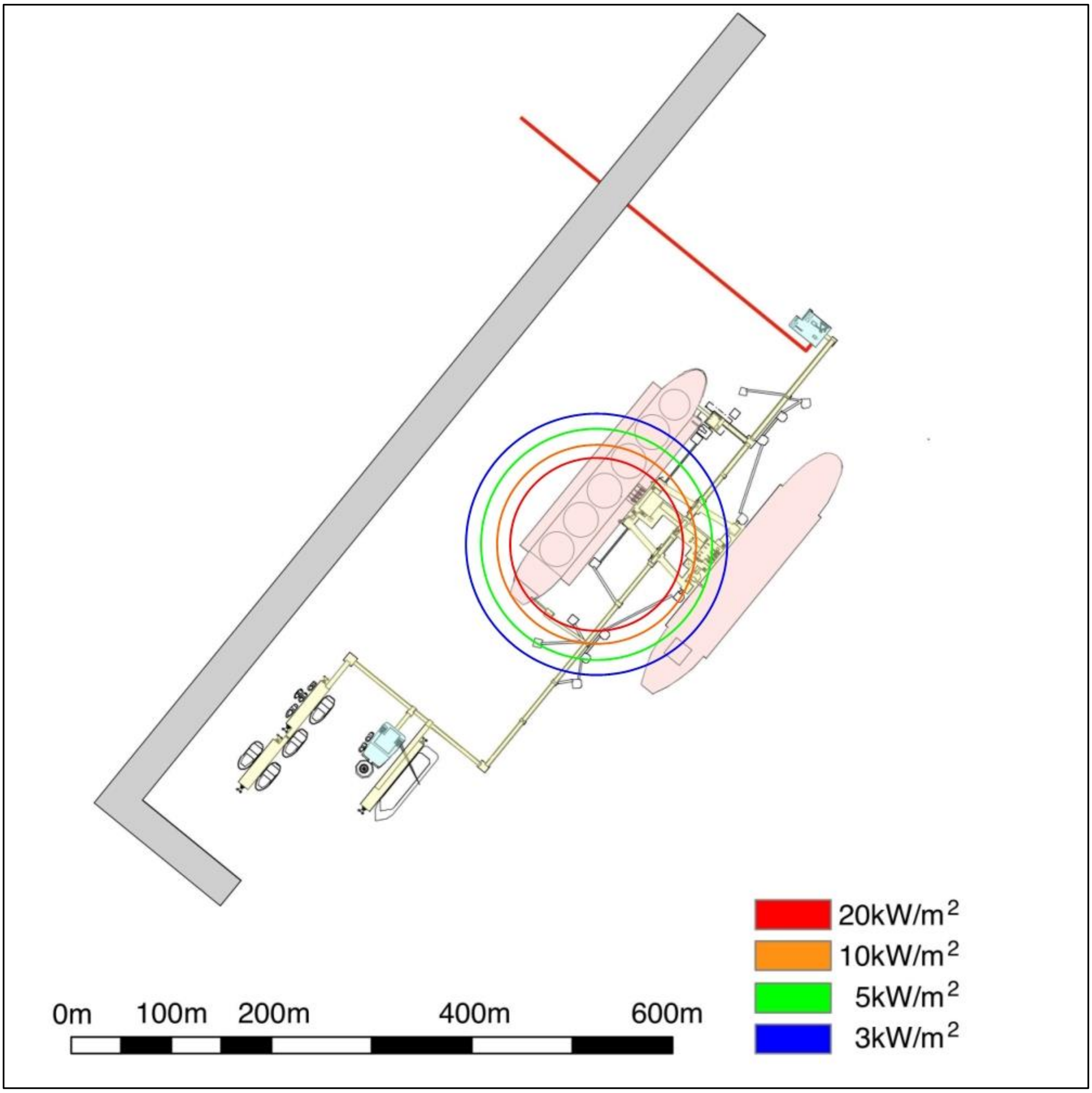


Figure 5-32 MAE N-11 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following loss of containment from a representative failure (50 mm) may more likely result in a liquid pool fire for MAE N-11 – in particular, if the release is directed vertically downwards and the momentum is removed. The size of a pool on the deck of the FLNG is limited to a pool or 50m by 50m. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-33 and Table 5-45 respectively.

Table 5-45 MAE N-11 50mm Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	97	172
	5	78	134
	10	43	61
	20	31	41
5/D	3	98	169
	5	81	132
	10	48	64
	20	39	45

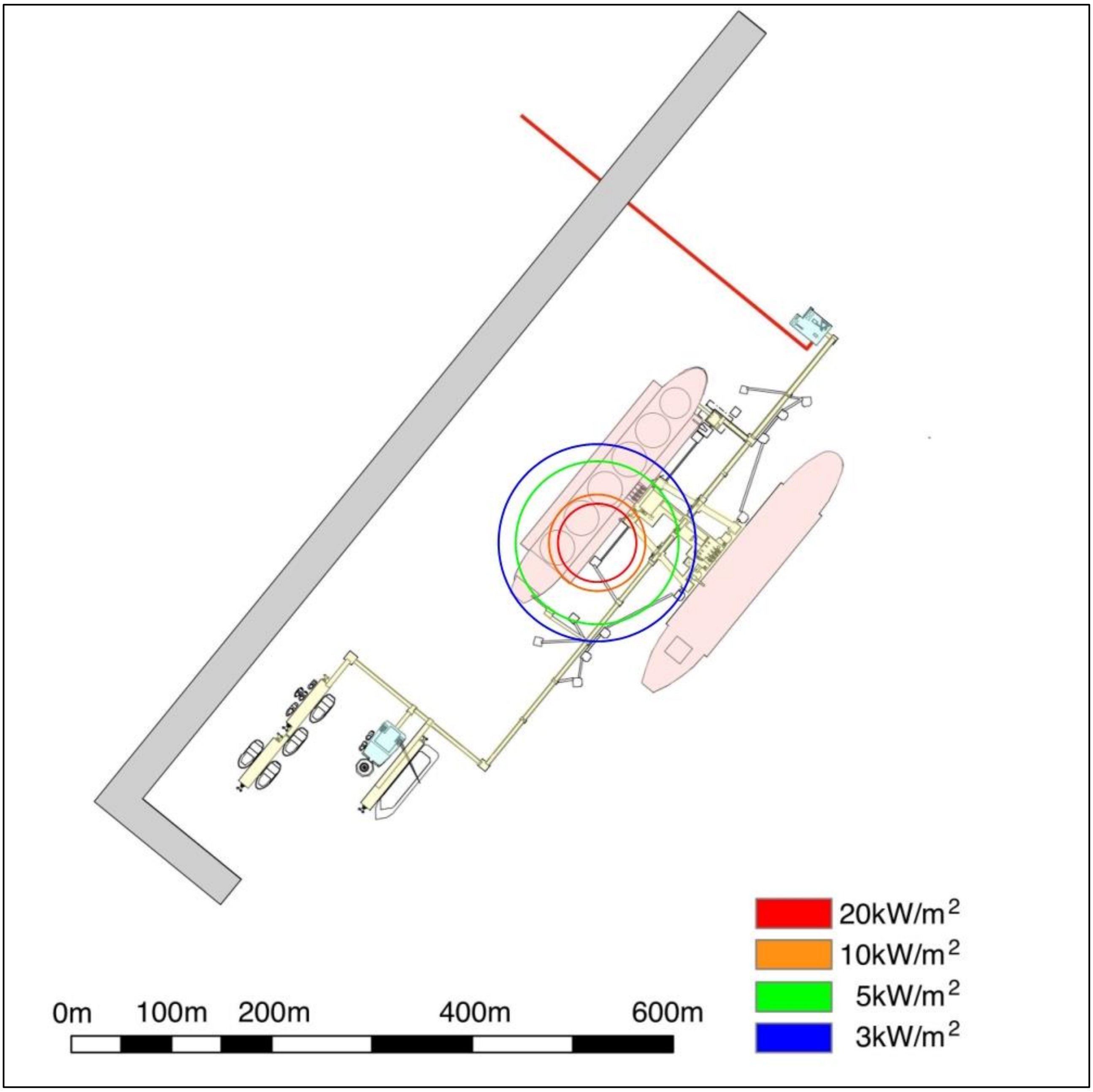


Figure 5-33 MAE N-11 Radiation Contours for Pool Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a liquid pool fire for MAE N-11. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-34 and Table 5-46 respectively.

Table 5-46 MAE N-11 Catastrophic Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	294	544
	5	237	425
	10	176	299
	20	127	201
5/D	3	300	536
	5	245	422
	10	187	302
	20	143	209

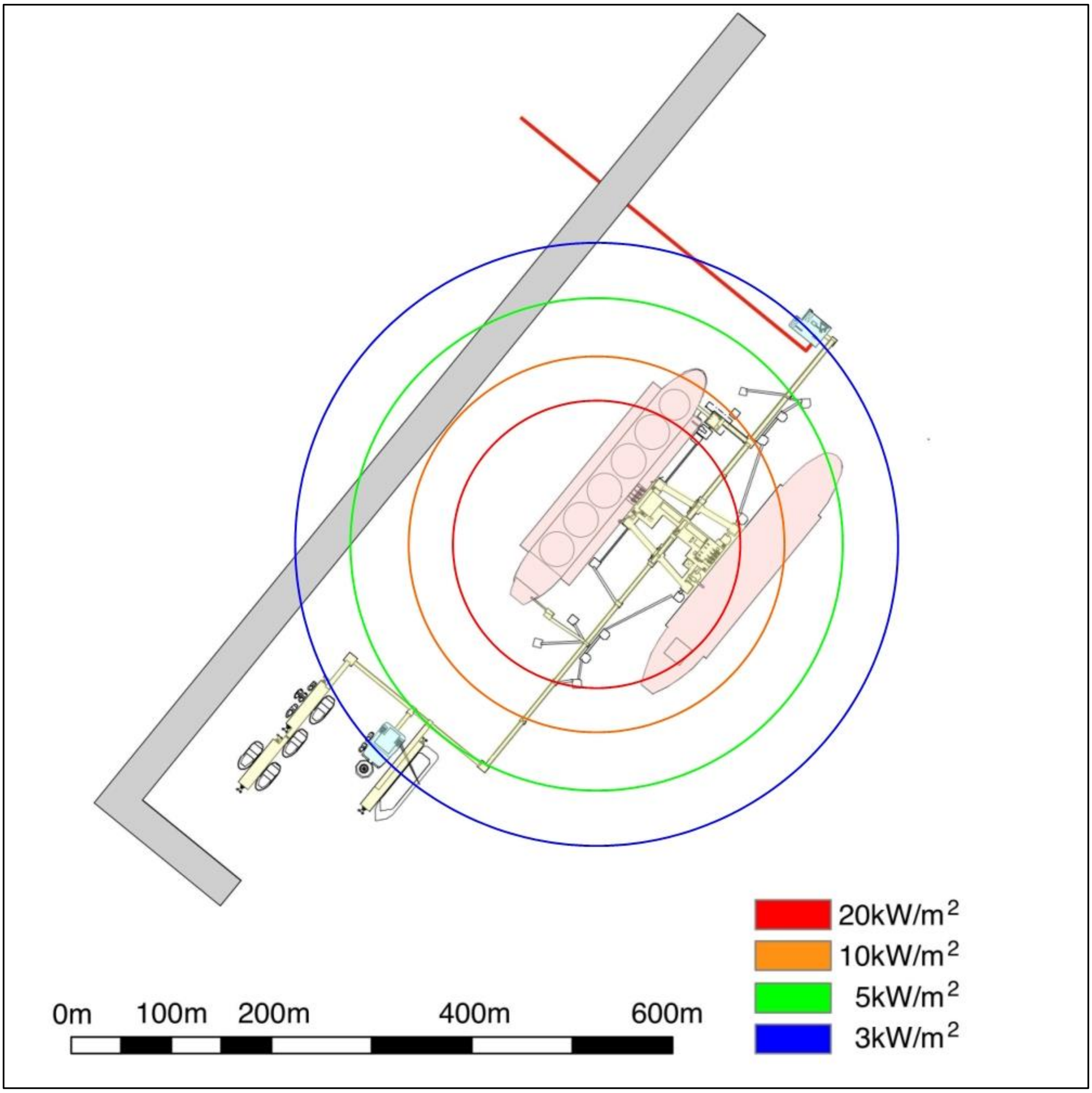


Figure 5-34 MAE N-11 Radiation Contours for Pool Fire from Catastrophic Failure (scale in m)

5.11.3. Flash Fire Results

Delayed ignition of flammable vapour released into an open or uncongested area will result in a flash fire for MAE N-11. The distances to 100% LFL are presented in Table 5-47 and

Table 5-48 for a representative failure (50 mm) and catastrophic failure (credible worst case) respectively. The contour plots to 100% LFL are presented in Figure 5-35 and Figure 5-36 for a representative failure (50 mm) and catastrophic failure (credible worst case) respectively.

Table 5-47 MAE N-11 50mm 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	101
5/D	99

Table 5-48 MAE N-11 Catastrophic Failure 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	160
5/D	115

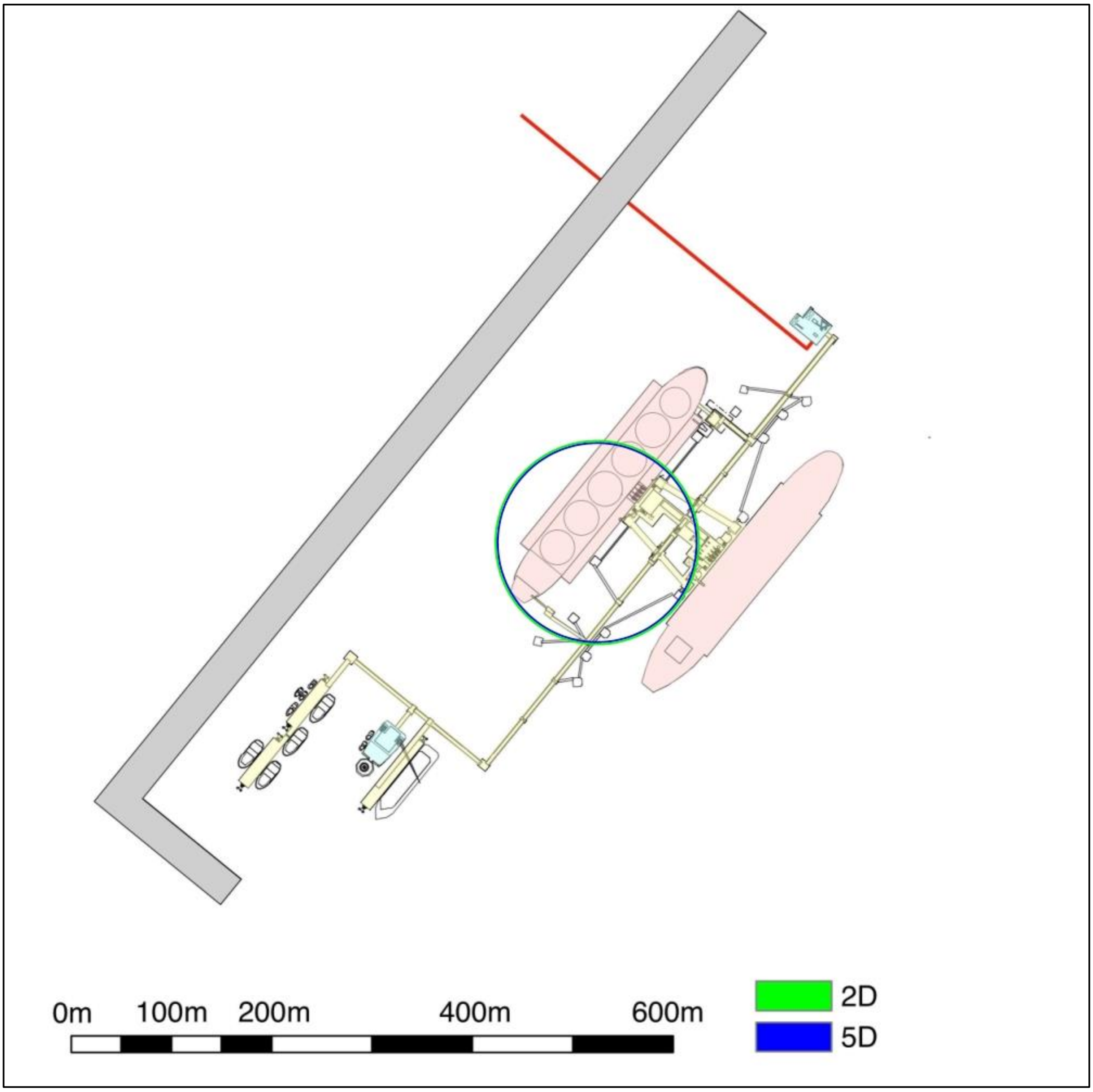


Figure 5-35 MAE N-11 Flashfire Extent to 100% LFL for 50mm Failures (scale in m)

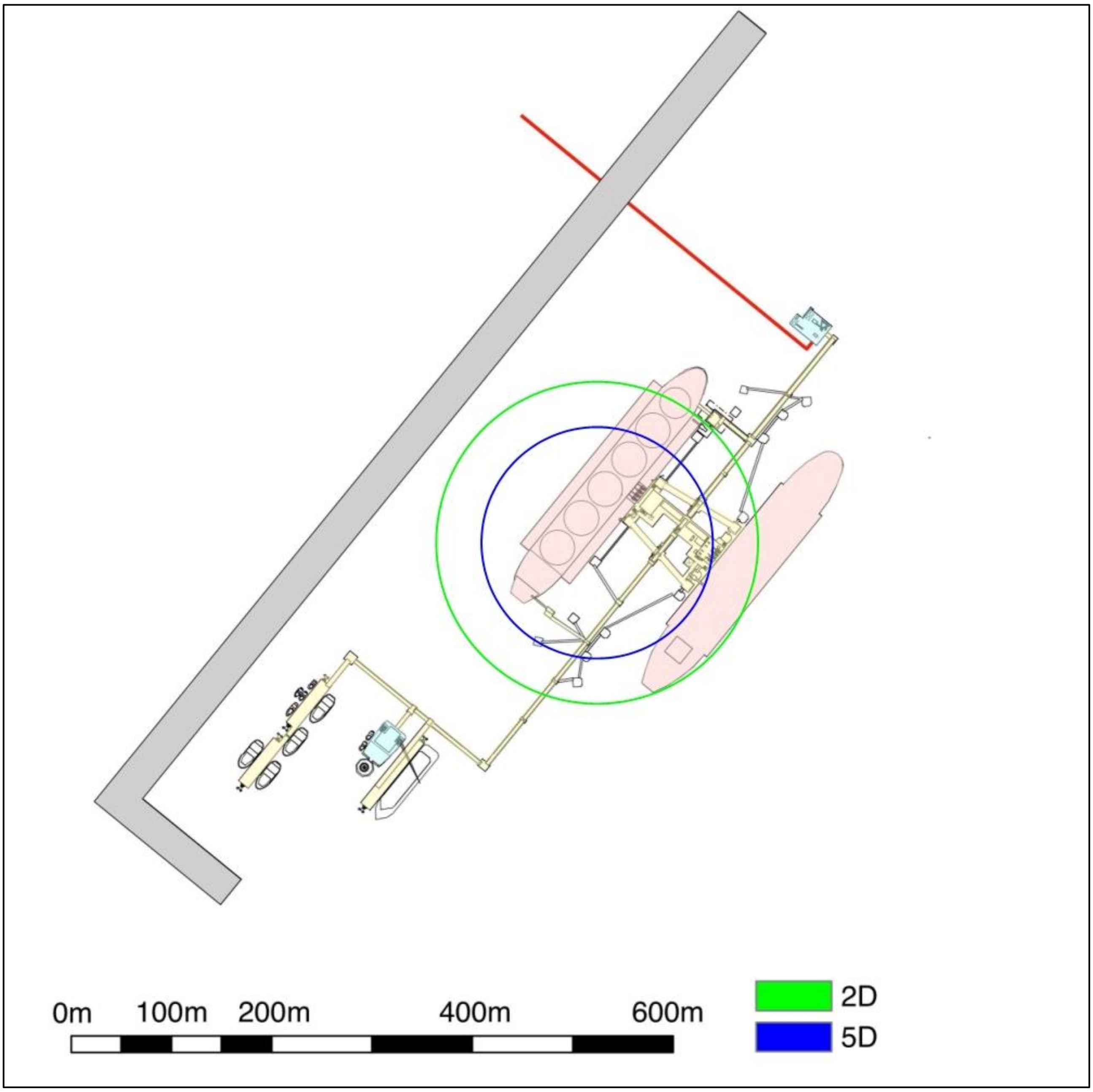


Figure 5-36 MAE N-11 Flashfire Extent to 100% LFL for Catastrophic Failures (scale in m)

5.11.4. Explosion Results

Delayed ignition of flammable vapour dispersed into a congested region (portside sponson) following loss of containment for MAE N-11 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) completely fills the congested region. The contour plot and overpressures for this explosion are shown in Figure 5-37 and Table 5-49 respectively.

Table 5-49 MAE N-11 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1013
0.05	443
0.14	189
0.35	103

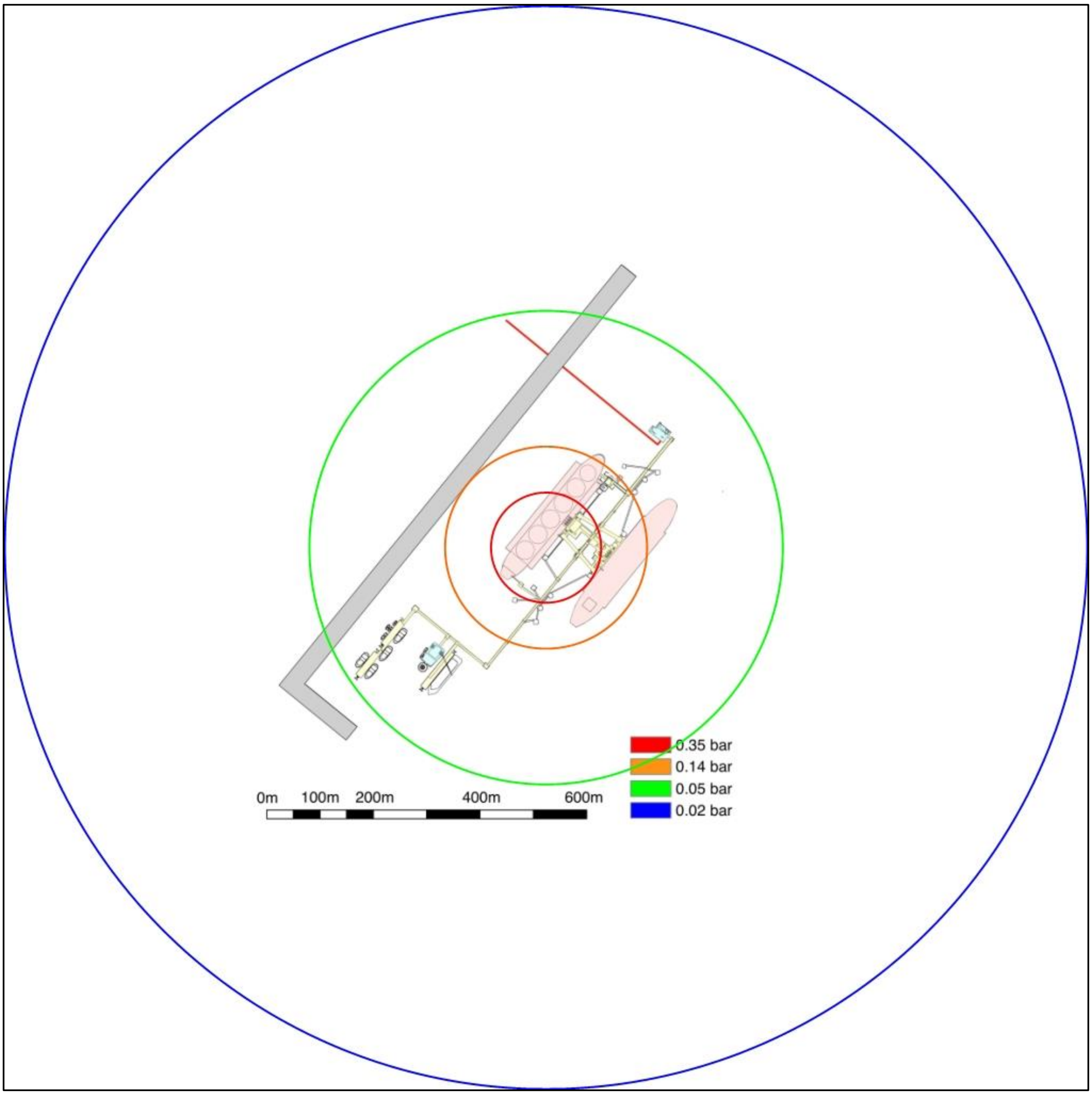


Figure 5-37 MAE N-11 Explosion Contours (scale in m)

5.11.5. Cryogenic Spill Results

The extent of a cryogenic pool has been determined for a representative and credible worst case release associated with MAE N-11. For a representative failure (50 mm) the pool spreads to a radius of 18m while for a catastrophic vessel failure the pool spreads to 28m which is approximately half of the deck area of the FLNG – it is considered that the pool will be limited from spreading further due to coaming arrangements and other restrictions, or from the spill flowing overboard.

Table 5-50 MAE N-11 Cryogenic Spill Results

Release Scenario	Pool Radius (m)
Representative failure (50 mm)	18
Catastrophic failure (credible worst case)	28

5.12. MAE N-12: BLEVE of Vessel on FLNG Containing Refrigerant

5.12.1. Event Description

This MAE is a BLEVE of one of the Refrigerant Storage / Make-up Vessels – ethylene, propane or i-pentane.

Modelling for this MAE has been completed for the ethylene and propane vessels using input data as outlined in Table 5-51, which are taken from the MAR study (Appendix B.1.1) – BLEVE of the i-pentane vessel is considered less likely due to the lower storage pressure (close to atmospheric).

Table 5-51 MAE N-12 Stream Parameters

Parameter	Input	Input
MAR Inventory	Ethylene Make Up	Propane Make Up
Process Unit	LNG Train	LNG Train
Assumed Material	Ethylene	Propane
Pressure (bara)	3	9
Temperature (deg C)	-83	25
Phase	Liquid	Liquid
Inventory (kg)	11,400	25,500

5.12.2. BLEVE Results

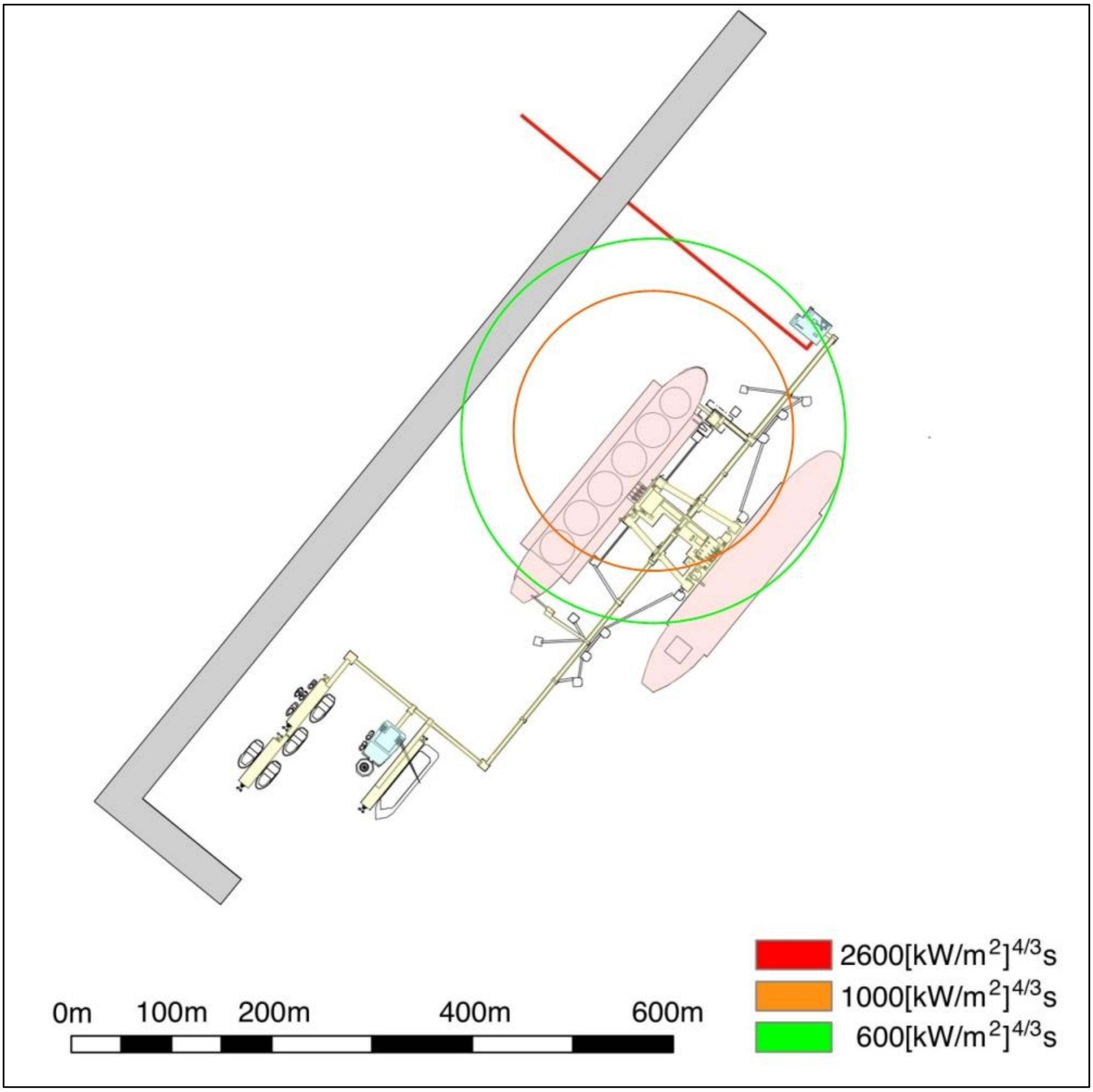
A BLEVE may occur for MAE-12 due to fire impingement onto the refrigerant vessel and heating of the liquid ethylene or propane. A fireball will result following the explosion – the contour plot and hazard ranges for thermal dose due to the fireball are shown in Figure 5-38 and Table 5-52 respectively for the ethylene vessel and in Figure 5-39 and Table 5-53 respectively for the propane vessel.

Table 5-52 MAE N-12 Fireball Results for Ethylene Vessel BLEVE

BLEVE Radius (m)	Thermal Dose ($[kW/m^2]^{4/3}$ s)	Distance from Release Point (m)
74	600	191
	1000	139
	2600	Not Reached

Table 5-53 MAE N-12 Fireball Results for Propane Vessel BLEVE

BLEVE Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
87	600	243
	1000	181
	2600	49



NOTE: The higher thermal dose level was not reached.

Figure 5-38 MAE N-12 Fireabll Contour for Ethylene Vessel BLEVE (scale in m)

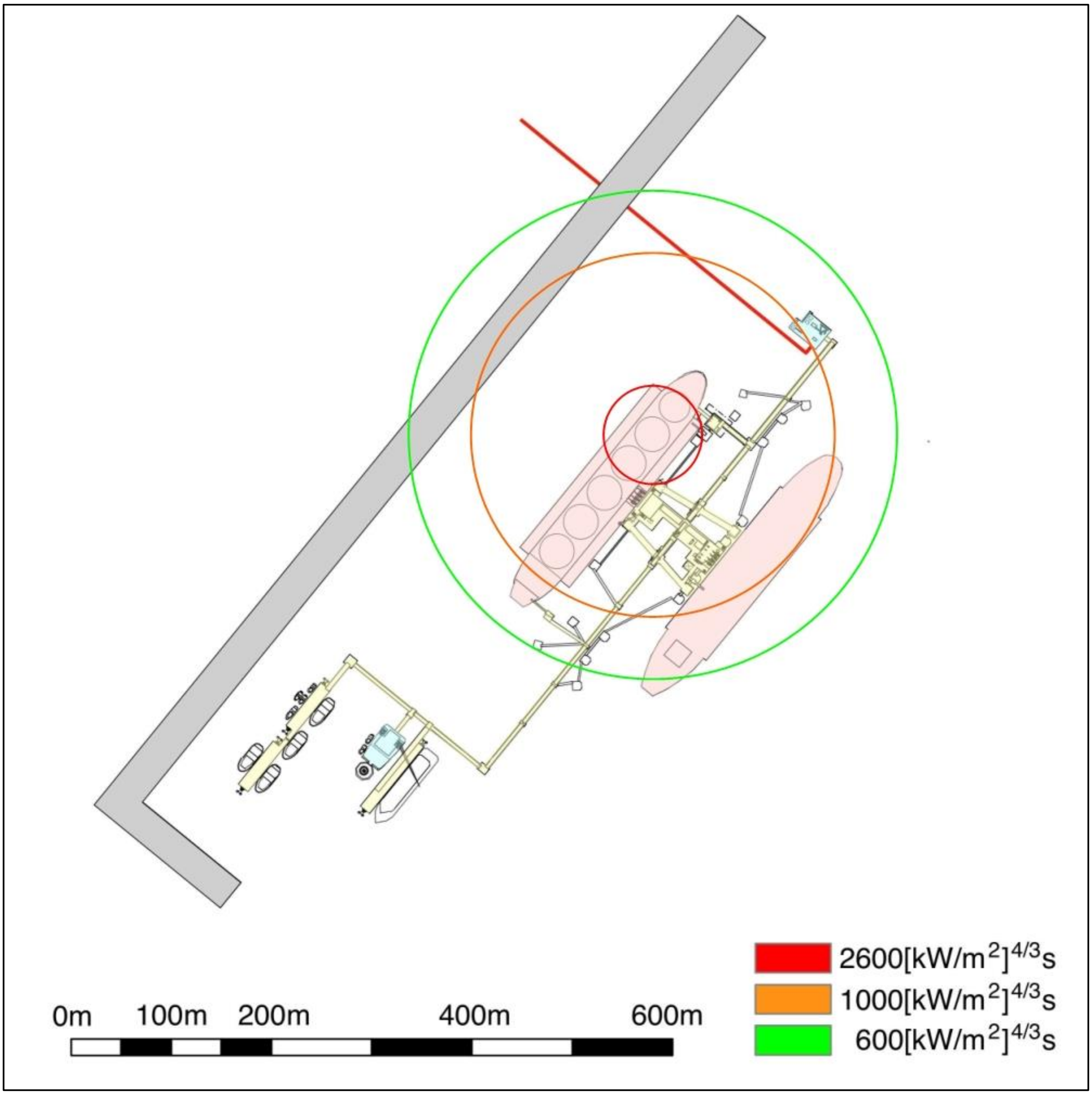


Figure 5-39 MAE N-12 Fireball Contour for Propane Vessel BLEVE (scale in m)

5.13. MAE N-13: Gas Release from FLNG SMR Refrigerant Closed Loop

5.13.1. Event Description

This MAE is a release of flammable gas from the refrigerant loop – a mix of ethylene, propane and i-pentane. The section includes the following major equipment items:

- Main Liquefaction Exchanger (vapour space)
- Suction Drum
- Stage 1 Mixed Refrigerant Compressor
- Inter-stage Drum

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-54 – propane has been used as representative of the refrigerant.

Table 5-54 MAE N-13 Stream Parameters

Parameter	Input
MAR Inventory	-
Process Unit	Boil Off Gas
Assumed Material	Propane
Pressure (bara)	10.4
Temperature (deg C)	45
Phase	Gas
Inventory (kg)	1,725
Outflow Rate for Representative Failure (50mm) (kg/s)	5.4
Estimated Release Duration for Representative (50mm) Failure	1-5mins
Congested Volume (m^3)	20,300

5.13.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-13. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-40 and Table 5-55 respectively.

Table 5-55 MAE N-13 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	44	61
	5	39	47
	10	34	33
	20	29	22
5/D	3	43	61
	5	39	47
	10	35	32
	20	31	21

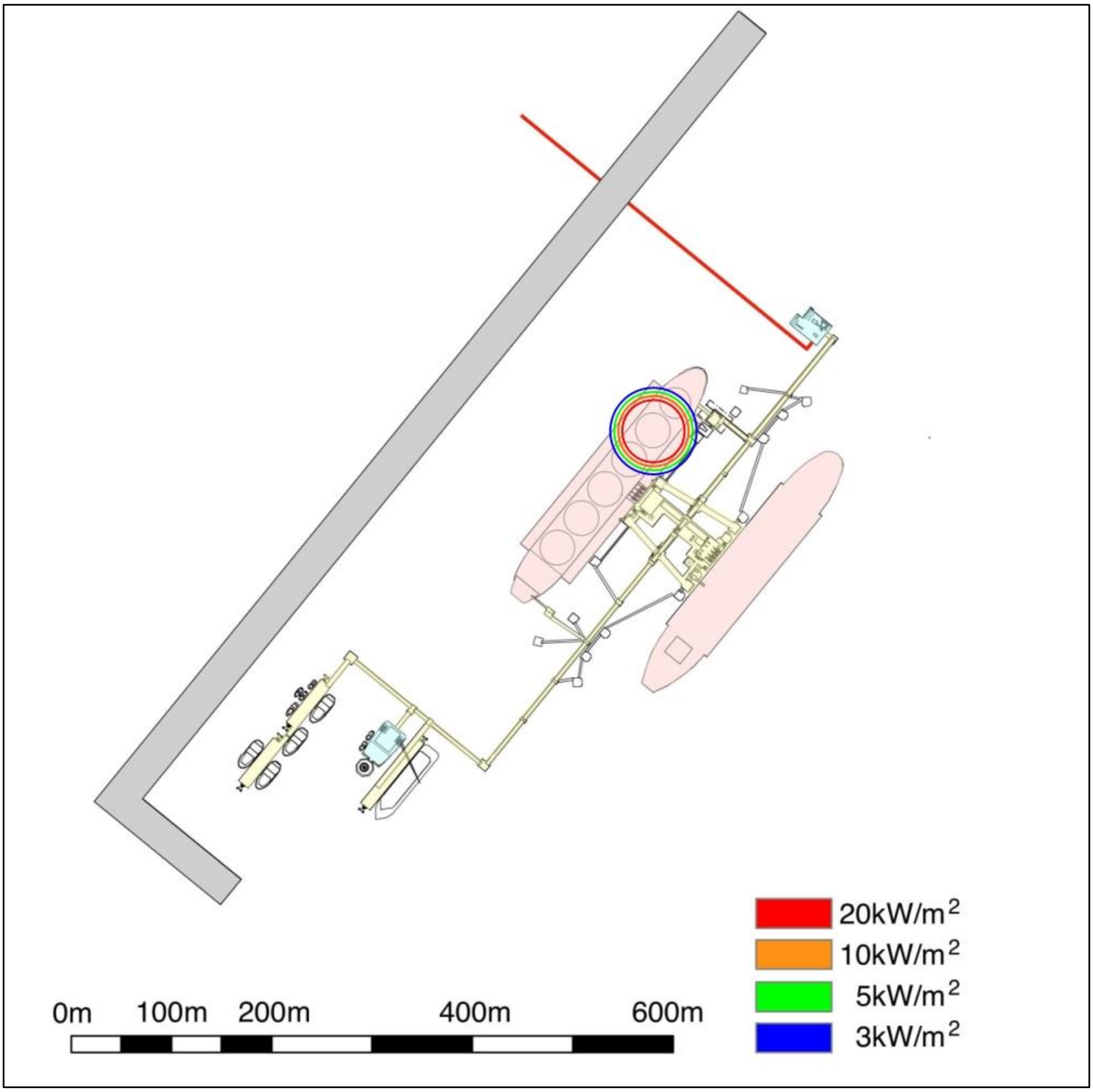
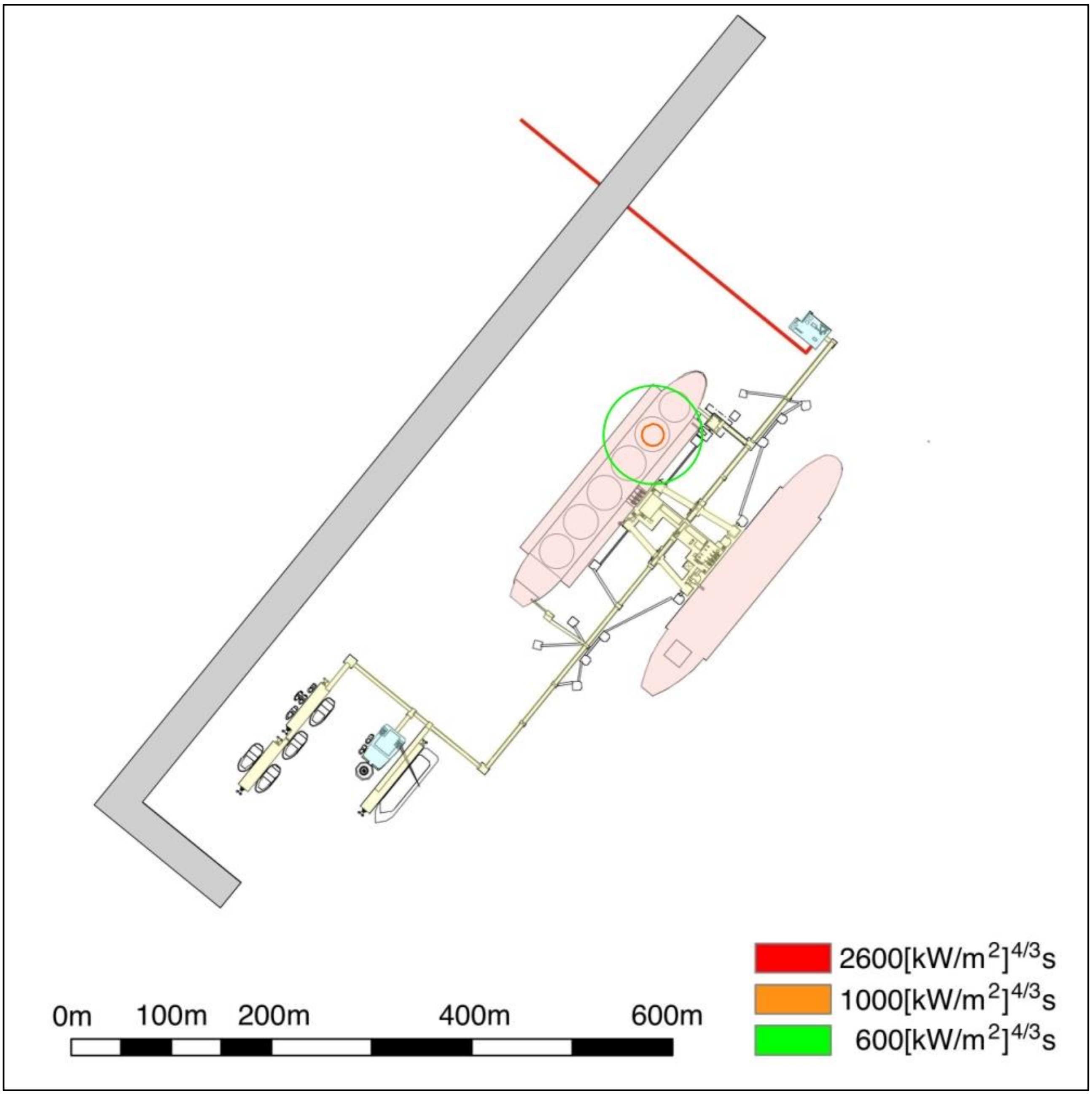


Figure 5-40 MAE N-13 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a fireball for MAE N-13. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-41 and Table 5-56 respectively.

Table 5-56 MAE N-13 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
37	600	49
	1000	11
	2600	Not Reached



NOTE: The higher thermal does level was not reached.

Figure 5-41 MAE N-13 Fireball Contour for Catastrophic Failure (scale in m)

5.13.3. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (portsdie sponson) following loss of containment for MAE N-13 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) completely fills the congested region. The contour plot and overpressures hazard ranges for this explosion are shown in Figure 5-42 and Table 5-57 respectively.

Table 5-57 MAE N-13 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1045
0.05	457
0.14	195
0.35	106

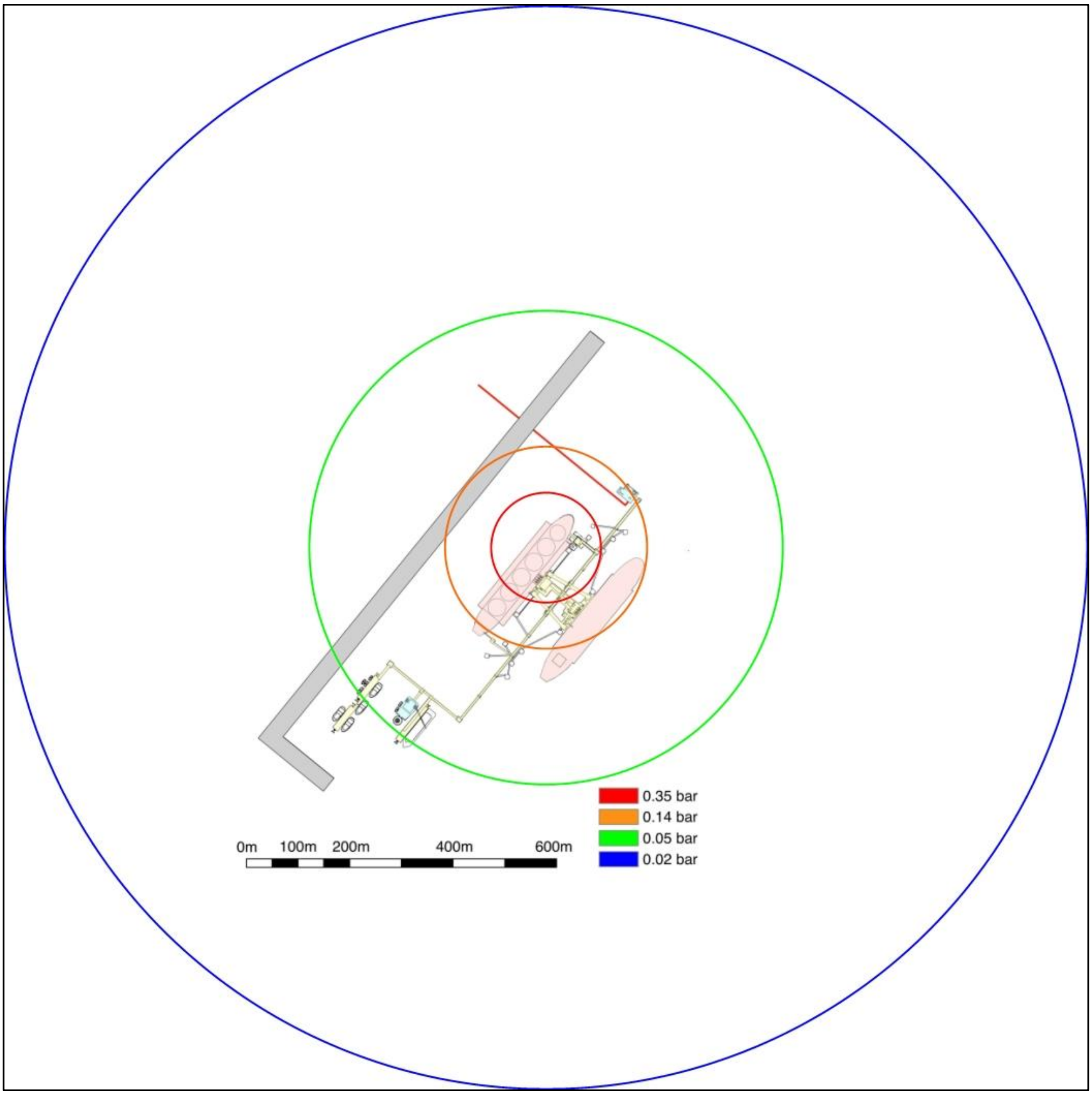


Figure 5-42 MAE N-13 Explosion Contours (scale in m)

5.14. MAE N-14: Liquid / Two Phase Release from FLNG SMR Refrigerant Closed Loop

5.14.1. Event Description

This MAE is a release of liquid or two-phase hydrocarbon from the refrigerant loop – a mix of ethylene, propane and i-pentane. The section includes the following major equipment items:

- Inter-stage Drum
- Stage 2 Mixed Refrigerant Compressor
- Discharge Drum
- Main Liquefaction Exchanger

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-58, which are taken from the MAR study (Appendix B.1.1). Note: propane has been used as representative of the refrigerant.

Table 5-58 MAE N-14 Stream Parameters

Parameter	Input
MAR Inventory	Propane Make Up
Process Unit	LNG Train
Assumed Material	Propane
Pressure (bara)	40
Temperature (deg C)	55
Phase	2-Phase/Liquid
Inventory (kg)	15,624
Outflow Rate for Representative Failure (50mm) (kg/s)	75.3
Estimated Release Duration for Representative (50mm) Failure	1-5mins
Congested Volume (m^3)	20,300

5.14.2. Fire Results

Liquid or two-phase refrigerant released from MAE N-14 is expected to flash on release from a representative failure (50 mm) or form a liquid spray. Immediate ignition of this release will result in a jet / liquid spray fire for MAE N-14. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-43 and Table 5-59 respectively.

Table 5-59 MAE N-14 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	177	259
	5	157	201
	10	136	146
	20	120	105
5/D	3	163	261
	5	142	202
	10	120	143
	20	104	105

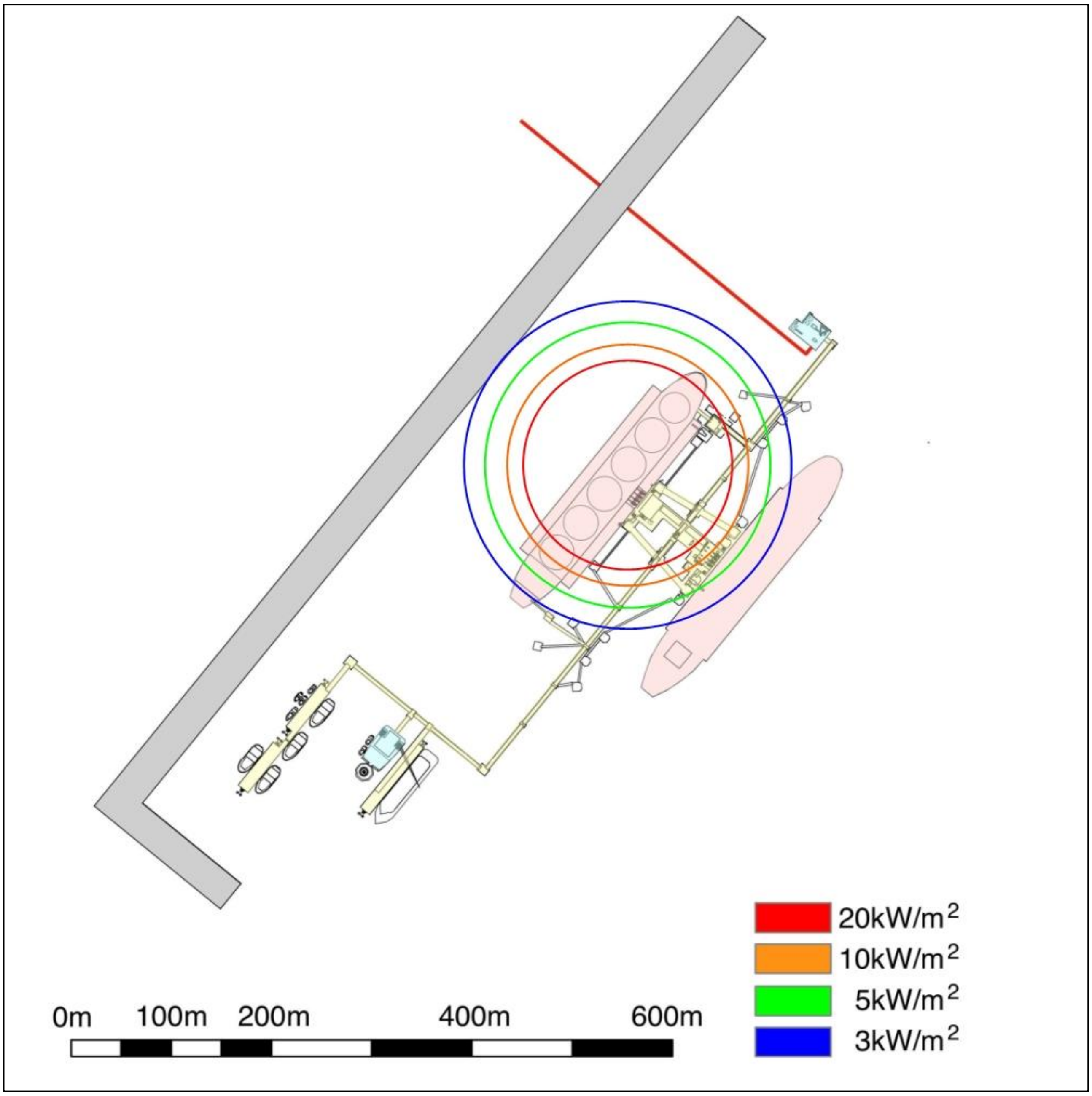


Figure 5-43 MAE N-14 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Mixed refrigerant released from MAE N-14 is expected to mostly flash on release following a catastrophic failure (credible worst case), or to form small airborne liquid droplets. Ignition of a catastrophic failure for MAE N-14 is considered to be best represented by a fireball. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-44 and Table 5-60 respectively.

Table 5-60 MAE N-14 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ($[kW/m^2]^{4/3}$ s)	Distance from Release Point (m)
75	600	217
	1000	163
	2600	56

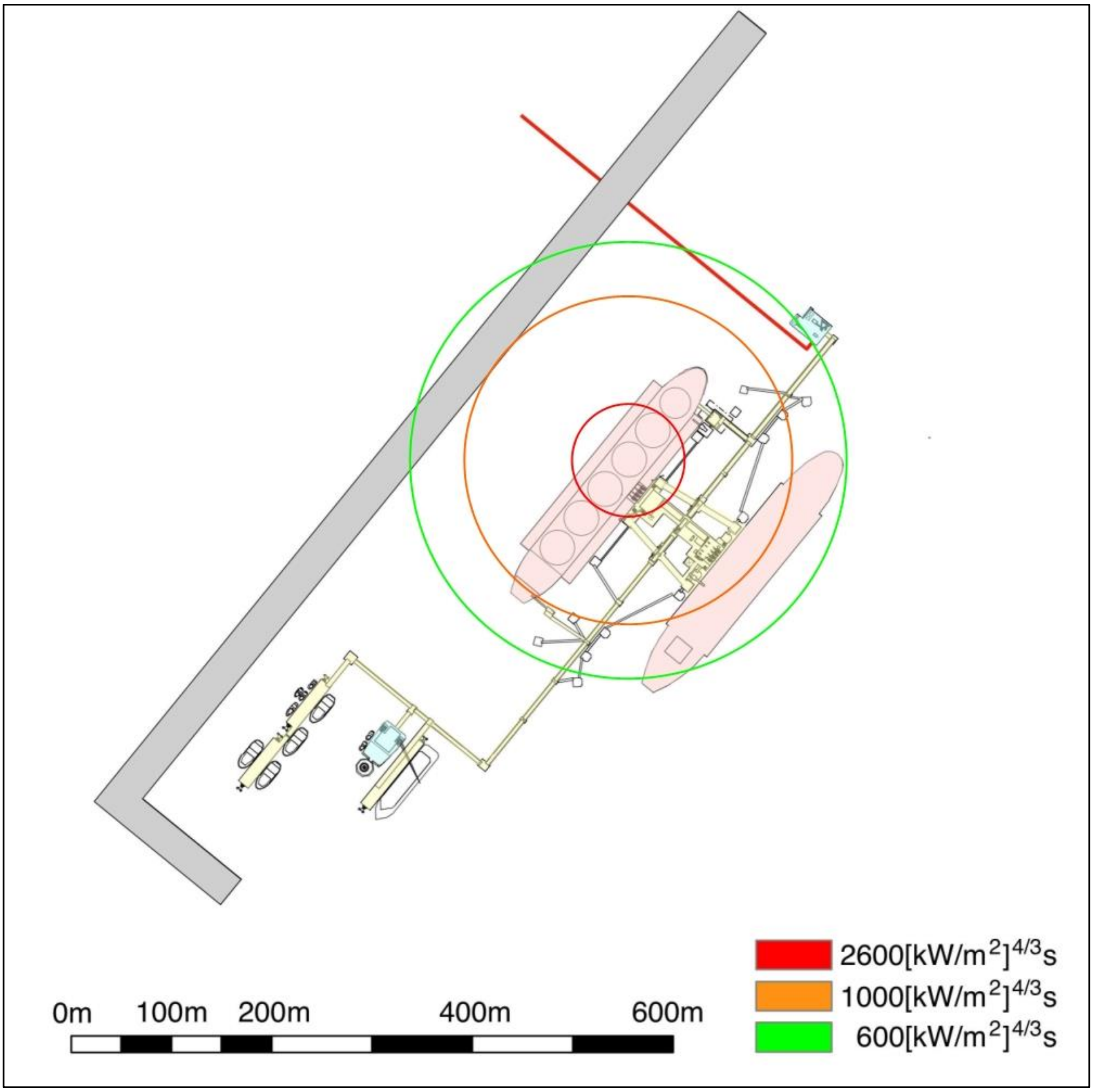


Figure 5-44 MAE N-14 Fireball Contour for Catastrophic Failure (scale in m)

5.14.3. Flash Fire Results

Delayed ignition of flammable vapour dispersed into non-congested regions will result in flash fires for MAE N-14. The distances to 100% LFL are presented in Table 5-61 and Table 5-62 for a representative failure (50 mm) and catastrophic failure (credible worst case) respectively. The contour plots to 100% LFL are presented in Figure 5-45 and Figure 5-46 for a representative failure (50 mm) and catastrophic failure (credible worst case) respectively.

Table 5-61 MAE N-14 50mm 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	282
5/D	158

Table 5-62 MAE N-14 Catastrophic Failure 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	543
5/D	280

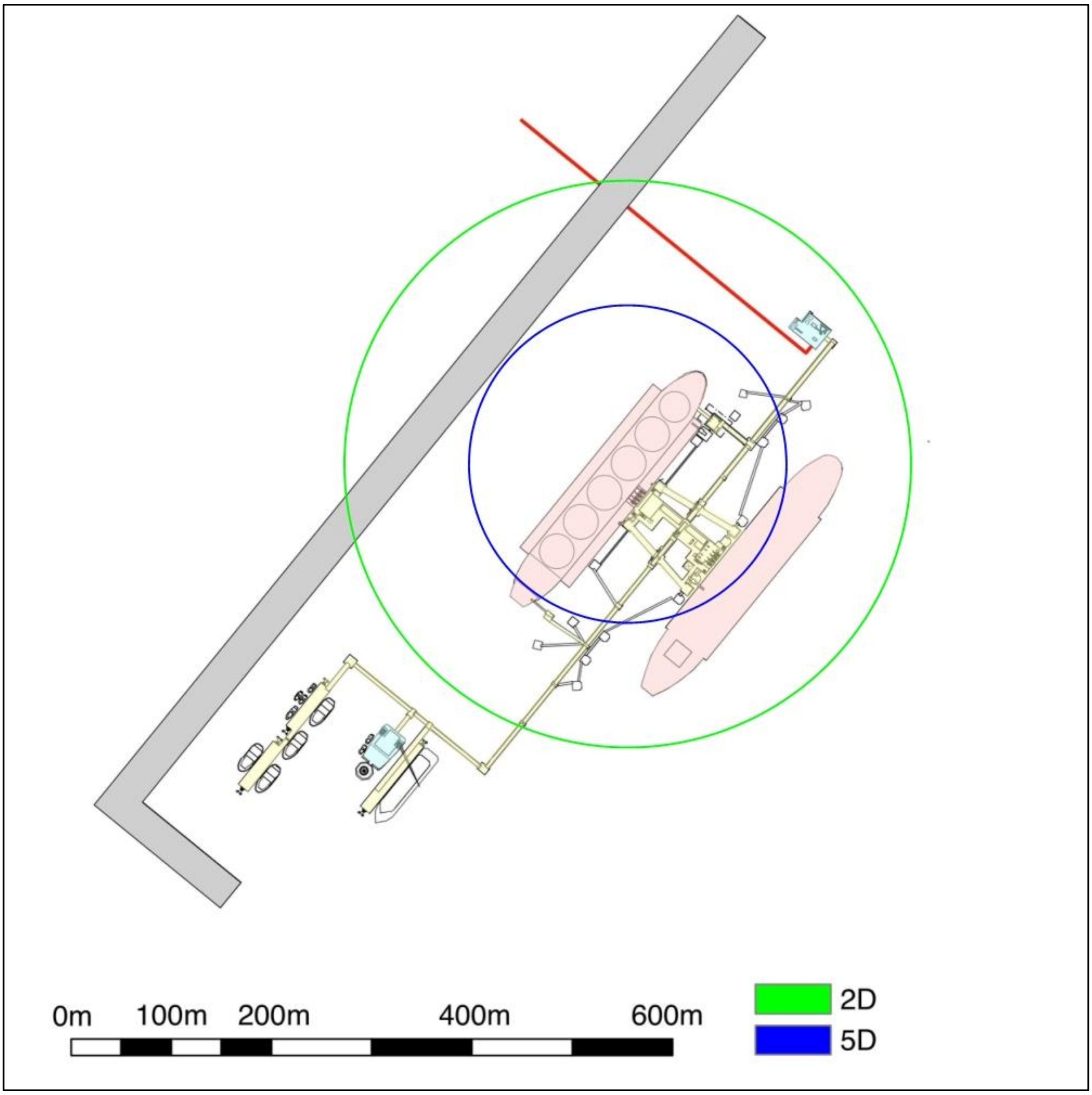


Figure 5-45 MAE N-14 Flashfire Extent to 100% LFL for 50mm Failures (scale in m)

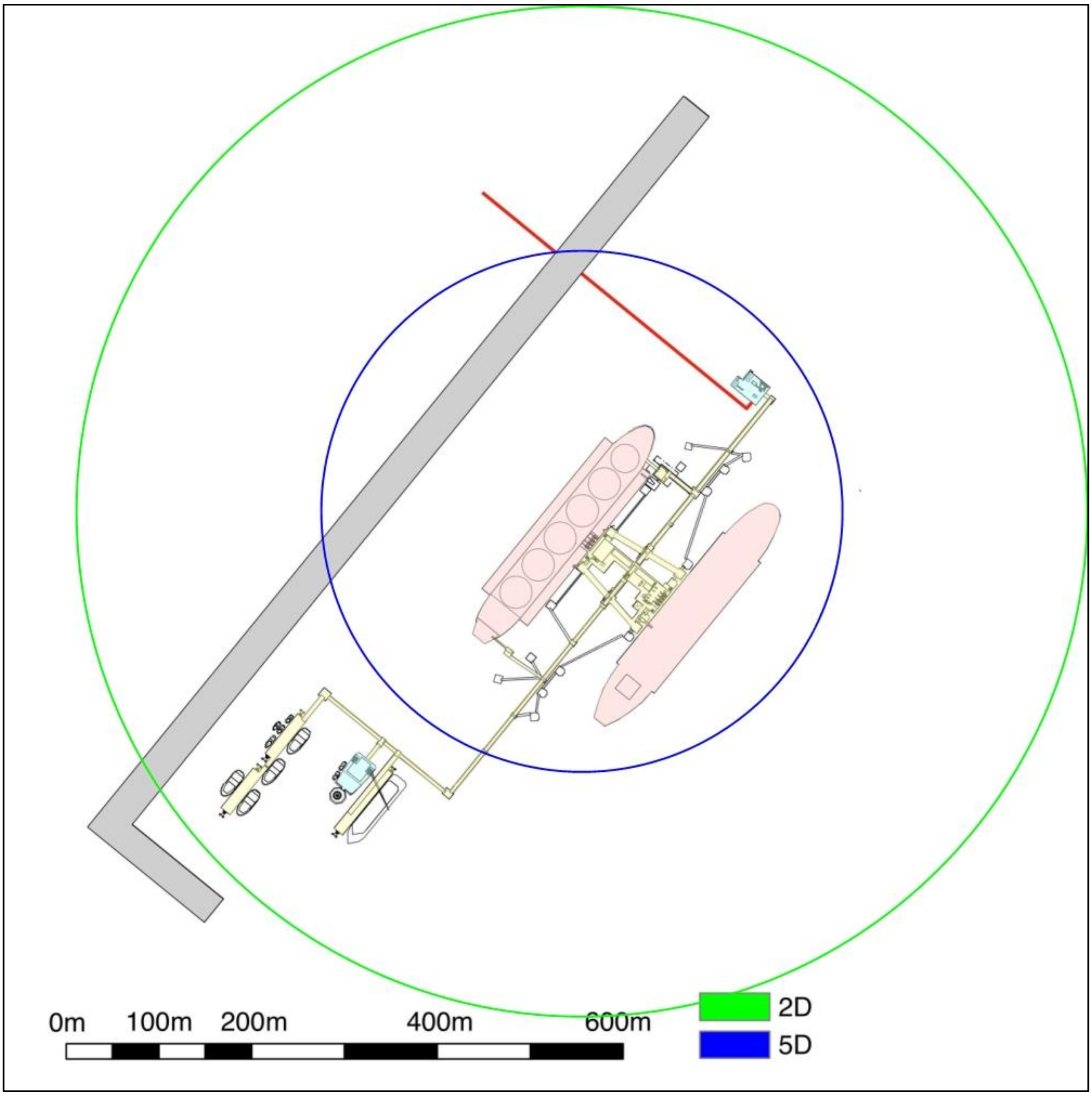


Figure 5-46 MAE N-14 Flashfire Extent to 100% LFL for Catastrophic Failures (scale in m)

5.14.4. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (portside sponson) following loss of containment for MAE N-14 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) completely fills the congested region. The contour plot and overpressures hazard ranges are shown in Figure 5-47 and Table 5-63 respectively.

Table 5-63 MAE N-14 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	1045
0.05	457
0.14	195
0.35	106

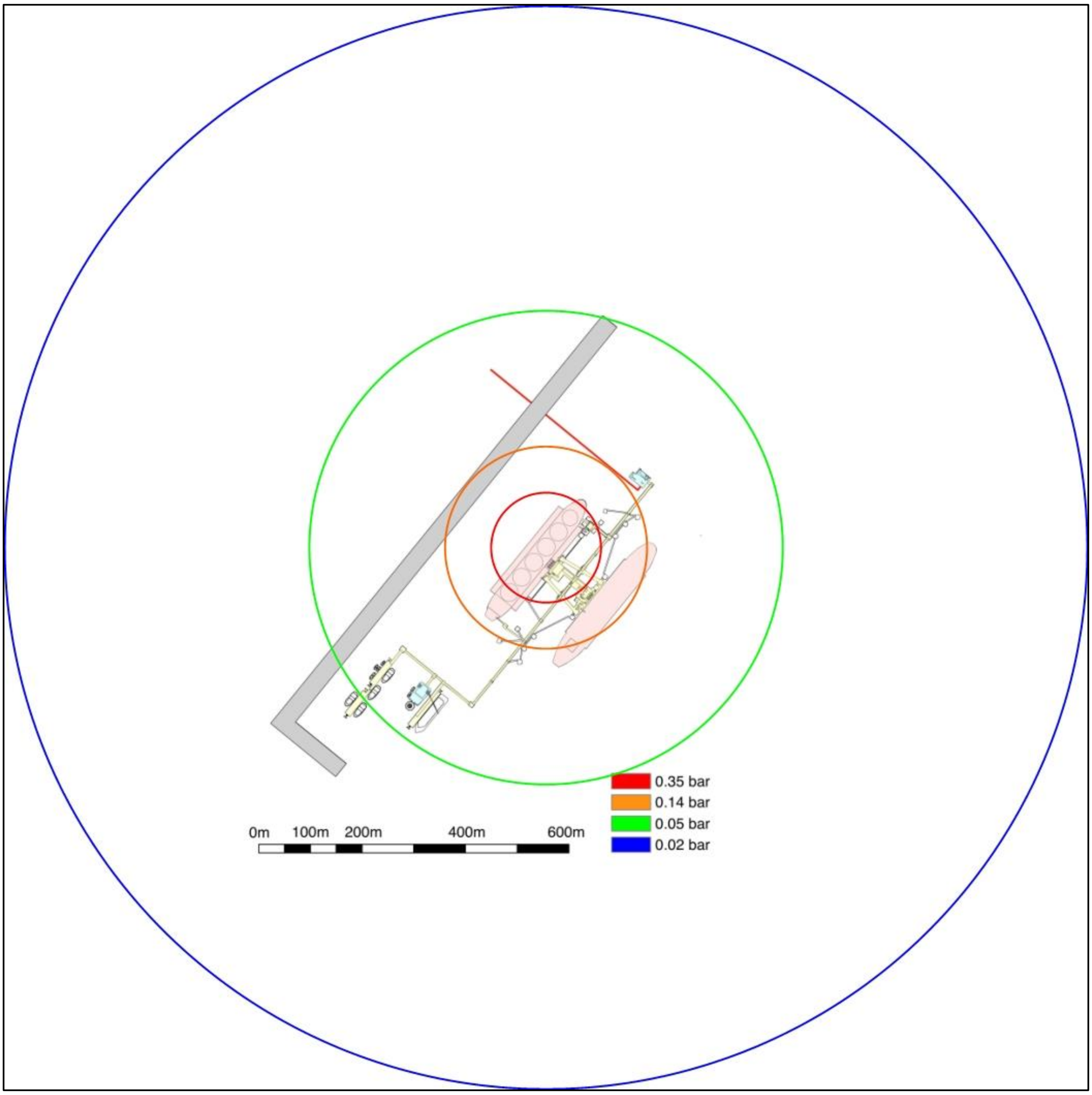


Figure 5-47 MAE N-14 Explosion Contours (scale in m)

5.14.5. Cryogenic Spill Results

The extent of a cryogenic pool has been determined for a representative and credible worst case release associated with MAE N-14. For a representative failure (50 mm) the pool spreads to a radius of 20m while for a catastrophic vessel failure the pool spreads to 24m.

Modelling of a cryogenic spill has been completed using propane as representative of the SMR. It is noted that a release propane will not be a cryogenic threat however, when mixed with ethylene the liquid temperature following discharge may be dropped significantly, presenting a risk to structures, equipment and personnel.

Table 5-64 MAE N-14 Cryogenic Spill Results

Release Scenario	Pool Radius (m)
Representative failure (50 mm)	20
Catastrophic failure (credible worst case)	24

5.15. MAE N-15: Refrigerant Release from FLNG Refrigerant Storage

5.15.1. Event Description

This MAE is a loss of containment from one of the three refrigerant storage vessels – propane, ethylene and i-pentane.

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-65, which are taken from the MAR study [Appendix B.1.1]. Analysis has been predominately based on a failure of the propane vessel as loss of containment for this vessel is expected to result in the largest hazard ranges. However, explosion overpressure calculations are also presented for an ethylene VCE due to the high reactivity of this material. The cryogenic threat from N-15 is assessed by considering a release of ethylene – propane and pentane are discounted as a cryogenic hazard.

Table 5-65 MAE N-15 Stream Parameters

Parameter	Input	Input
MAR Inventory	Propane Make Up	Ethylene Make Up
Process Unit	LNG Train	LNG Train
Assumed Material	Propane	Ethylene
Pressure (bara)	9	3
Temperature (deg C)	25	-83
Phase	Liquid	Liquid
Inventory (kg)	25,500	11,400
Outflow Rate for Representative Failure (50mm) (kg/s)	36.7	-
Estimated Release Duration for Representative (50mm) Failure	15-30mins	-
Congested Volume (m^3)	12,180	12,180

5.15.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a liquid spray / jet fire for MAE N-15. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-48 and Table 5-66 respectively.

Table 5-66 MAE N-15 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	138	197
	5	122	153
	10	106	112
	20	94	80
5/D	3	128	199
	5	111	153
	10	94	108
	20	81	80

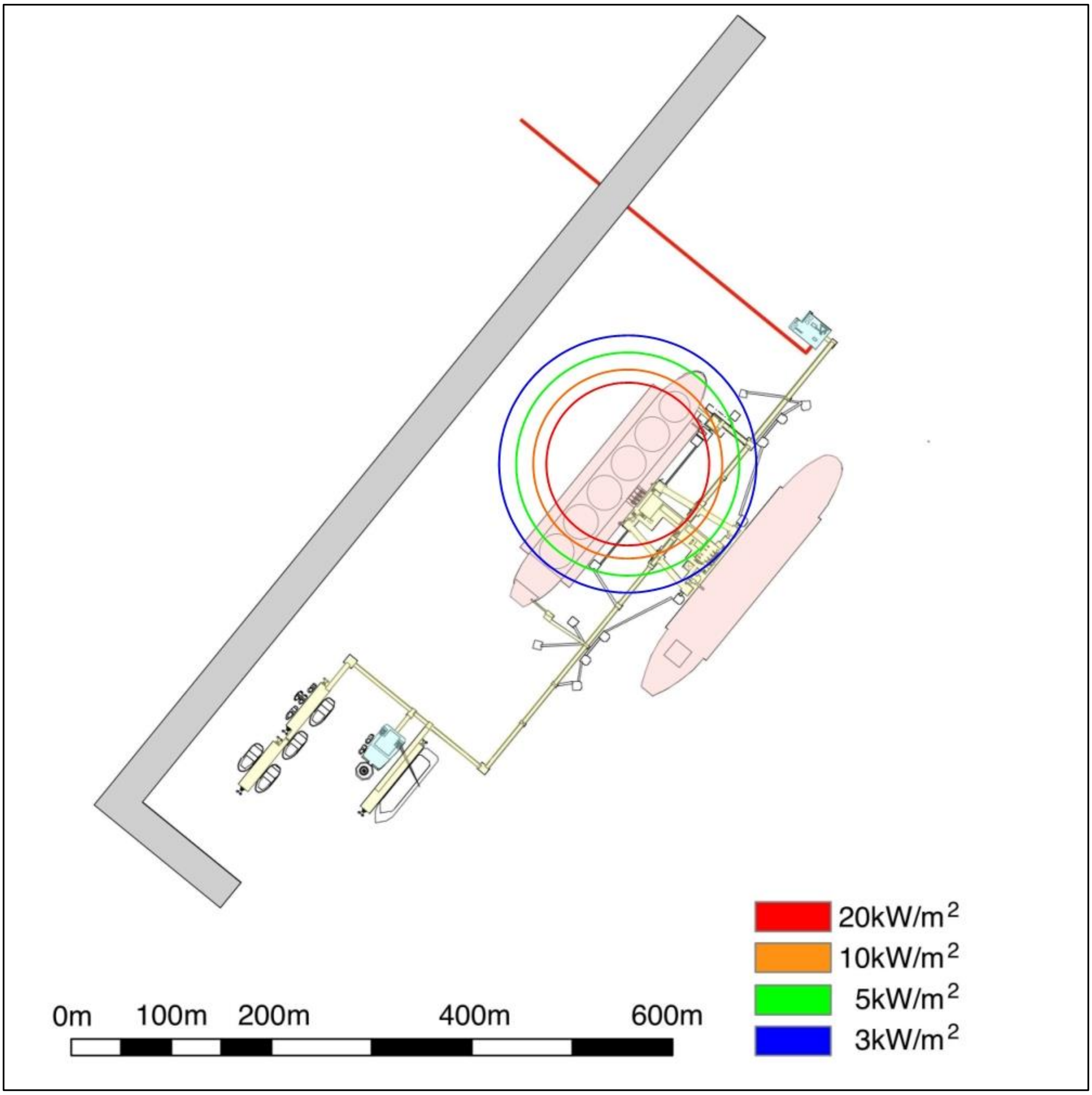


Figure 5-48 MAE N-15 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Ignition of a catastrophic failure for MAE N-15 is best represented by a fireball. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-49 and Table 5-67 respectively.

Table 5-67 MAE N-15 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
75	600	281
	1000	205
	2600	10

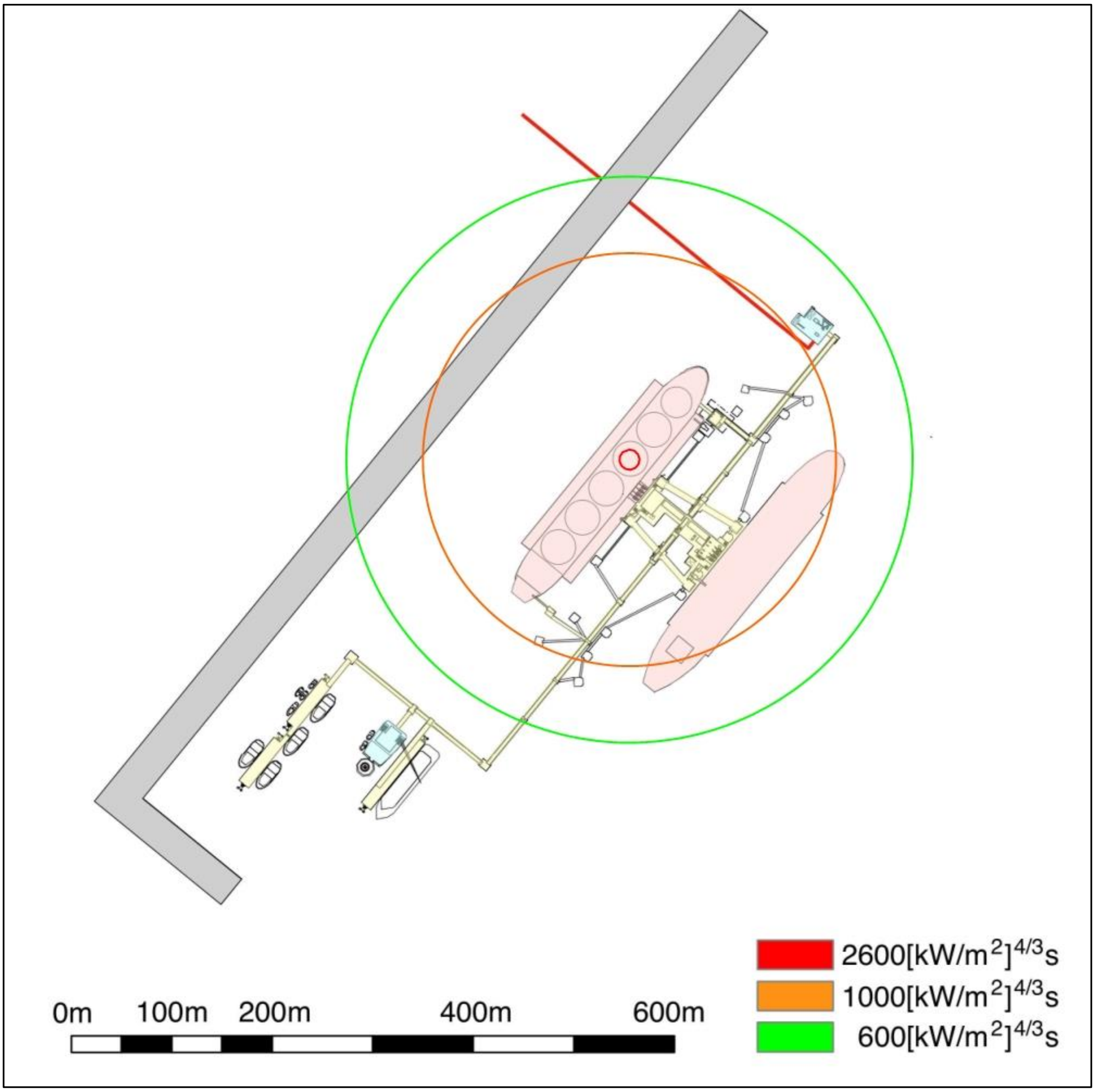


Figure 5-49 MAE N-15 Fireball Contour for Catastrophic Failure (scale in m)

5.15.3. Flash Fire Results

Delayed ignition of flammable gas dispersed into non-congested regions following loss of containment will result in flash fires for MAE N-15. The distances to 100% LFL are presented in Table 5-68 and Table 5-69 for a representative failure (50 mm) and catastrophic failure (credible worst case) respectively. The contour plots to 100% LFL are presented in Figure 5-50 for a representative failure (50 mm) and Figure 5-51 for a catastrophic failure (credible worst case).

Table 5-68 MAE N-15 50mm 100%LFL Flash Fire Extent Results (Propane)

Weather	Maximum Distance (m)
2/D	176
5/D	101

Table 5-69 MAE N-15 Catastrophic Failure 100%LFL Flash Fire Extent Results (Propane)

Weather	Maximum Distance (m)
2/D	580
5/D	284

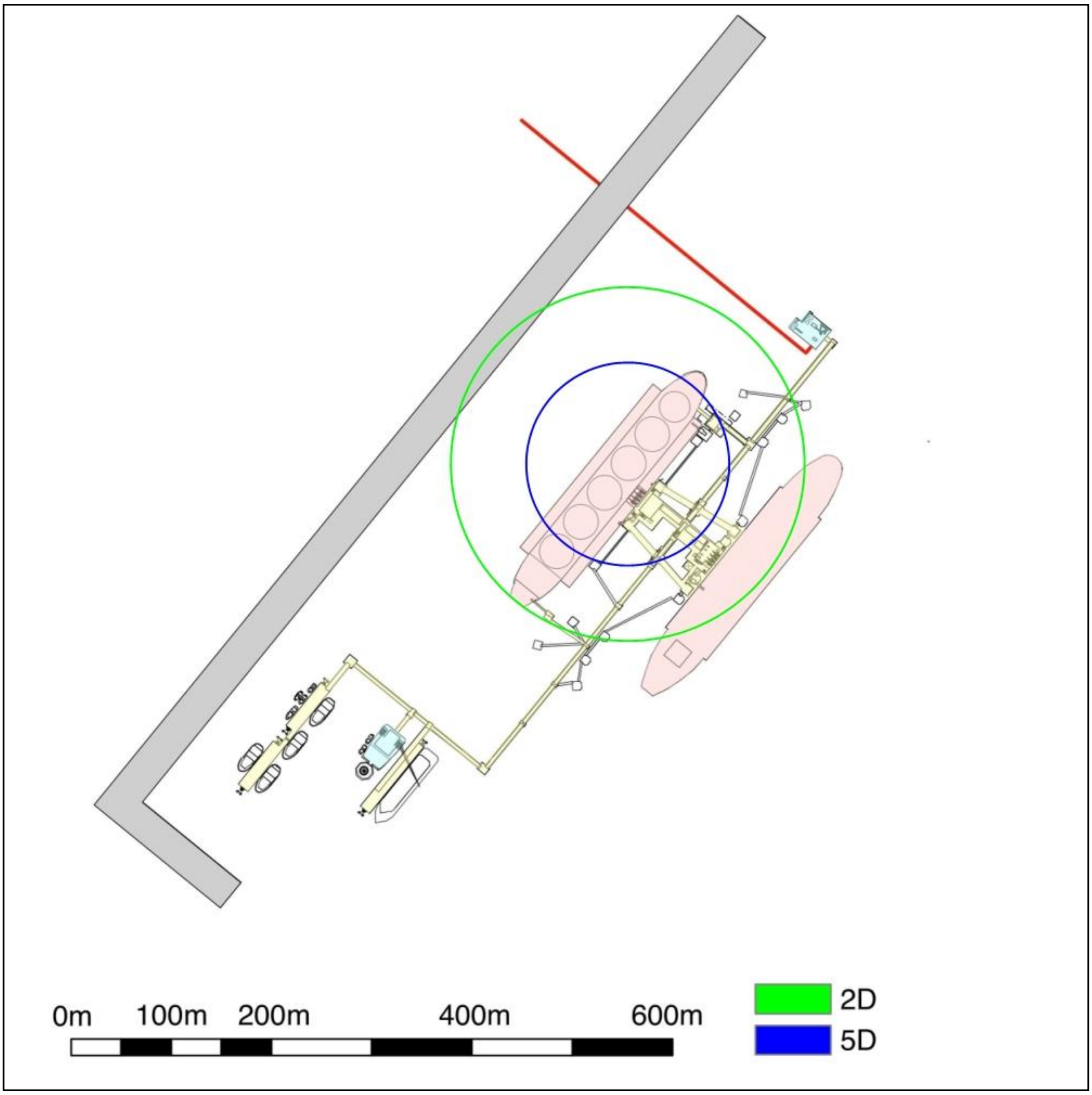


Figure 5-50 MAE N-15 Flashfire Extent to 100% LFL for 50mm Failures (Propane) (scale in m)

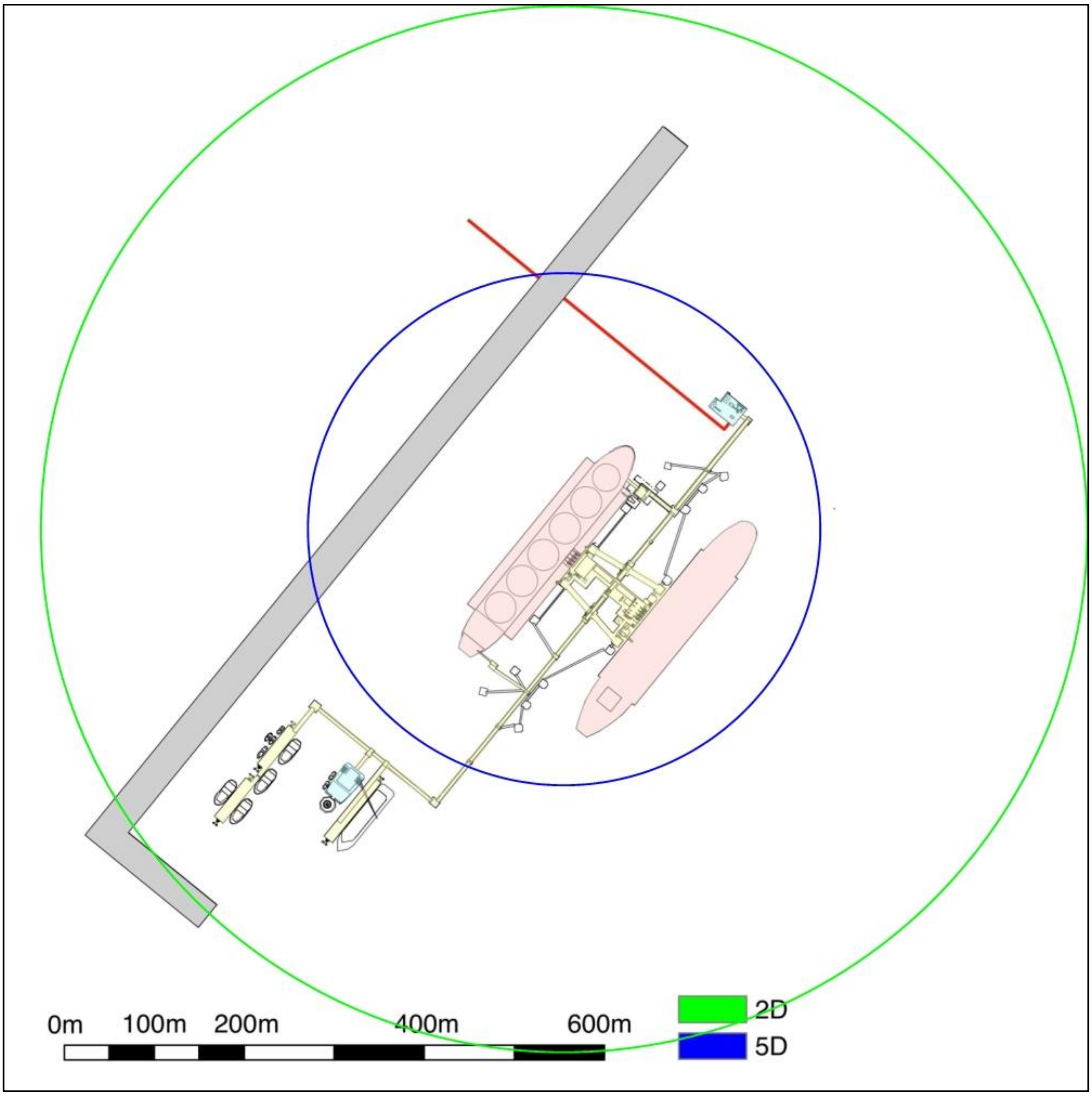


Figure 5-51 MAE N-15 Flashfire Extent to 100% LFL for Catastrophic Failures (Propane) (scale in m)

5.15.4. Explosion Results

Delayed ignition of flammable vapour dispersed into a congested region (portside sponson) for MAE N-15 will result in a vapour cloud explosion. Flammable gas from a representative failure (50 mm) and a catastrophic failure (credible worst case) is assumed to completely the lower section of the sponson. The contour plot and overpressure hazard ranges are shown in Figure 5-52 and Table 5-70 for a propane explosion and in Figure 5-52 and Table 5-70 for an ethylene explosion.

Table 5-70 MAE N-15 Explosion Results (Propane)

Over Pressure (bar)	Maximum Extent (m)
0.02	882
0.05	385
0.14	164
0.35	90

Table 5-71 MAE N-15 Explosion Results (Ethylene)

Over Pressure (bar)	Maximum Extent (m)
0.02	893
0.05	390
0.14	166
0.35	91

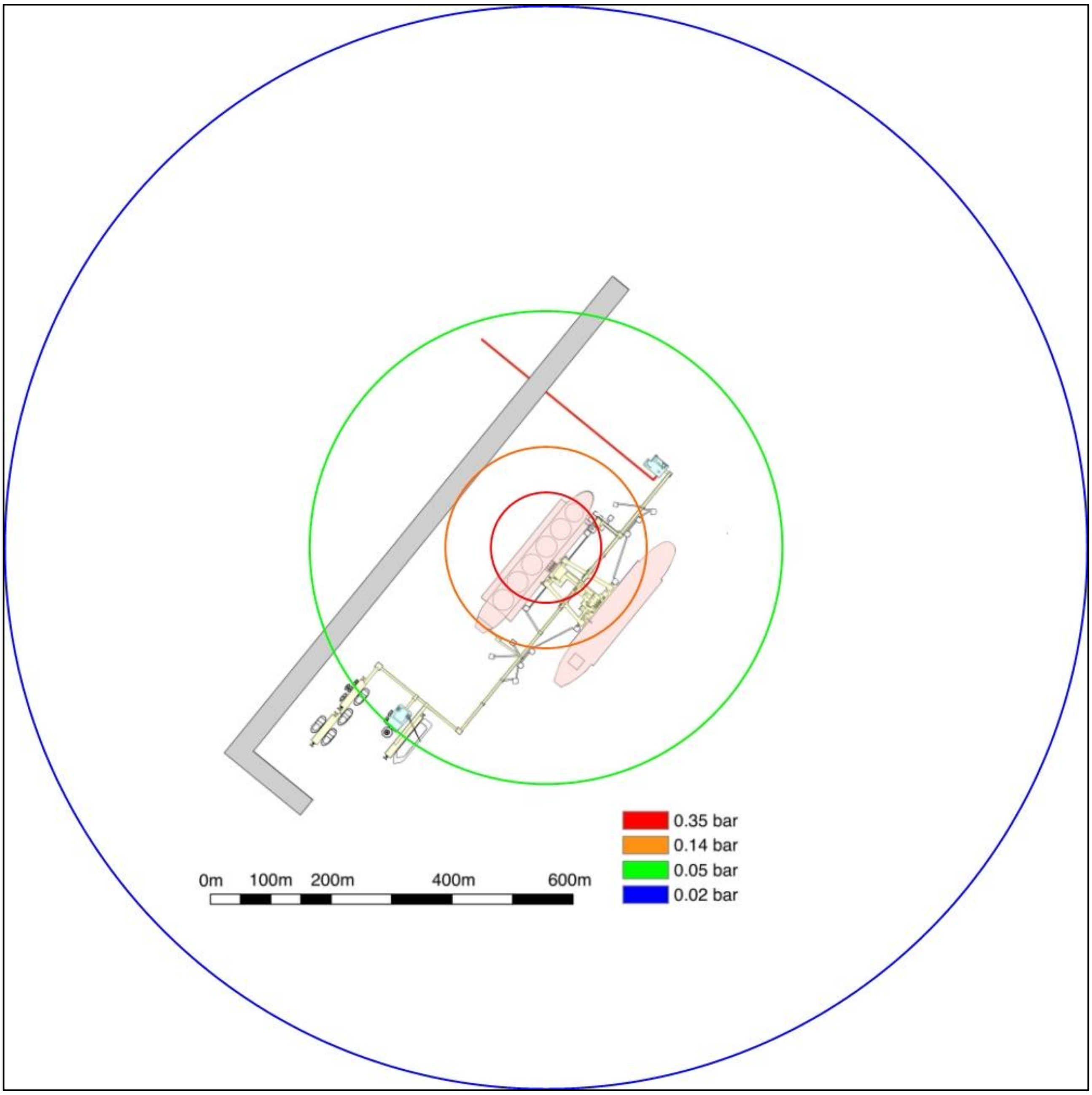


Figure 5-52 MAE N-15 Explosion Contour for 100% Fill of LNG Module (Propane) (scale in m)

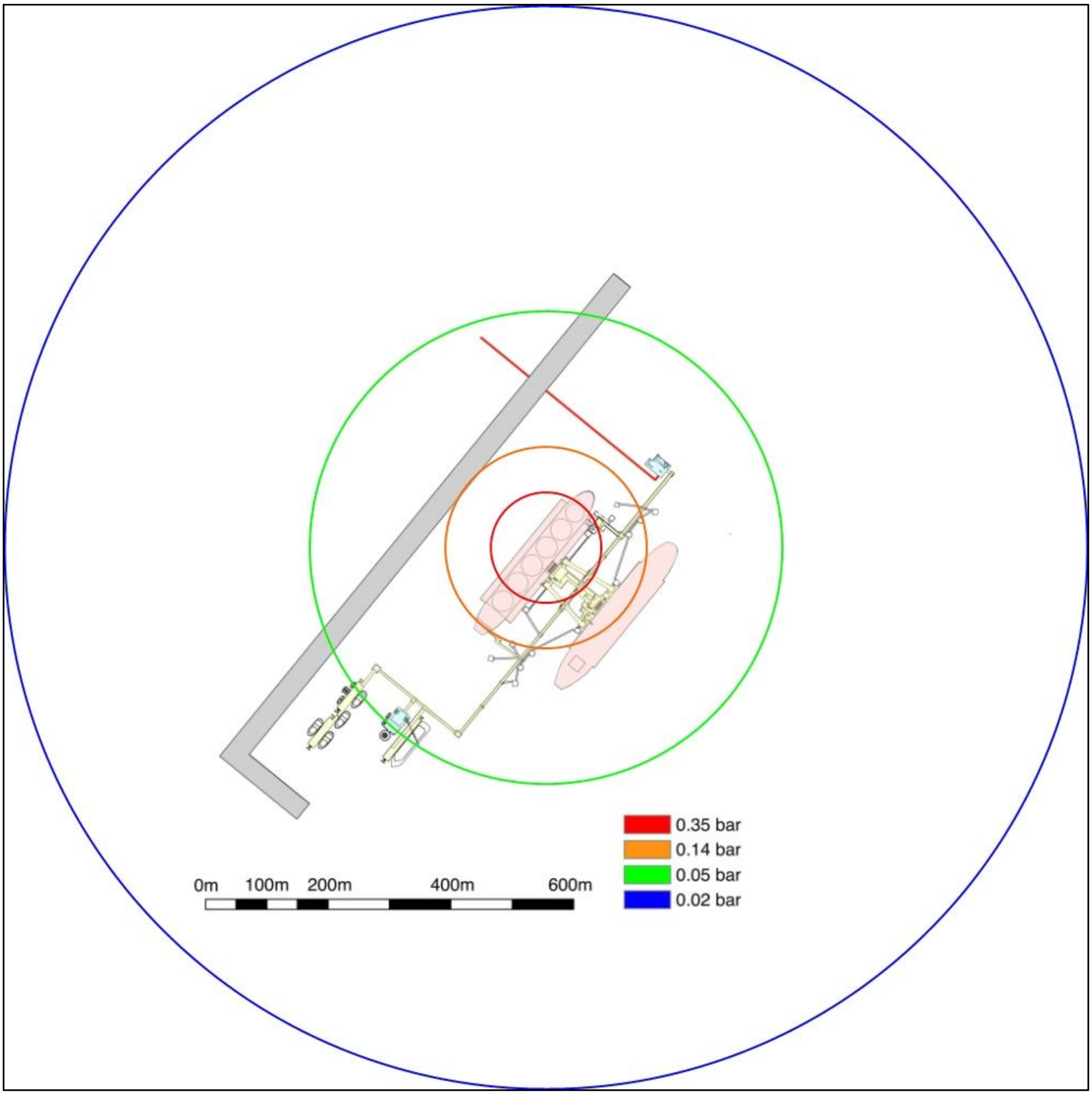


Figure 5-53 MAE N-15 Explosion Contour for 100% Fill of LNG Module (Ethylene) (scale in m)

5.15.5. Cryogenic Spill Results

The extent of a cryogenic pool has been determined for a representative and credible worst case release associated with MAE N-15. A release from the ethylene storage vessel is the primary cryogenic threat with the temperature following discharge to atmospheric pressure below -100ºC. Release of propane and pentane is discounted as a cryogenic hazard.

For a representative failure (50 mm) the ethylene pool spreads to a radius of 21m while for a catastrophic vessel failure the pool spreads to 28m which is approximately half of the deck area of the FLNG – it is considered that the pool will be limited from spreading further due to coaming arrangements and other restrictions, or from the spill flowing overboard.

Table 5-72 MAE N-15 Cryogenic Spill Results (Ethylene)

Release Scenario	Pool Radius (m)
Representative failure (50 mm)	21
Catastrophic failure (credible worst case)	28

5.16. MAE N-16: Gas Release (Fuel Gas) in QU Platform Utility Space / Area

5.16.1. Event Description

This MAE is a release of fuel gas on the QU Platform.

Modelling of fires and explosions for this MAE has been completed using input data as outlined in Table 5-73, which are taken from the MAR study (Appendix B.1.1).

Table 5-73 MAE N-16 Stream Parameters

Parameter	Input
MAR Inventory	Fuel Gas
Process Unit	QU Platform
Assumed Material	Methane
Pressure (bara)	38
Temperature (deg C)	45
Phase	Gas
Inventory (kg)	95
Outflow Rate for Representative Failure (50mm) (kg/s)	11.0
Estimated Release Duration for Representative (50mm) Failure	<1min
Congested Volume (m^3)	500

5.16.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) will result in a gas jet fire for MAE N-16. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-54 and Table 5-74 respectively.

Table 5-74 MAE N-16 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	63	91
	5	56	71
	10	48	49
	20	42	33
5/D	3	63	91
	5	56	70
	10	49	49
	20	44	33

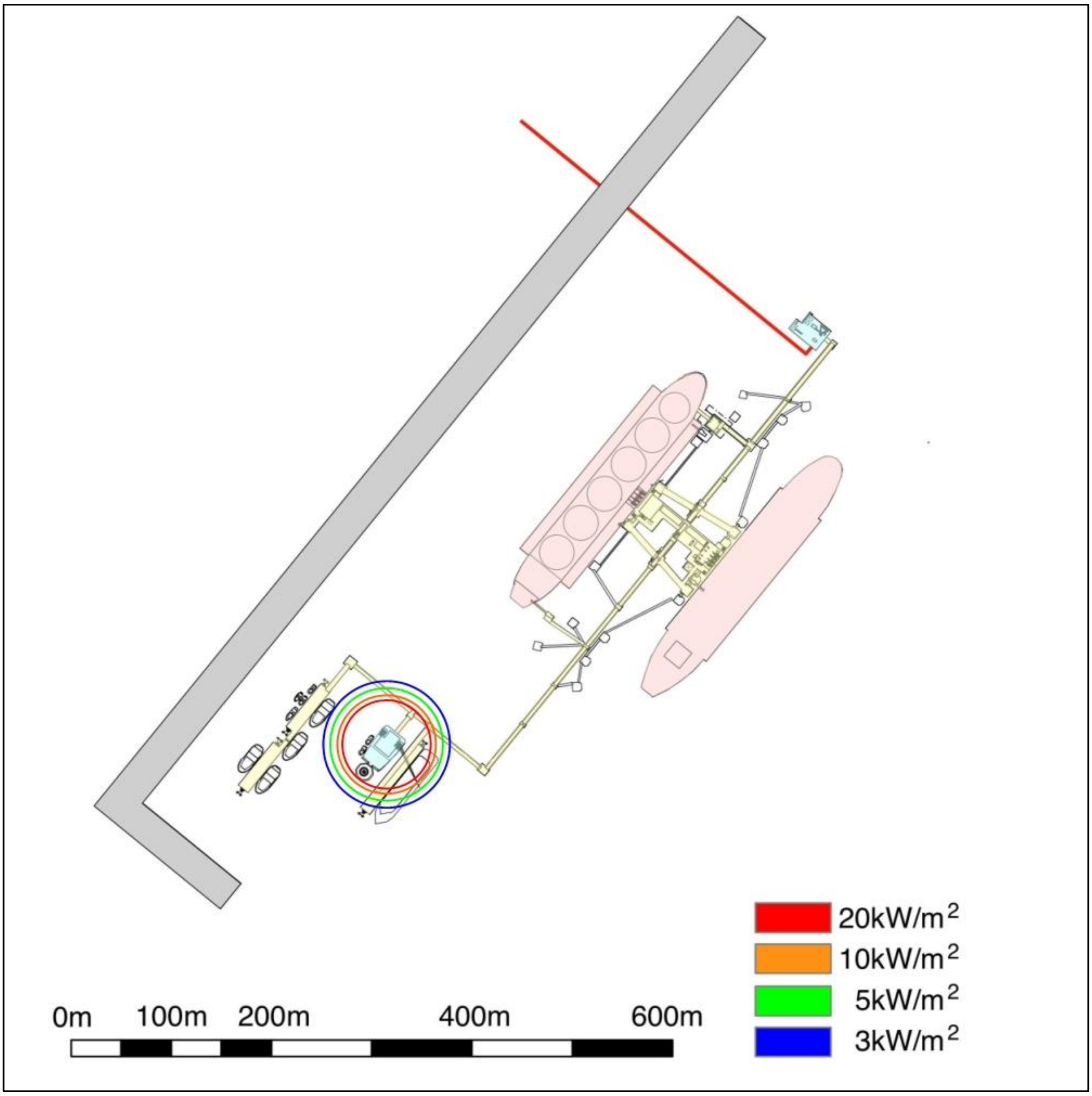
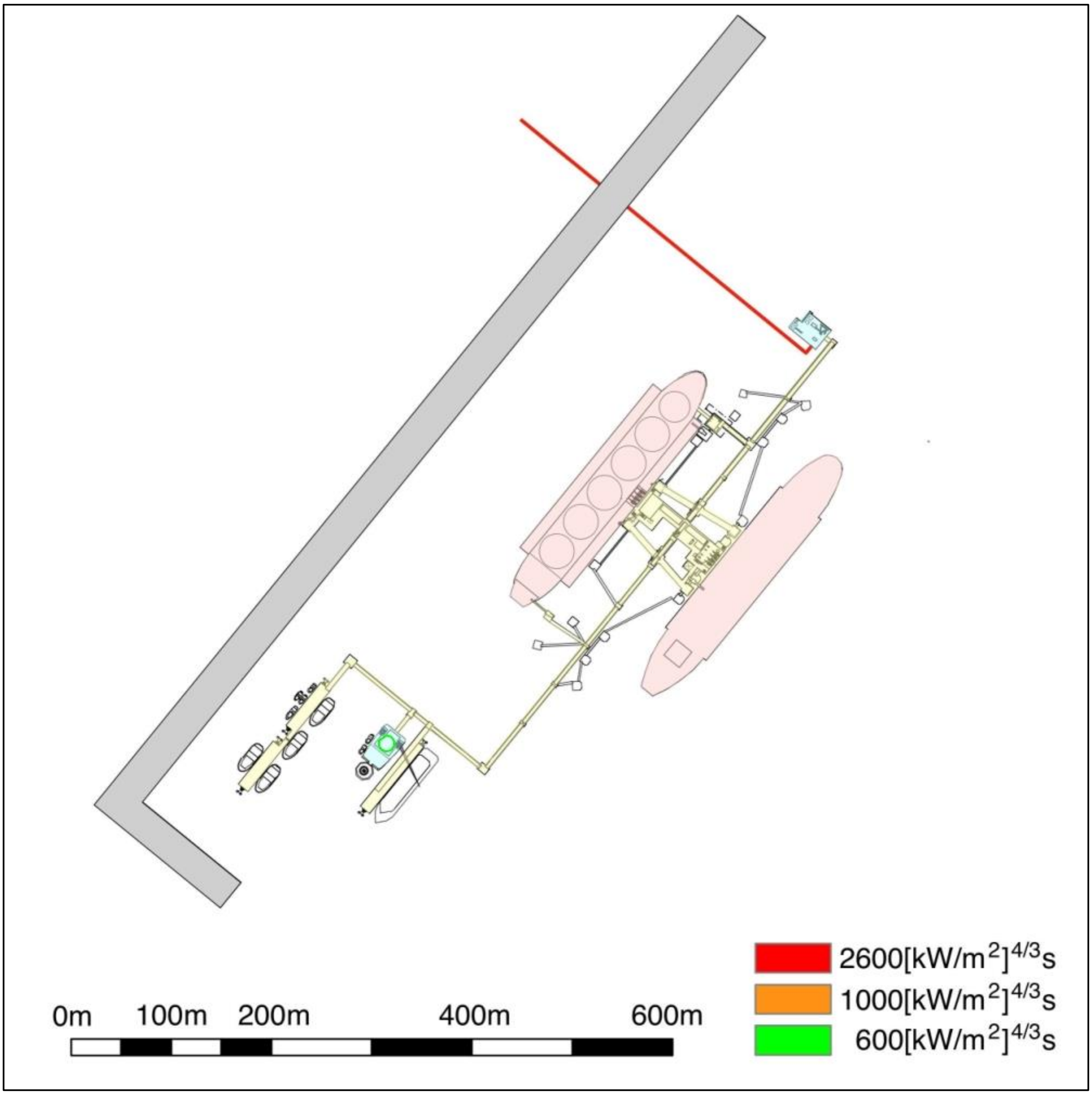


Figure 5-54 MAE N-16 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Ignition of a catastrophic failure for MAE N-16 is best represented by a fireball. The contour plot and hazard ranges due to the thermal dose from the associated fireball are shown in Figure 5-55 and Table 5-75 respectively. Due to the small inventory for this section the fireball duration is short and hence there is no impact at the higher thermal dose levels.

Table 5-75 MAE N-16 Catastrophic Failure Fireball Results

Fireball Radius (m)	Thermal Dose ([kW/m^2]$^{4/3}$ s)	Distance from Release Point (m)
15	600	8
	1000	Not Reached
	2600	Not Reached



NB: The higher thermal dose levels are not reached.

Figure 5-55 MAE N-16 Fireball Contour for Catastrophic Failure (scale in m)

5.16.3. Explosion Results

Delayed ignition of flammable gas dispersed into a congested region (QU Platform) following loss of containment for MAE N-16 will result in a vapour cloud explosion. Flammable vapour in an explosion from a representative failure (50 mm) and a catastrophic failure (credible worst case) is capped by the total mass in the section. The contour plot and overpressures hazard ranges are shown in Figure 5-56 and Table 5-76 respectively.

Table 5-76 MAE N-16 Explosion Results

Over Pressure (bar)	Maximum Extent (m)
0.02	295
0.05	129
0.14	55
0.35	30

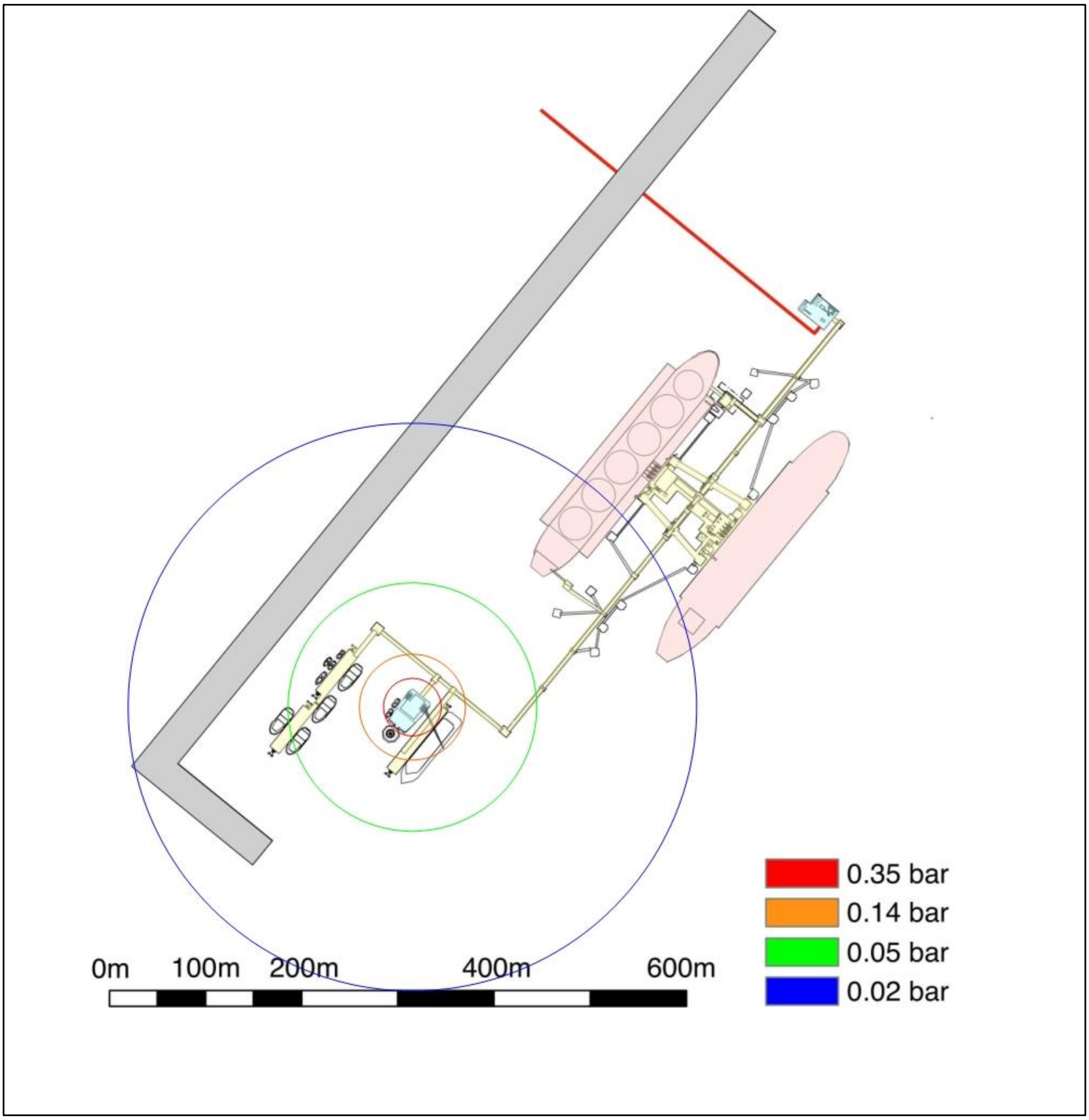


Figure 5-56 MAE N-16 Explosion Contour for 100% Fill of QU Platform (scale in m)

5.17. MAE N-17: LNG Release from FLNG / LNGC Storage Tanks

5.17.1. Event Description

This MAE is a failure of an LNG tank on the FLNG or LNGC.

Modelling of fires and gas dispersion for this MAE has been completed using input data as outlined in Table 5-77, which are taken from the MAR study (Appendix B.1.1). LNG is stored at atmospheric pressure but the release calculations have accounted for the hydrostatic pressure due to the liquid head, which is assumed to be 17m.

Table 5-77 MAE N-17 Stream Parameters

Parameter	Input
MAR Inventory	LNG Storage Tank 1
Process Unit	LNG Storage
Assumed Material	Methane
Pressure (bara)	1.8
Temperature (deg C)	-158
Phase	Liquid
Inventory (kg)	9,791,667

5.17.2. Fire Results

Immediate ignition following a credible worst case (750mm) breach of a cargo tank will result in an unrestricted sea surface pool fire for MAE N-17. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-57 and Table 5-78 respectively.

Table 5-78 MAE N-17 Catastrophic Failure Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	543	976
	5	434	752
	10	313	510
	20	212	322
5/D	3	566	971
	5	460	756
	10	350	524
	20	259	343

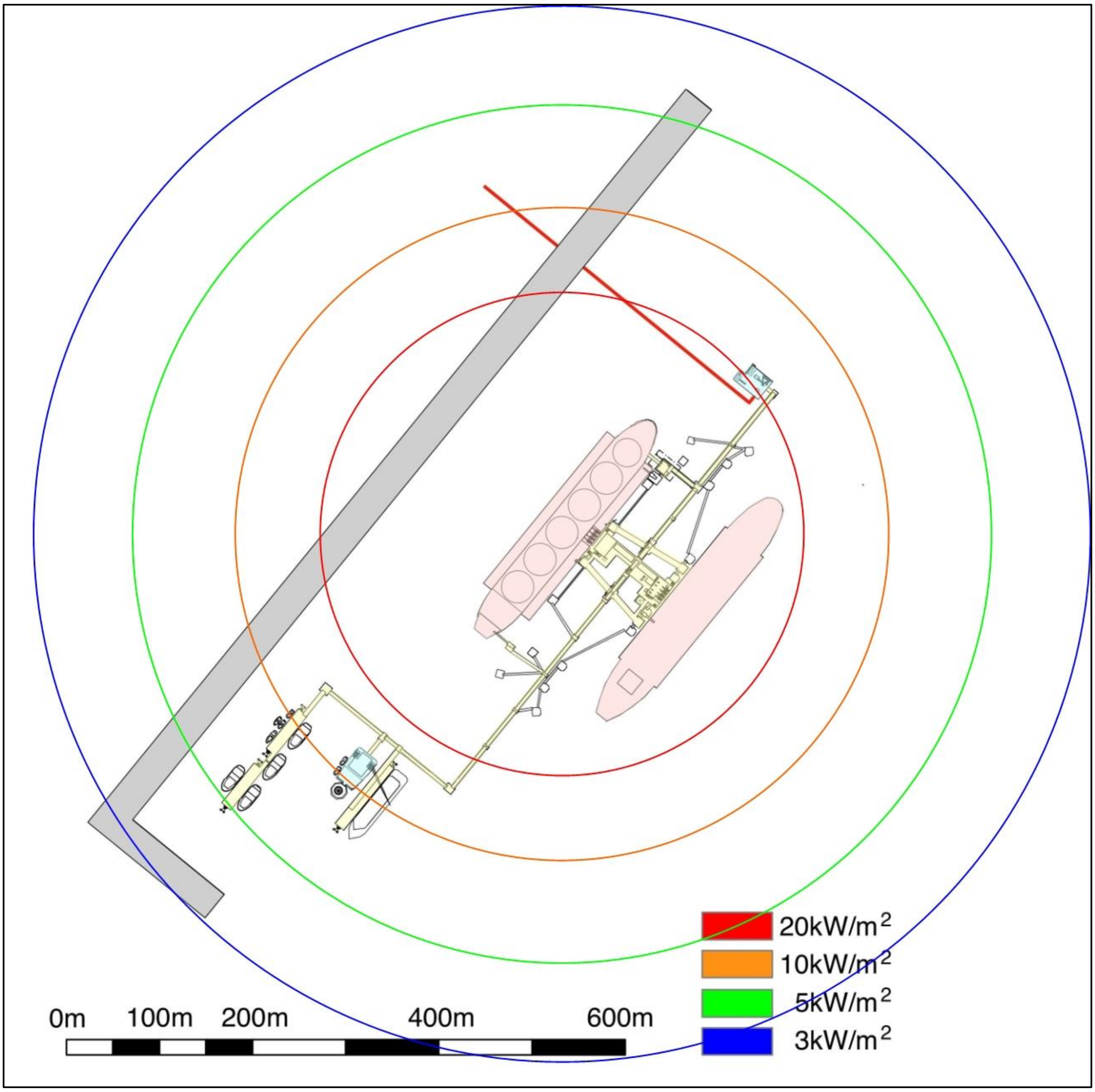


Figure 5-57 MAE N-17 Radiation Contours for Pool Fire from Catastrophic Failure (scale in m)

5.17.3. Flash Fire Results

Delayed ignition of a flammable gas cloud across the sea surface following a 750mm breach of a cargo tank will result in a flash fire for MAE N-17. The hazard distances and contour plot to 100% LFL are presented in Table 5-79 and in Figure 5-58.

Table 5-79 MAE N-17 Credible Worst Case Failure 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	1056
5/D	1076

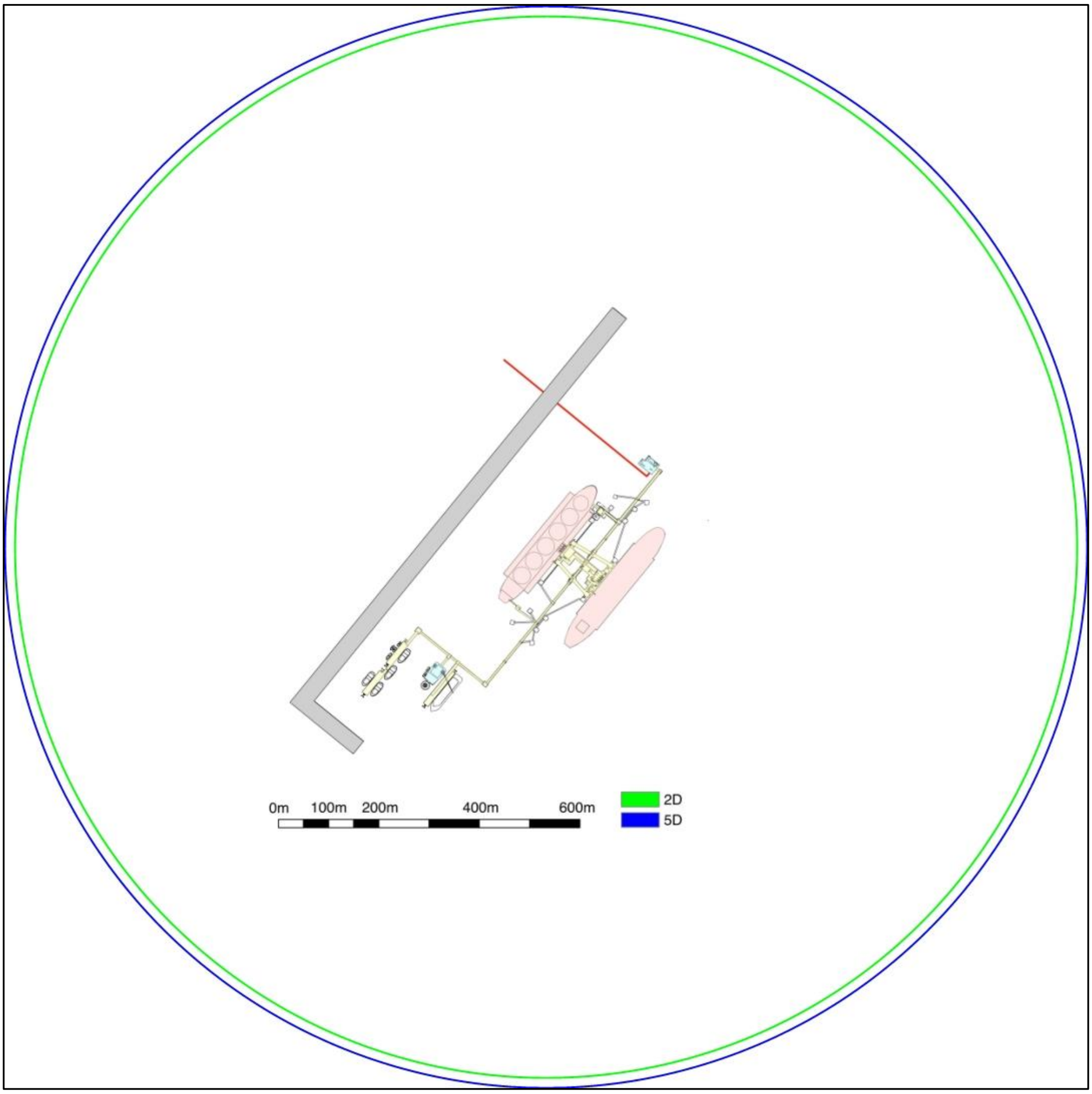


Figure 5-58 MAE N-17 Flashfire Extent to 100% LFL for Catastrophic Failures (scale in m)

5.17.4. Cryogenic Spill Results

The extent of a cryogenic pool has been determined for a credible worst case release associated with MAE N-17, shown in Table 5-80. This is for an unrestricted spill onto the sea surface.

Table 5-80 MAE N-17 Cryogenic Spill Results

Release Scenario	Pool Radius (m)
Catastrophic failure (credible worst case)	63

5.18. MAE N-18: LNG Release during LNGC Loading

5.18.1. Event Description

This MAE is a failure of the loading arms during transfer from the FLNG to the LNGC.

Modelling of fires and flammable for this MAE has been completed using input data as outlined in Table 5-81, which are taken from MAR Inventory 1 (Appendix B.1.1).

Table 5-81 MAE N-18 Stream Parameters

Parameter	Input
MAR Inventory	LNG Export
Process Unit	LNGC Loading
Assumed Material	Methane
Pressure (bara)	7
Temperature (deg C)	-158
Phase	Liquid
Inventory (kg)	18,800
Outflow Rate for Representative Failure (50mm) (kg/s)	28.5
Estimated Release Duration for Representative (50mm) Failure	15-30mins
Loading Rate (m^3/hr)	5,000 (Single Loading Arm)
Congested Volume (m^3)	-

5.18.2. Fire Results

Immediate ignition following loss of containment from a representative failure (50 mm) may result in a liquid spray / jet fire for MAE N-18 if the release is directed horizontally into an open space (e.g. outboard of the FPSO). The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-59 and Table 5-82 respectively.

Table 5-82 MAE N-18 50mm Jet Fire Extent Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	149	168
	5	133	134
	10	117	97
	20	105	63
5/D	3	134	167
	5	118	130
	10	101	96
	20	89	68

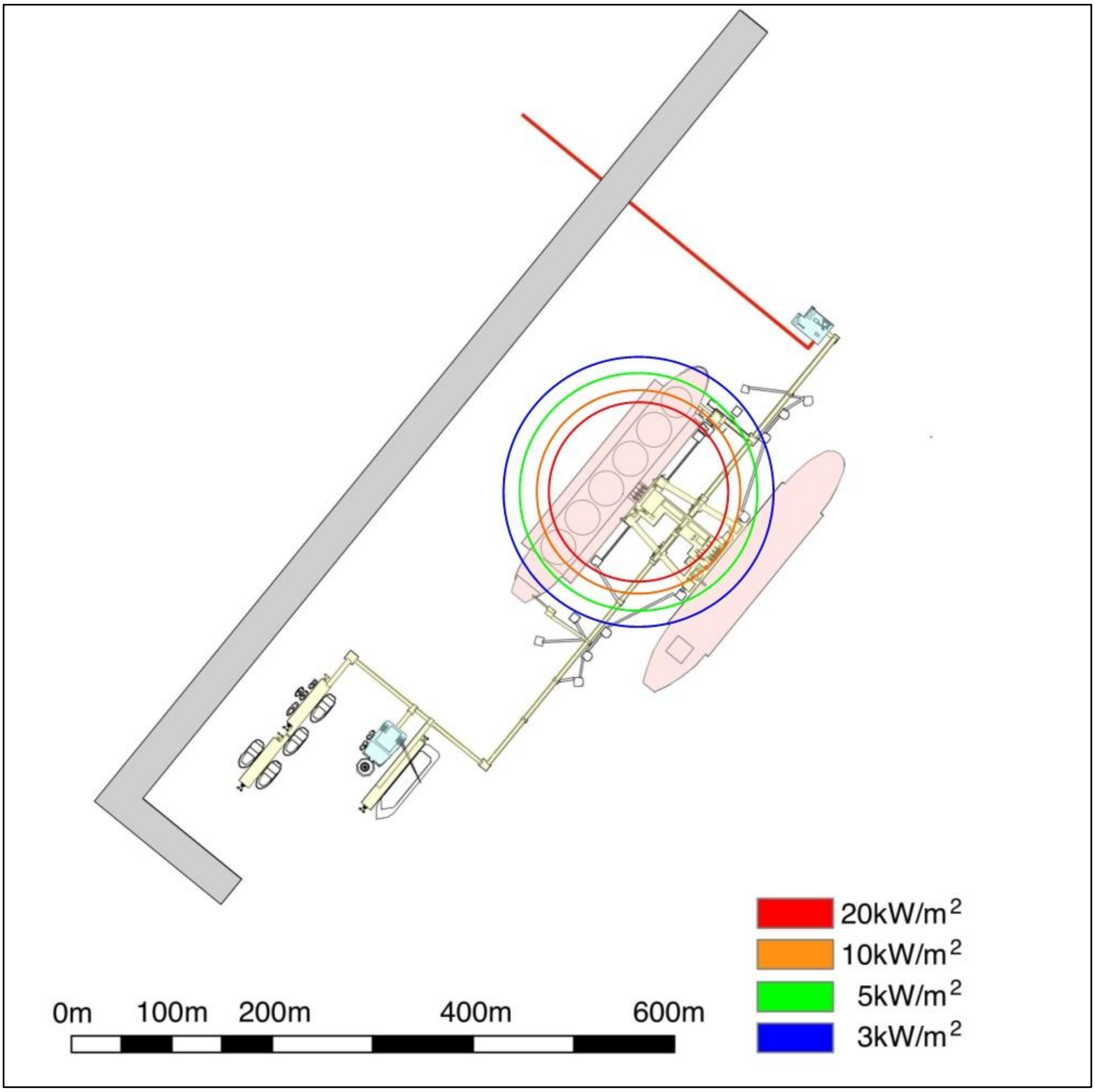


Figure 5-59 MAE N-18 Radiation Extent for Jet Fire from 50mm Failure (scale in m)

Immediate ignition following loss of containment from a representative failure (50 mm) may also result in a liquid pool fire for MAE N-18, for example, if the release is directed downwards and the momentum of discharge is removed. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-60 and Table 5-83 respectively.

Table 5-83 MAE N-18 50mm Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	83	138
	5	67	104
	10	33	41
	20	20	27
5/D	3	86	136
	5	71	104
	10	42	44
	20	27	29

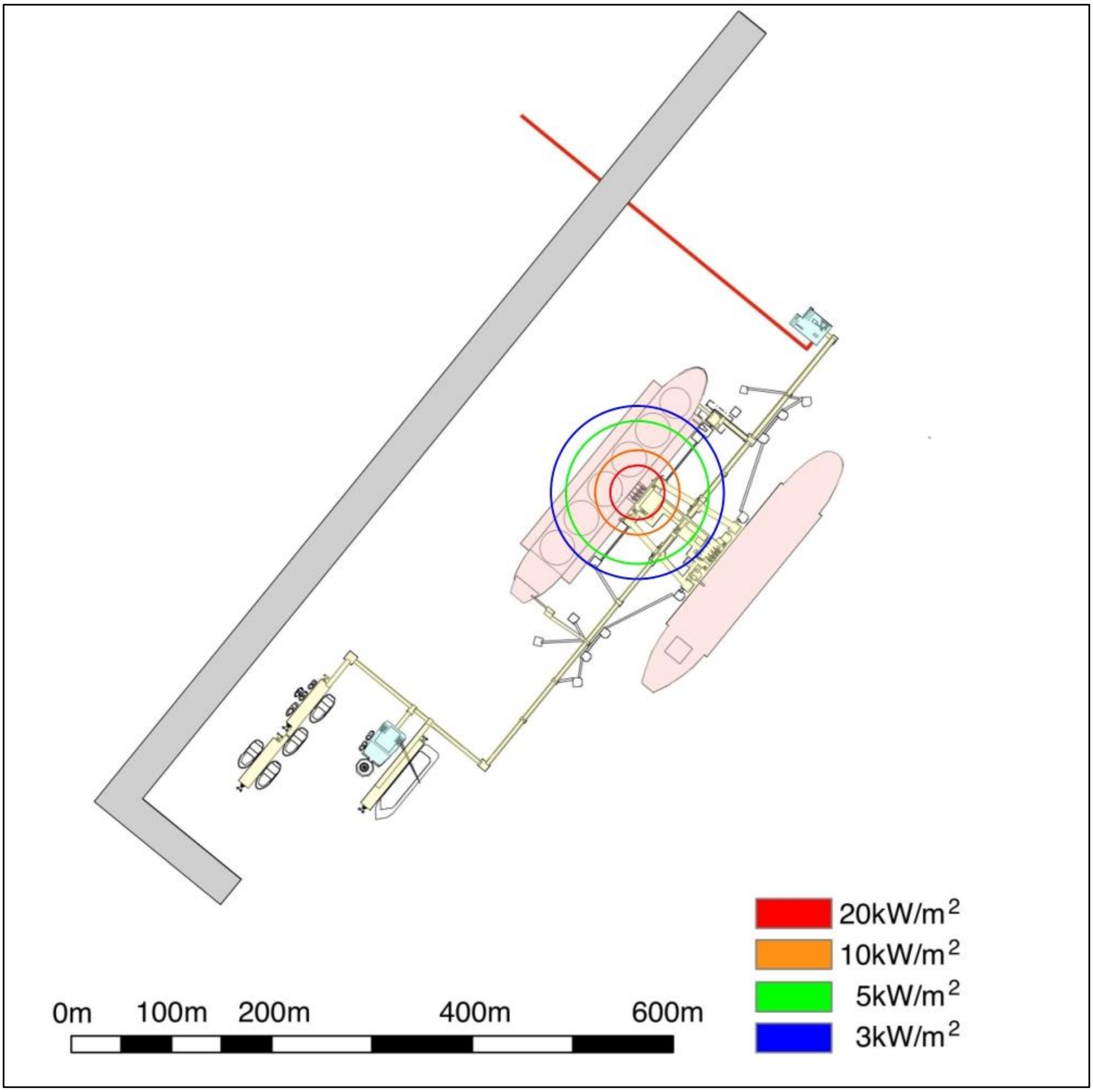


Figure 5-60 MAE N-18 Radiation Contours for Pool Fire from 50mm Failure (scale in m)

Immediate ignition following a catastrophic failure (credible worst case) will result in a liquid pool fire for MAE N-18. The contour plots and hazard ranges due to thermal radiation impact are shown in Figure 5-61 and Table 5-84 respectively.

Table 5-84 MAE N-18 Catastrophic Failure Pool Fire Results

Weather	Thermal Radiation (kW/m^2)	Maximum downwind extent (m)	Maximum crosswind extent (m)
2/D	3	359	667
	5	289	522
	10	215	368
	20	155	249
5/D	3	366	658
	5	299	519
	10	227	372
	20	175	259

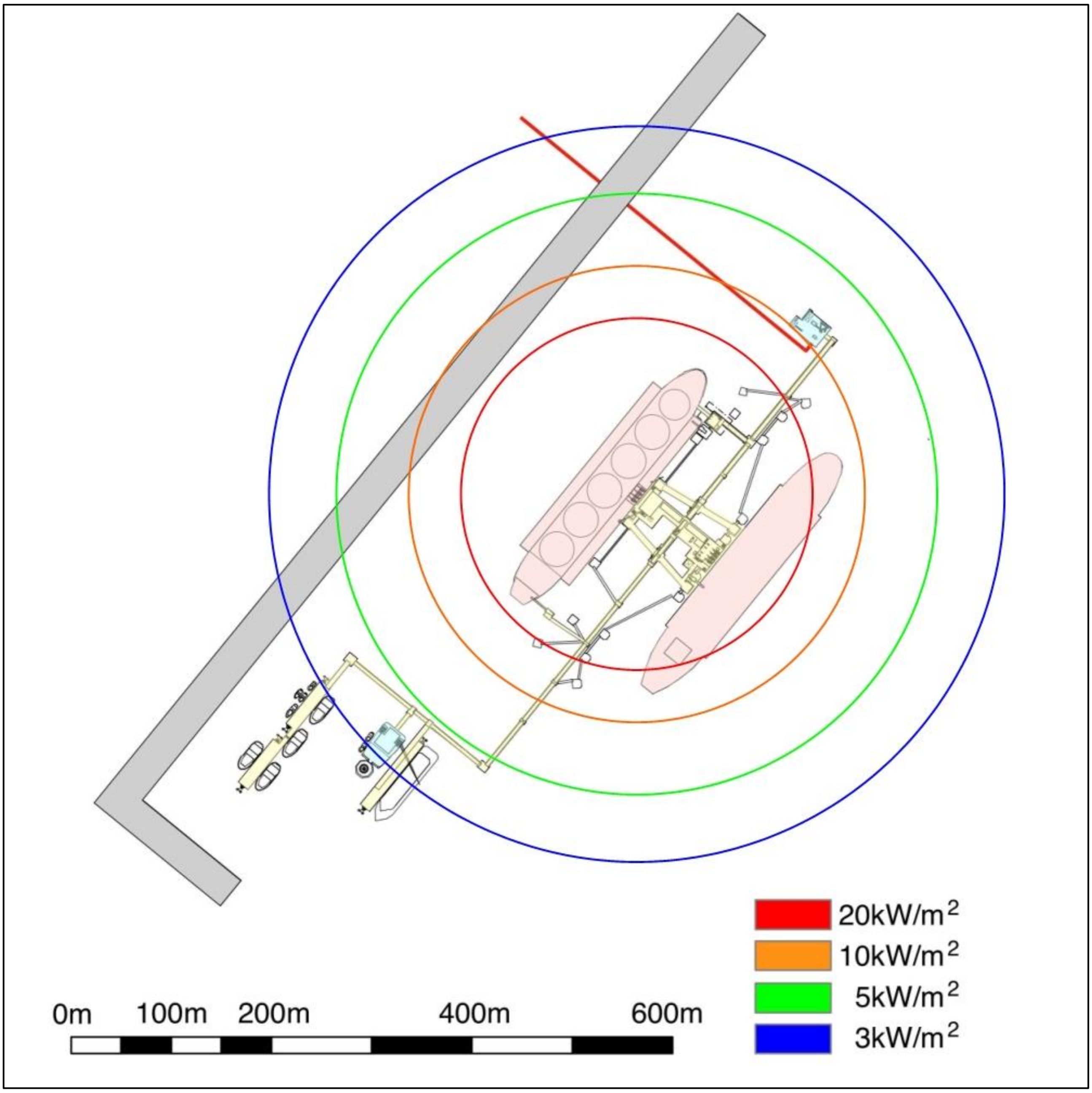


Figure 5-61 MAE N-18 Radiation Contours for Pool Fire from Catastrophic Failure (scale in m)

5.18.3. Flash Fire Results

Delayed ignition of flammable gas dispersed across the sea surface will result in a flash fire for MAE N-18. The distances to 100% LFL are presented in Table 5-85 and Table 5-86 for a representative failure (50 mm) and credible worst case (rupture of loading arms) failure respectively. The contour plots to 100% LFL are presented in Figure 5-62 and Figure 5-63 for a representative failure (50 mm) and credible worst case failure respectively.

Table 5-85 MAE N-18 50mm 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	117
5/D	76

Table 5-86 MAE N-18 FBR 100%LFL Flash Fire Extent Results

Weather	Maximum Distance (m)
2/D	223
5/D	159

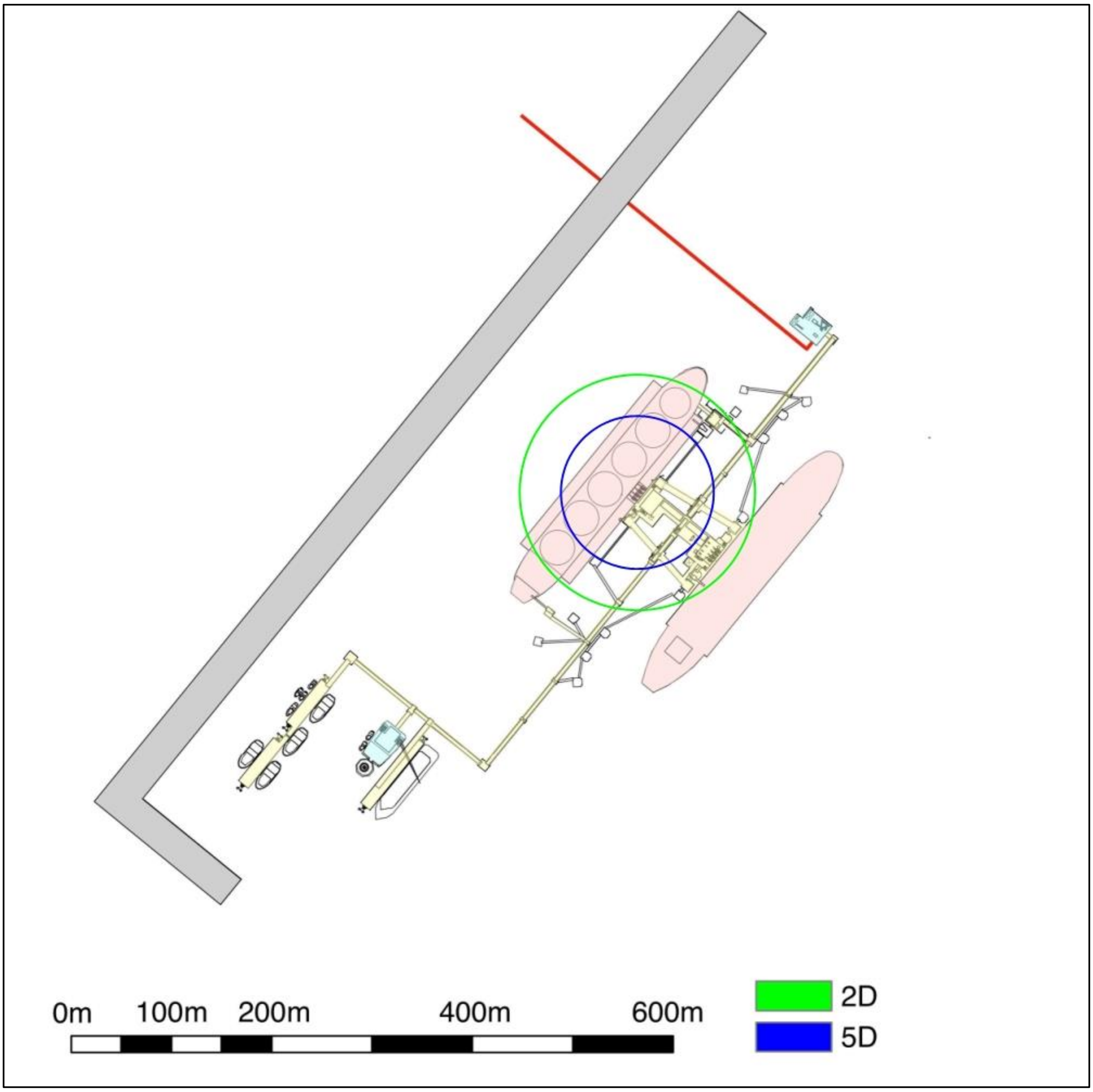


Figure 5-62 MAE N-18 Flashfire Extent to 100% LFL for a 50mm Failure (scale in m)

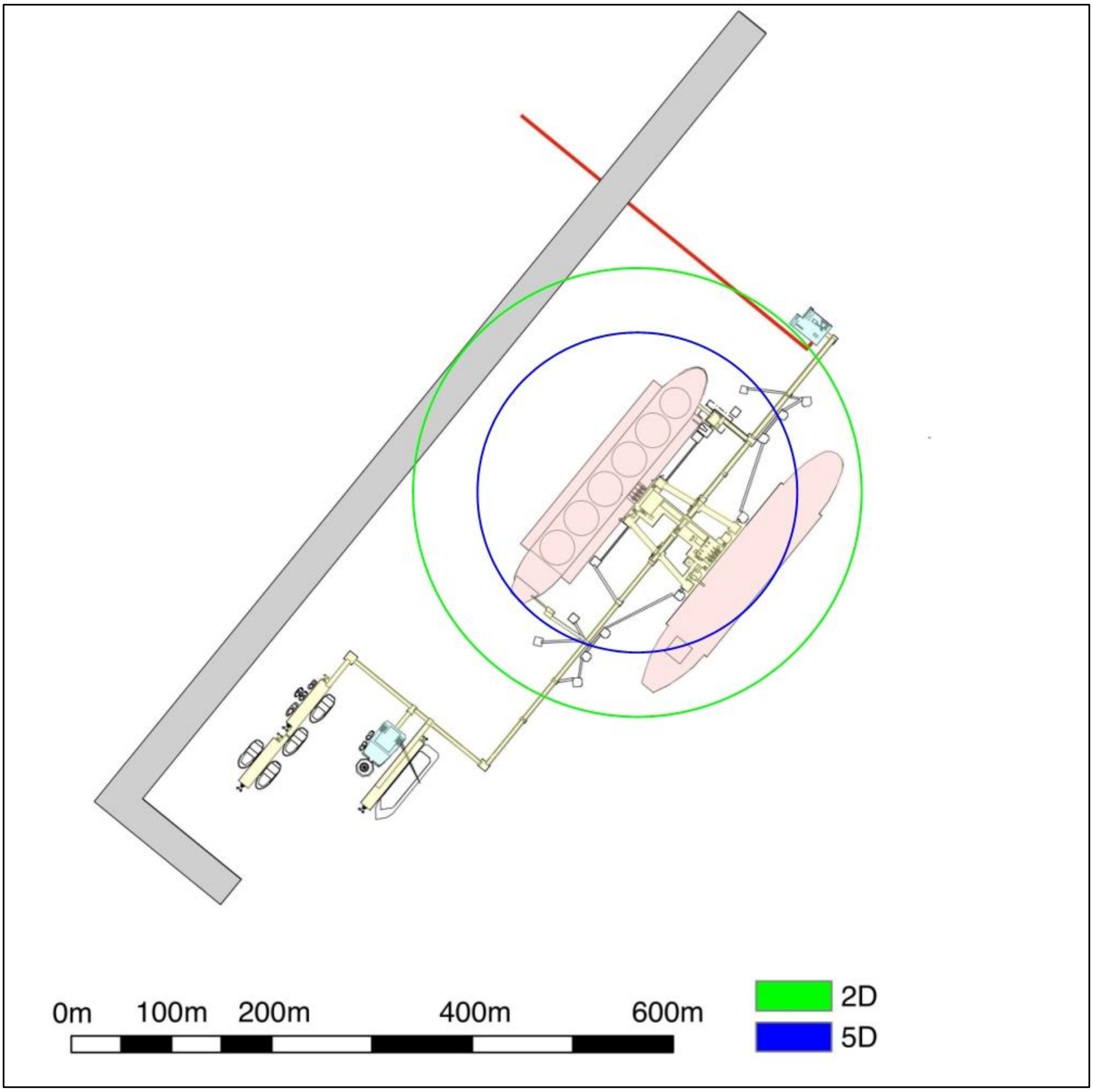


Figure 5-63 MAE N-18 Flashfire Extent to 100% LFL for a Full Bore Rupture (scale in m)

5.18.4. Cryogenic Spill Results

The extent of a cryogenic pool has been determined for a representative and credible worst case release associated with MAE N-18. For a representative failure (50 mm) the pool spreads to a radius of 19m while for a catastrophic vessel failure the pool spreads to a radius of 43m.

Table 5-87 MAE N-18 Cryogenic Spill Results

Release Scenario	Pool Radius (m)
Representative failure (50 mm)	19
Catastrophic failure (credible worst case)	43

5.19. Near Shore Hub Failure Scenario Summary Tables

This section summarises the impairment potential for various EER provisions on the facilities that make up the Near Shore Hub – the Riser Platform, the FLNG, QU Platform, which includes the TR and the nearby evacuation facilities – see Figure 1-2. Consideration is also included of potential impact from hazardous effects beyond the 500m safety zone around the NSH.

Impairment potential of EER provisions and the safety zone has been based on the same criteria and approach as for the FPSO. Where a ✓ is shown in the tables below, impairment of the EER provisions / safety zone is possible based on the criteria and assumptions listed in Section 4.14.

Event ID: **N-01 Gas Release from Import Gas Riser**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	✓	×	×	×
Fireball	✓	×	×	×
Discussion	Due to the large inventory contained within the riser and import gas line, event durations will be considerable (greater than one hour) for both a representative (50mm) release and a full bore rupture (for which the initial fireball would be followed by a long duration jet fire). High levels of thermal radiation from both jet fires and fireballs could result in significant numbers of immediate fatalities on the riser platform with any personnel unaffected potentially trapped from returning to the QU platform. The event is sufficiently remote to discount impact of the TR and the fire sizes do not extend beyond the safety zone. It is not expected that evacuation facilities would be required but these are nevertheless un-impaired.			

Event ID: **N-02 Gas Release from Trestle Feed Gas Flowline / Hose to FLNG**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Discussion	Event durations for a representative failure (50 mm) will be around 1-5 minutes. Thermal radiation from jet fires and fireballs could impact the main escape routes from the riser platform, FLNG and LNGC to the QU platform but this would be for only a short duration and hence impairment is discounted. The event is sufficiently remote to discount impact of the TR and the fire sizes do not extend beyond the safety zone. Escalation potential is limited and evacuation facilities at the QU platform are not expected to be required.			

Event ID: **N-03 Gas Release from Trestle Fuel Gas Flowline to QU Platform**	**Impairment Potential**			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Discussion	Due to the high pressure of the release and the relatively small inventory, event durations will be very short (under 1 minute). Thermal radiation from jet fires and fireballs could cause temporary impact to escape routes from the riser platform FLNG and LNGC vessels to the QU platform. However, in all cases, personnel will be able to wait out the event on any of the installations before returning to the TR. Impact beyond the safety zone and impairment of the TR is discounted. There would not be any significant escalation or requirement for evacuation.			

Event ID: **N-04 Gas Release from FLNG Inlet Metering and Amine Treatment**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	✓	×	×	×
Fireball	×	×	N/A	×
Explosions	✓	×	×	✓
Discussion	The release duration for a representative failure (50 mm) will be around 30 minutes. High levels of thermal radiation from jet fires would be a threat to personnel on the FLNG and, depending on release direction, could cause impairment of escape routes from the riser platform and FLNG vessel, preventing personnel from returning to the QU platform. There is potential for escalation on the FLNG but, if required, evacuation facilities would be unimpaired. High thermal radiation levels from fireballs could impact personnel on the riser platform and both vessels however, impact will be short-lived and surviving personnel would be able to reach the QU platform after a short delay. Impact on the TR and beyond the safety zone is discounted for both jet fires and fireballs. High overpressures from explosions can cause escape route impairment. The TR on the QU platform may be impacted by low overpressures but these will not be high enough to cause impairment. There is potential for escalation on the FLNG but evacuation facilities are un-impaired. Hazard ranges for the lowest overpressures extend beyond 500m and hence the safety zone is considered to be impaired.			

Event ID: **N-05 Gas Release from FLNG Dehydration and Regeneration**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	✓	×	×	×
Fireball	×	×	N/A	×
Explosions	✓	×	×	✓
Discussion	Event durations for a representative failure (50 mm) will be around 20 minutes. High levels of thermal radiation from jet fires would be a threat to personnel on the FLNG and, depending on release direction, could cause impairment of escape routes from the riser platform and FLNG / LNGC vessels, preventing personnel from returning to the QU platform and presenting an escalation threat. High thermal radiation levels from fireballs could impact personnel on both the FLNG and LNGC vessels however, impact will be short-lived and surviving personnel would be able to reach the QU platform after a short delay. Impact on the TR, evacuation facilities and beyond the safety zone is discounted for both jet fires and fireballs. High overpressures from explosions can cause escape route impairment. The TR on the QU platform may be impacted by low overpressures but these will not be high enough to cause impairment. Escalation may be caused by explosion damage but evacuation facilities are not considered to be threatened. Hazard ranges for the lowest overpressures extend beyond 500m and hence the safety zone is considered to be impaired.			

Event ID: **N-06 Gas Release from FLNG Boil Off Gas / Flash Gas Compression**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	×	×	N/A	×
Discussion	Due to the small inventory associated with this event, release durations will be short (<1 minute) in all cases; impairment potential is limited and personnel surviving the initial fire/explosion will be able to escape via the main escape route to the QU platform. There is expected to be limited escalation potential and evacuation would not be required.			

Event ID: **N-07 Fuel Gas Release from FLNG HP Fuel Gas System**	Impairment Potential			
	Escape Routes	TR	Evacuation	Safety Zone
Jet Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	×	×	N/A	×
Discussion	Due to the small inventory associated with this event, release durations will be short (<1 minute) in all cases; impairment potential is limited and personnel surviving the initial fire/explosion will be able to await rescue on any of the installations or escape via the main escape route to the QU platform. There is expected to be limited escalation potential and evacuation would not be required.			

Event ID: **N-08 Gas Release from FLNG Fractionation**	Impairment Potential			
	Escape Routes	TR	Evacuation	Safety Zone
Jet Fire	×	×	×	×
Fireball	×	×	N/A	×
Explosions	✓	×	×	✓
Discussion	Event durations for a representative failure (50 mm) will be around 15 minutes. High levels of thermal radiation from jet fires will impair the aft of the FLNG or the escape route along the trestle. However, due to the directional nature of the jet fire, simultaneous impairment of all routes to the QU platform is discounted and personnel will be able to return to the TR either via the trestle escape route or along the portside of the FLNG. The TR is unaffected but there is some potential for escalation – if required an orderly evacuation can be completed. Thermal radiation from fireballs could affect personnel on both the FLNG and LNGC vessels however, impact will be short-lived and surviving personnel would be able to reach the QU platform after a short delay. Impact on the TR and beyond the safety zone is discounted; there is no expected requirement for evacuation. Explosions could also cause impairment of escape routes from the riser platform, FLNG and LNGC vessels with some personnel needing to await rescue. There is potential for escalation however, whilst low explosion overpressures could reach the TR and evacuation facilities on the QU platform these will not be high enough to cause impairment. Hazard ranges for the lowest overpressures extend beyond 500m and hence the safety zone is considered to be impaired.			

Event ID: **N-09 Light Hydrocarbon Liquid Release from FLNG Fractionation**	Impairment Potential			
	Escape Routes	TR	Evacuation	Safety Zone
Spray Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	✓	×	×	✓
Flammable Gas	×	✓	×	×
Discussion	Release durations for this event will be short (<5 minutes). Whilst high levels of thermal radiation from jet fires and fireballs could reach both the FLNG and LNGC vessels, the short durations of the events mean that, in all cases, surviving personnel will be able to await rescue on either vessel or escape to the QU platform via the escape route. Explosions overpressures will be high enough to cause impairment of the main escape route to the QU platform with some surviving personnel needing to await rescue. There is potential for escalation however, whilst low explosion overpressures could reach the TR on the QU platform, these will not be high enough to cause impairment. Hazard ranges for the lowest overpressures extend beyond 500m and hence the safety zone is considered to be impaired. Dispersion of flammable gas clouds could cause high gas concentrations at the LNGC vessel and QU platform as well as the FLNG although duration of release short and hence escape impairment is discounted. Ingress of flammable gas if the dampers fail to close on demand would impair the TR although the frequency of this event will be very low.			

Event ID: **N-10 LNG Release from FLNG Liquefaction Process**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Spray Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	✓	×	×	✓
Flammable Gas	×	×	N/A	×
Cryogenic Spill	×	×	×	×
Discussion	Whilst high levels of thermal radiation from jet fires and fireballs could reach both the FLNG and LNGC vessels, the short durations of the events mean that, in all cases, surviving personnel will be able to wait for the fire to finish before escaping to the TR at the QU platform and waiting out the event – there is no requirement for evacuation. Explosions overpressures will be high enough to cause impairment of the main escape route to the QU platform. Surviving personnel may need to await rescue. There is potential for escalation however, whilst low explosion overpressures could reach the TR, these will not be high enough to cause impairment. Hazard ranges for the lowest overpressures extend beyond 500m and hence the safety zone is considered to be impaired. Dispersion of flammable gas clouds could result in high gas concentrations at both the FLNG and LNGC vessels but not beyond. The duration of release is short and hence escape impairment is discounted. A cryogenic spill could spread across the FLNG and impact escape routes on the starboard and/or portside of the FLNG but personnel would be able reach the TR via the trestle escape route. Cryogenic impact may result in an escalation threat but the release does not extend to impact the TR, evacuation facilities or safety zone.			

Event ID: **N-11 LNG Release from FLNG Flash Gas Drum**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Spray Fire	✓	×	×	×
Pool Fire	✓	×	×	×
Explosions	✓	×	×	✓
Flammable Gas	✓	×	N/A	×
Cryogenic Spill	×	×	×	×
Discussion	Release durations for a representative failure (50 mm) will be around 20 minutes and hence high levels of thermal radiation from jet fires and pool fires could cause impairment of escape routes from the riser platform, FLNG and LNGC vessels to the QU platform. Personnel who survive the initial fire event would have to wait out the event on either vessel. Pool fires from a catastrophic failure would have widespread impact across the NSH; some surviving personnel would not be able to return directly to the TR. The TR and evacuation facilities would be impacted at lower radiation levels but this is not expected to be sufficient to cause impairment. Explosions could also cause impairment of escape routes from the riser platform, FLNG and LNGC vessels. As with the fire case, surviving personnel will have to await rescue on either vessel. There is potential for escalation however, whilst low explosion overpressures could reach the TR on the QU platform, these will not be high enough to cause impairment. Hazard ranges for the lowest overpressures extend beyond 500m and hence the safety zone is considered to be impaired. Depending on wind direction, dispersion of flammable gas clouds could cause high gas concentrations along the trestle escape route, preventing return to the TR. Flammable gas does not extend to QU platform and hence TR impairment is discounted and there is no requirement for evacuation. A cryogenic spill could spread across the FLNG and impact escape routes on the starboard and portside of the FLNG but personnel would be able to reach the TR via the trestle escape route. Cryogenic impact may result in an escalation threat but the release does not extend to impact the TR, evacuation facilities or safety zone.			

Event ID: **N-12 BLEVE of a Vessel on FLNG Containing Refrigerant**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
BLEVE	×	×	N/A	×
Discussion	High levels of thermal radiation from BLEVEs could cause impact on escape routes from the riser platform, FLNG and LNGC vessels to the QU platform. However, fireballs are a short duration events and impairment of EER facilities is not expected. A BLEVE would likely be caused by flame impingement from an initial fire scenario. The explosion would occur after a period of flame engulfment, limiting initial fatalities and allowing personnel to escape.			

Event ID: **N-13 Gas Release from FLNG SMR Refrigerant Closed Loop**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	✓	×	×	✓
Discussion	Event durations for a representative failure (50 mm) will be less than 5 minutes. Thermal radiation from jet fires and fireballs will be limited to the release vicinity and personnel surviving the initial jet fire or fireball event will be able to safely reach and shelter in the TR after the release finishes. There is no expected requirement for evacuation. Explosions could cause impairment of escape routes from the riser platform and LNGC vessel, preventing return to the TR – personnel would need to await rescue. There is potential for escalation however, whilst overpressure from the original explosion could reach the TR on the QU platform, these will not be high enough to cause impairment. The lowest overpressures extend beyond 500m and hence the safety zone is considered to be impaired.			

Event ID: **N-14 Liquid / Two Phase Release from FLNG SMR Refrigerant Closed Loop**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Spray Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	✓	×	×	✓
Flammable Gas	×	✓	×	×
Cryogenic Spill	×	×	×	×
Discussion	Fire durations will be under 5 minutes in all cases. Whilst high levels of thermal radiation from jet fires and fireballs could impact on both the FLNG and LNGC vessels, the short durations mean that, in all cases, impairment can be discounted. Explosions overpressures will be high enough to cause impairment of the main escape routes to the QU platform. Surviving personnel from the riser platform and LNGC will have to await rescue. There is potential for escalation however, whilst overpressure from the original explosion could reach the QU platform, this should not be high enough to cause impairment of the TR or evacuation facilities. The lowest overpressures extend beyond 500m and hence the safety zone is considered to be impaired. Dispersion of flammable gas clouds could cause high gas concentrations at the LNGC vessel and QU platform as well as the FLNG however, the release duration is short and escape route impairment is discounted. Ingress of flammable gas to the TR from a catastrophic release in low wind conditions could occur if the dampers fail to close on demand, although the likelihood of this event would be very low. Due to the short release duration impairment of the evacuation facilities is discounted. A cryogenic spill could spread across the FLNG and impact escape routes on the starboard and portside of the FLNG however, personnel would still be able to reach the TR via the trestle escape route. Cryogenic impact may result in an escalation threat but the release does not extend to impact the TR, evacuation facilities or safety zone.			

Event ID: **N-15 Refrigerant Release from FLNG Refrigerant Storage**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Spray Fire	✓	×	N/A	×
Fireball	×	×	N/A	×
Explosions	✓	×	×	✓
Flammable Gas	✓	✓	×	×
Cryogenic Spill	×	×	N/A	×
Discussion	Event durations for a representative failure (50 mm) will be around 20 minutes. High levels of thermal radiation from jet fires could cause impairment of escape routes from the riser platform, FLNG and LNGC vessels to the QU platform. Personnel surviving the initial event would need to wait out the event. Fireballs are short duration events and impairment of escape routes is discounted. High explosion overpressure can impair escape routes on the FLNG and trestle – personnel on the riser platform and LNGC may need to await rescue. There is potential for escalation however, whilst overpressure from the original explosion could reach the QU platform, this would not be high enough to cause impairment of the TR or evacuation facilities. The lowest overpressures extend beyond 500m and hence the safety zone is considered to be impaired. Depending on wind direction, flammable gas from a 50mm release could cause impairment of escape routes to the QU. There is also potential for gas ingress from a catastrophic failure if the dampers fail to close on demand, although the likelihood of this event is low. Evacuation facilities are not considered to be impaired – only dispersion from a catastrophic release in low wind speed condition can reach this area, but the release duration will be short and impaired is discounted. A cryogenic spill would impact escape routes local to the release on the FLNG but personnel could still escape to the TR via an alternative route. Cryogenic impact may result in an escalation threat but the release does not extend to impact the TR, evacuation facilities or safety zone.			

Event ID: **N-16 Fuel Gas Release in QU Platform Utility Space / Area**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Jet Fire	×	×	N/A	×
Fireball	×	×	N/A	×
Explosions	✓	×	N/A	×
Discussion	Due to the small inventory associated with this event, fire durations will be short (<1 minute) in all cases; impairment potential from a jet fire or fireball is therefore discounted. Explosions at the QU platform may prevent access to the TR but are not considered to damage the TR structure itself which is expected to be designed to withstand overpressures from this event. If access to the TR is prevented personnel may therefore be required to muster elsewhere on the NSH but evacuation is unlikely to be required. Potential for escalation is limited and hence there would be no requirement for evacuation.			

Event ID: **N-17 LNG Release from FLNG / LNGC Storage Tanks**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Pool Fire	✓	×	✓	✓
Flammable Gas	✓	✓	✓	✓
Cryogenic Spill	✓	×	×	×
Discussion	Release durations from a worst case failure (750mm breach) will be over 1 hour due the large inventory of a cargo tank. Thermal radiation from pool fires will cause widespread immediate fatalities and, for those not impacted, impair escape routes back to the QU platform. Although fire impact will be for a long duration thermal radiation at the TR is sufficiently low that TR integrity should not be directly threatened. Evacuation facilities would be impaired and the lowest level of radiation impacts beyond the safety zone. Dispersion of flammable gas can impair all EER facilities on the NSH and extends beyond the 500m safety zone – impairment of the TR would occur if HVAC dampers fail to close on demand, although the likelihood of this event is low. The pool spreads to a diameter of over 100m; beyond this range, the potential for impairment of EER facilities will depend on the wind direction. A cryogenic spill will prevent personnel not impacted by the initial release from returning to the TR but will not reach the QU platform to impact the TR itself or impact the evacuation facilities.			

Event ID: **N-18 LNG Release during LNGC Loading**	Impairment Potential			
	Escape Routes	**TR**	**Evacuation**	**Safety Zone**
Spray Fire	✓	×	×	×
Pool Fire	✓	×	×	×
Flammable Gas	×	×	N/A	×
Cryogenic Spill	×	×	×	×
Discussion	Event durations for a representative failure (50 mm) will be around 15 minutes. Jet and pool fires could cause impairment of escape routes from the riser platform, FLNG and LNGC vessels to the QU platform. Pool fires from catastrophic failures are for a short duration and surviving personnel will be able to wait out the event before returning to the TR. There is no impact at the TR from jet or pool fires following a 50mm failure; a pool fire from a full bore rupture would impact at lower radiation levels for a short duration but this would not be sufficient to cause impairment. Dispersion of flammable gas from a full bore rupture can, depending on release direction, impact escape routes to the TR. However, this would only be for a short period and hence impairment is discounted. Flammable gas from a 50mm release does not prevent escape. TR impairment for all releases is discounted as flammable gas does not extend to the QU platform and there would be no requirement to evacuate. A cryogenic spill would impact escape routes local to the release but personnel could still escape to the TR via an alternative route. The release does not spread sufficiently to impact the TR, evacuation facilities or safety zone.			

6. Conclusions

6.1. Summary of Worst Case Impact

6.1.1. Jet Fires

The largest gas jet fires on the FPSO are from a 50mm failure of the production riser (MAE F-01) while for the NSH the greatest threat is from a failure of the gas import riser (MAE N-01). The largest two-phase jet / liquid spray fires are from a 50mm failure of the liquid side of the slug catchers on the FPSO (MAE F-04) or the liquid side of the fractionation unit on the FLNG (MAE N-09).

The maximum extent from thermal radiation due to jet fires on the FPSO and NSH is shown in Figure 6-1 and Figure 6-2 respectively.

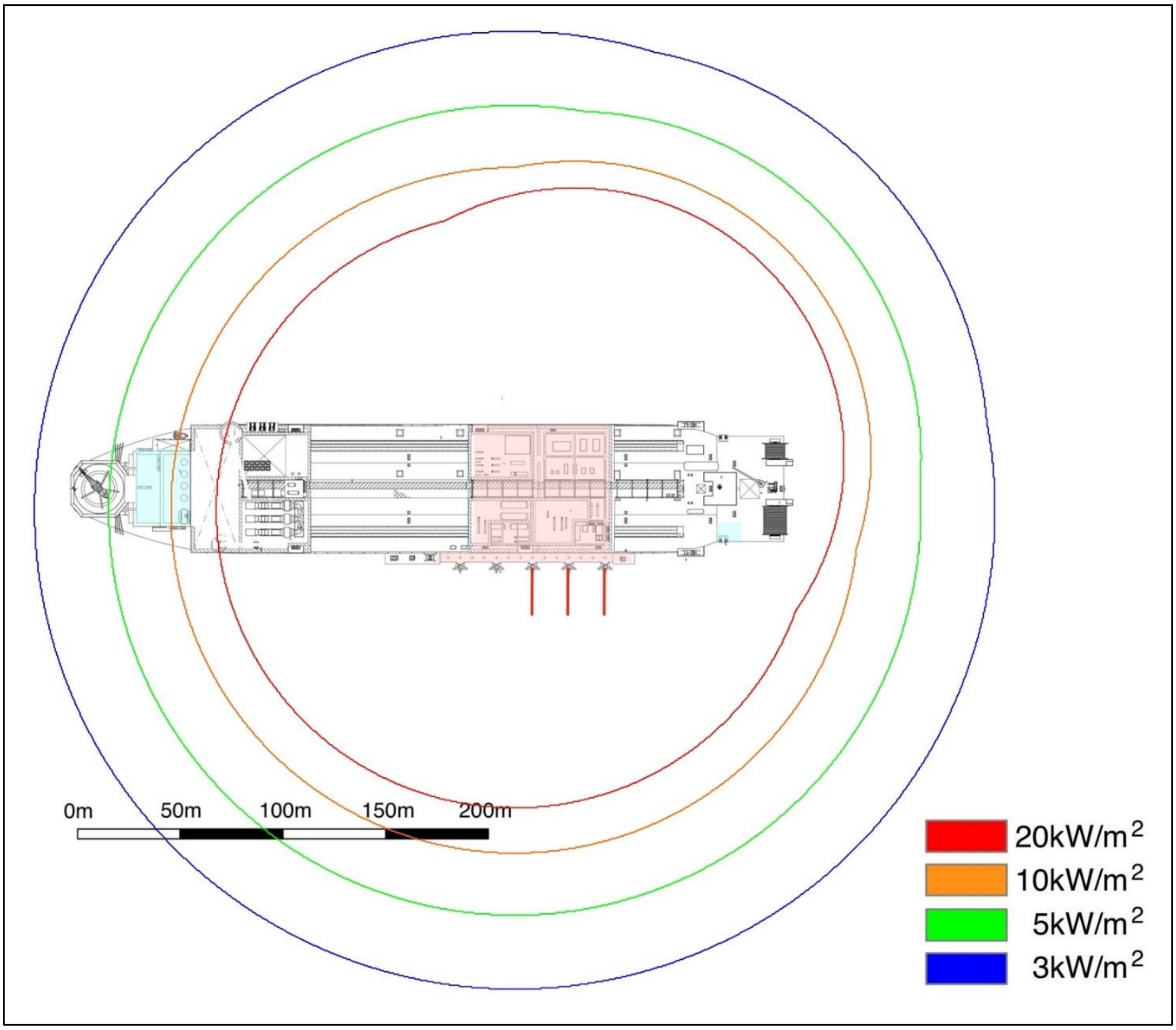


Figure 6-1 Maximum Extent of Thermal Radiation from Jet Fires on FPSO

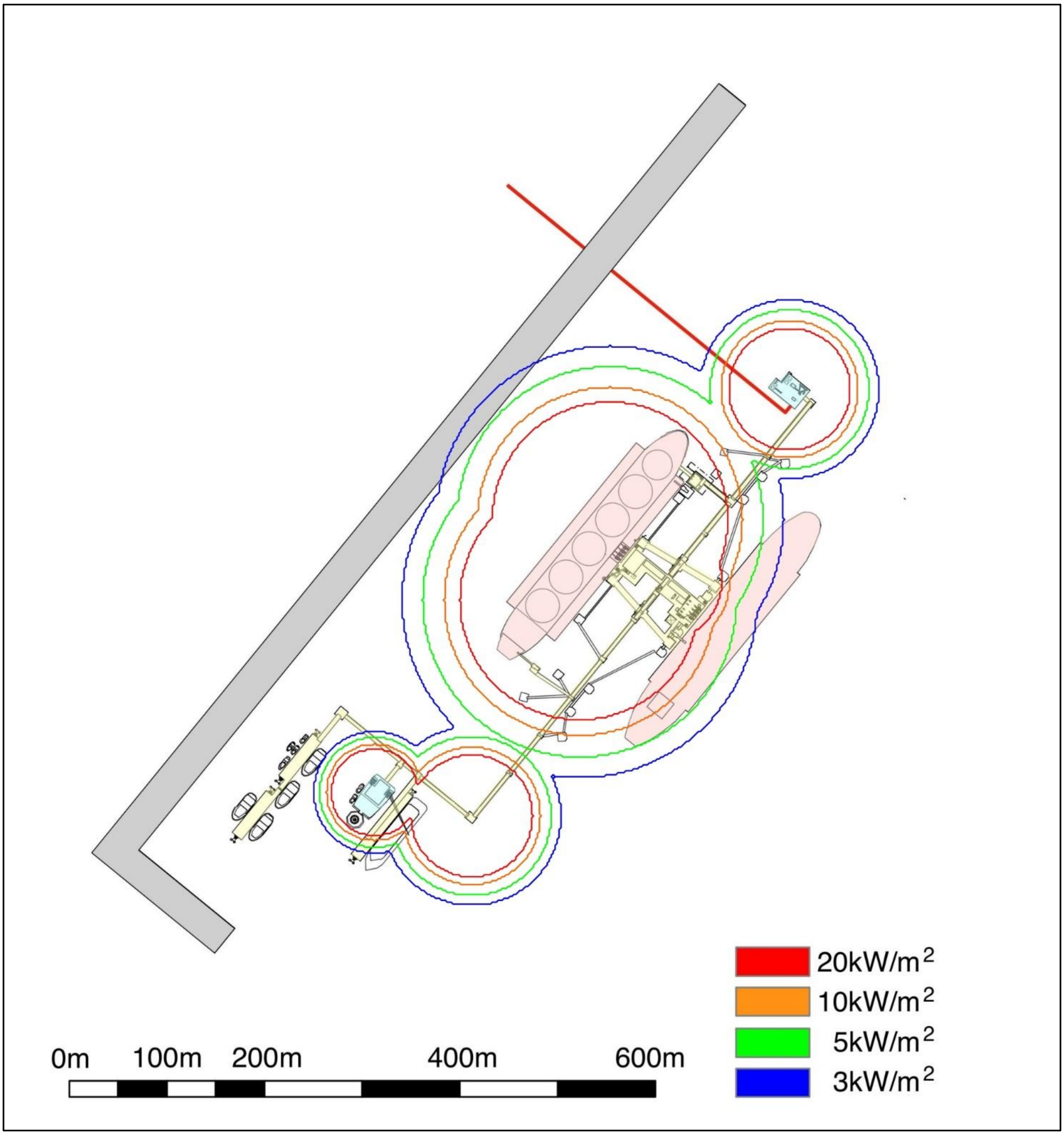


Figure 6-2 Maximum Extent of Thermal Radiation from Jet Fires on NSH

6.1.2. Pool Fires

The largest impact due to thermal radiation associated with a pool fire on the FPSO is from a release of hydrocarbon liquid associated with the MP separator (MAE F-07). For the NSH the largest pool fire is from an unrestricted spill onto the sea surface from a storage / cargo tank failure of the FLNG / LNGC (MAE N-17).

The maximum extent from thermal radiation due to pool fires on the FPSO and NSH is shown in Figure 6-3 and Figure 6-4 respectively.

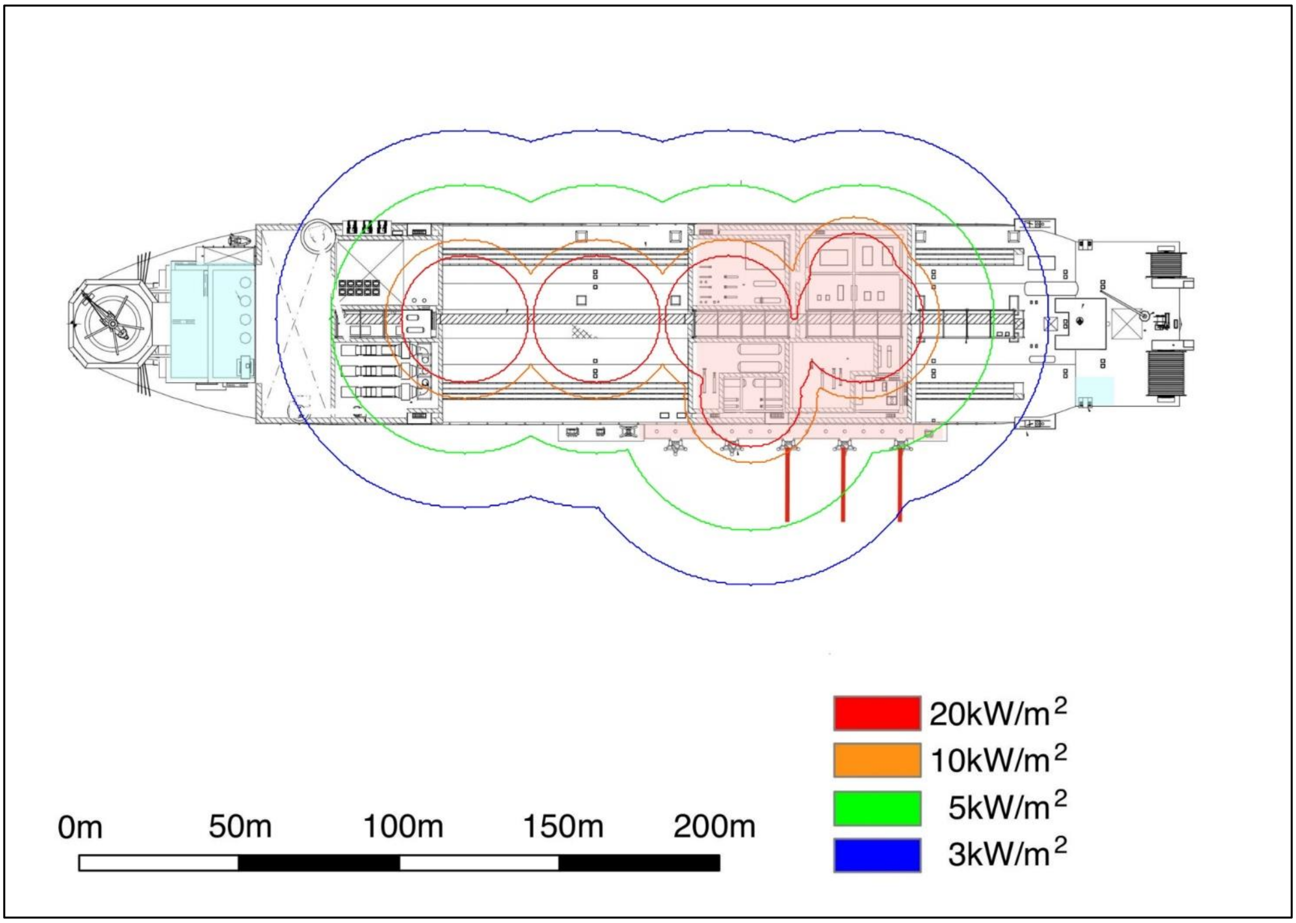


Figure 6-3 Maximum Extent of Thermal Radiation from Pool Fires on FPSO

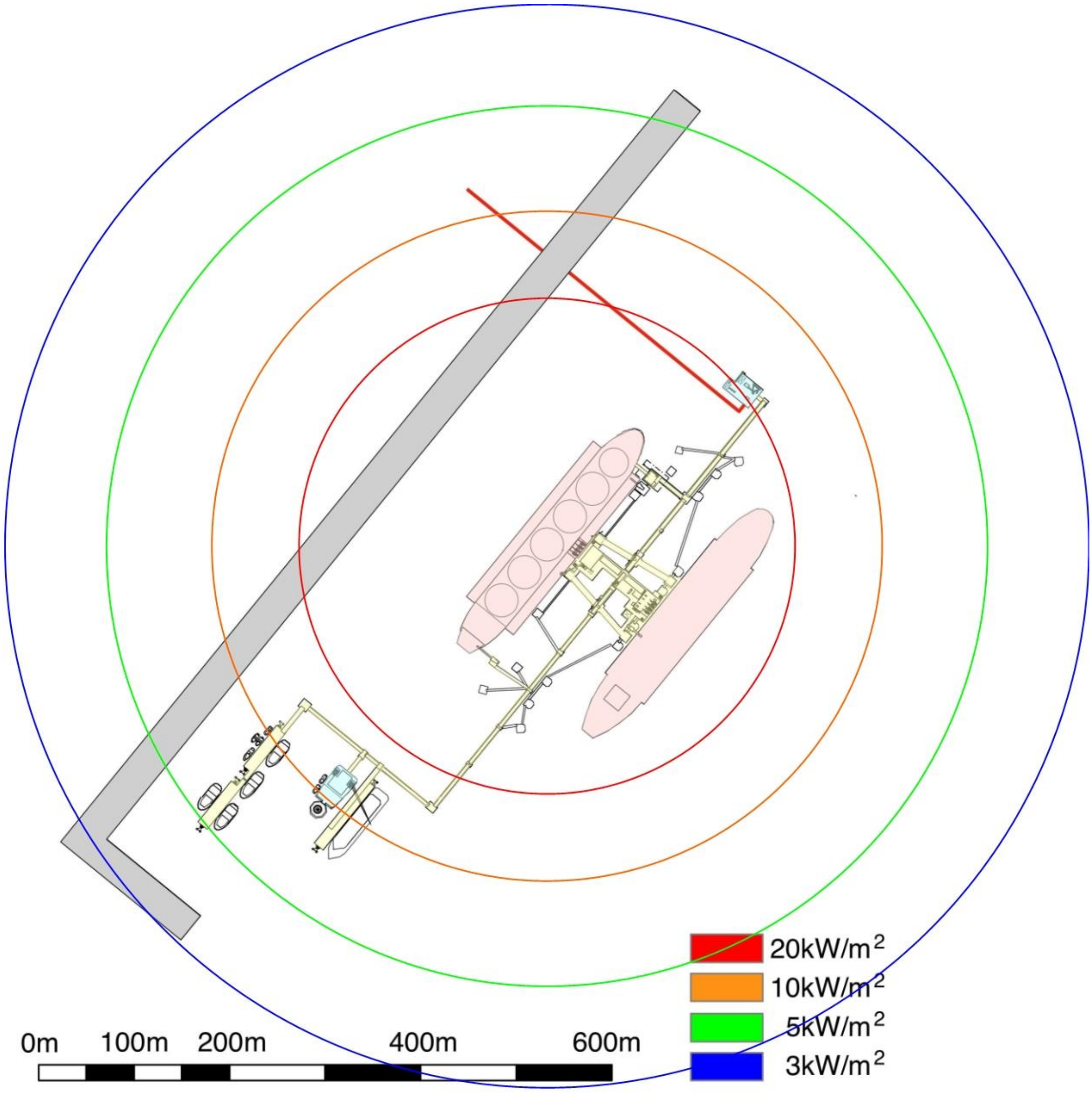


Figure 6-4 Maximum Extent of Thermal Radiation from Pool Fires on NSH

6.1.3. Fireballs and BLEVEs

The largest fireball on the FPSO is from a rupture of the production riser (MAE F-01). For the NSH the largest fireball following a credible worst case failure is from a rupture of the gas import riser (MAE N-01). Fireballs are also considered for BLEVEs of the refrigerant storage vessels (MAE N-12) with the greatest extent from a BLEVE of the propane vessel.

The maximum extent from thermal dose due to fireballs on the FPSO and NSH is shown in Figure 6-5 and Figure 6-6 respectively.

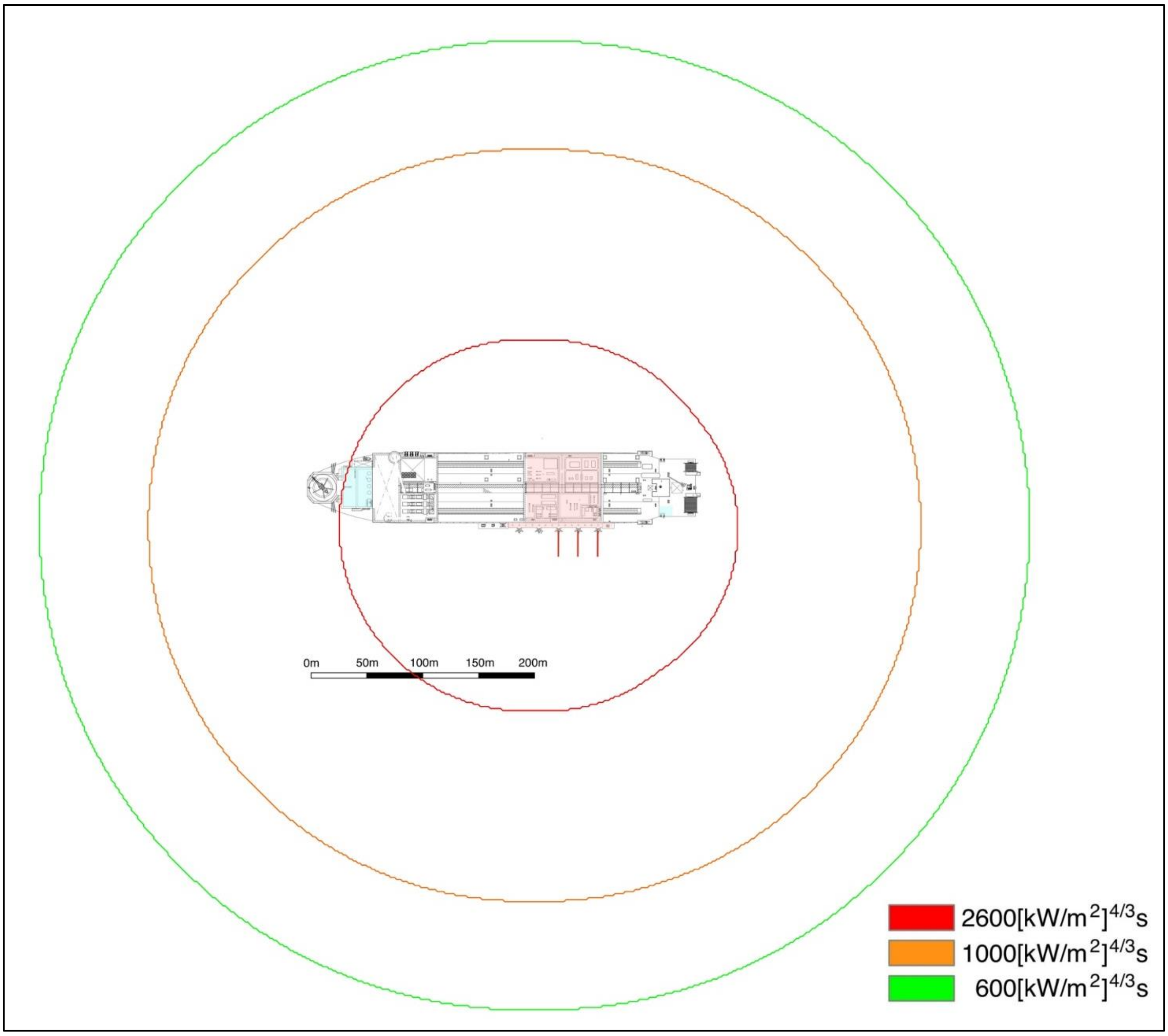


Figure 6-5 Maximum Extent of Thermal Dose from Fireballs on FPSO

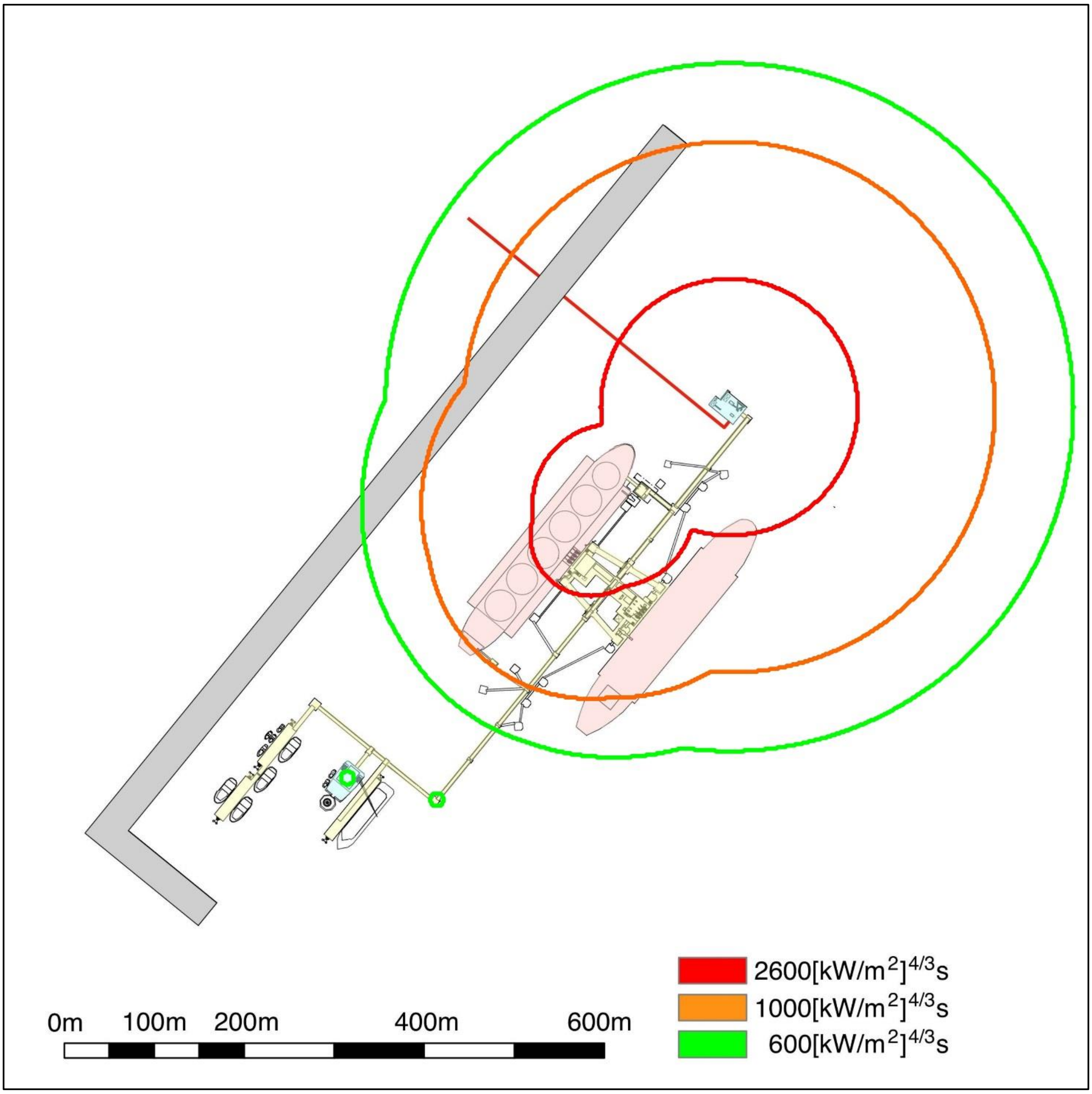


Figure 6-6 Maximum Extent of Thermal Dose from Fireballs on NSH

6.1.4. Flash Fires

The largest flammable gas cloud is from the unrestricted spill from a catastrophic cargo tank failure of the FLNG / LNGC (MAE N-17). The maximum extent of flammable gas on the NSH is shown in Figure 6-7.

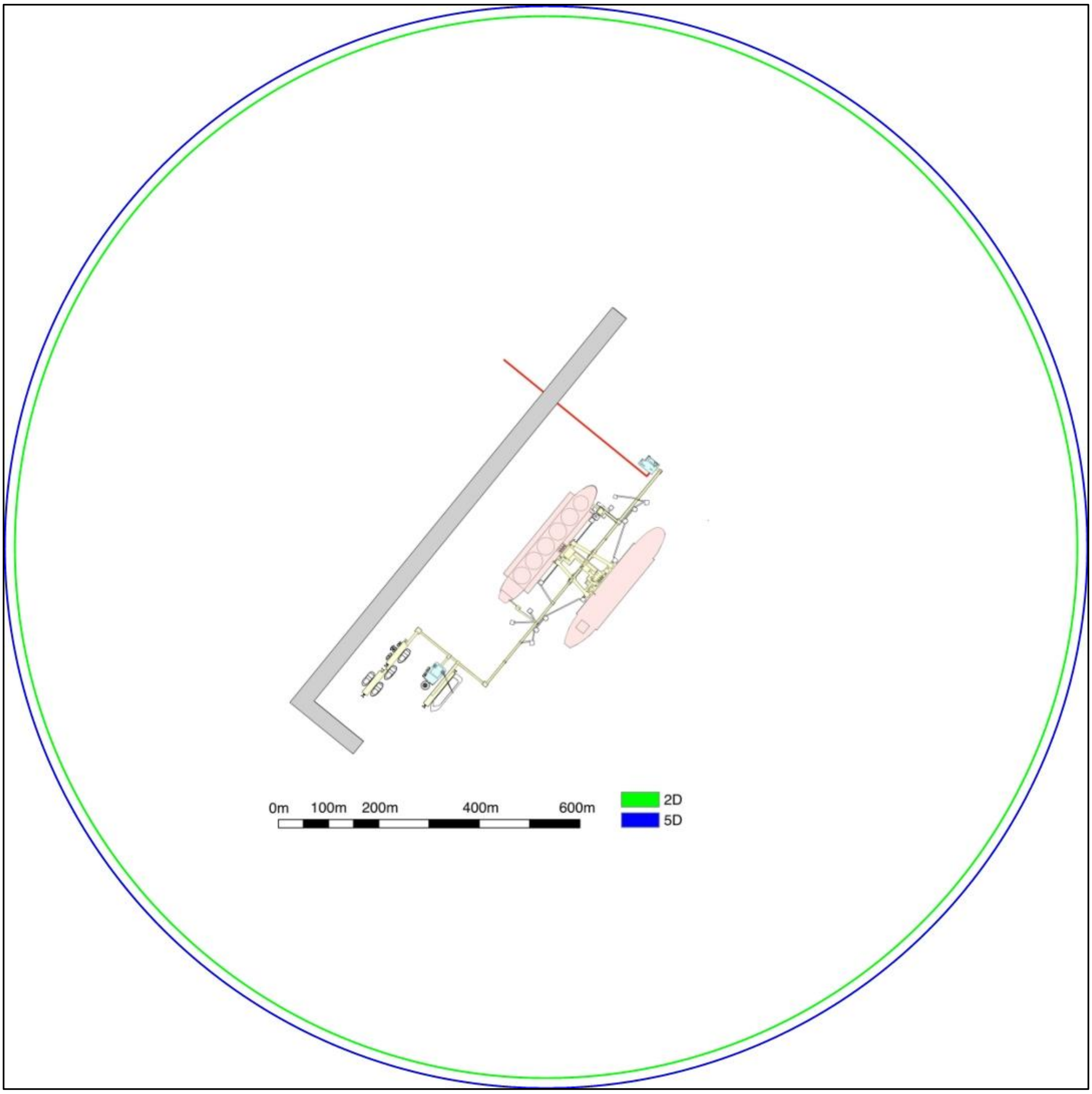


Figure 6-7 Maximum Extent of Flammable Gas Dispersion on NSH

6.1.5. Explosions

The largest explosions on the FPSO are from flashing vapour associated with a liquid release of the LP separator (MAE F-08). For the FLNG, the largest explosions are due to a gas release from the liquefaction unit (MAE N-09) or a release from the refrigerant loops (MAEs N-13 and N-14) within the LNG trains.

The maximum extent from overpressure due to VCEs on the FPSO and NSH is shown in Figure 6-8 and Figure 6-9 respectively.

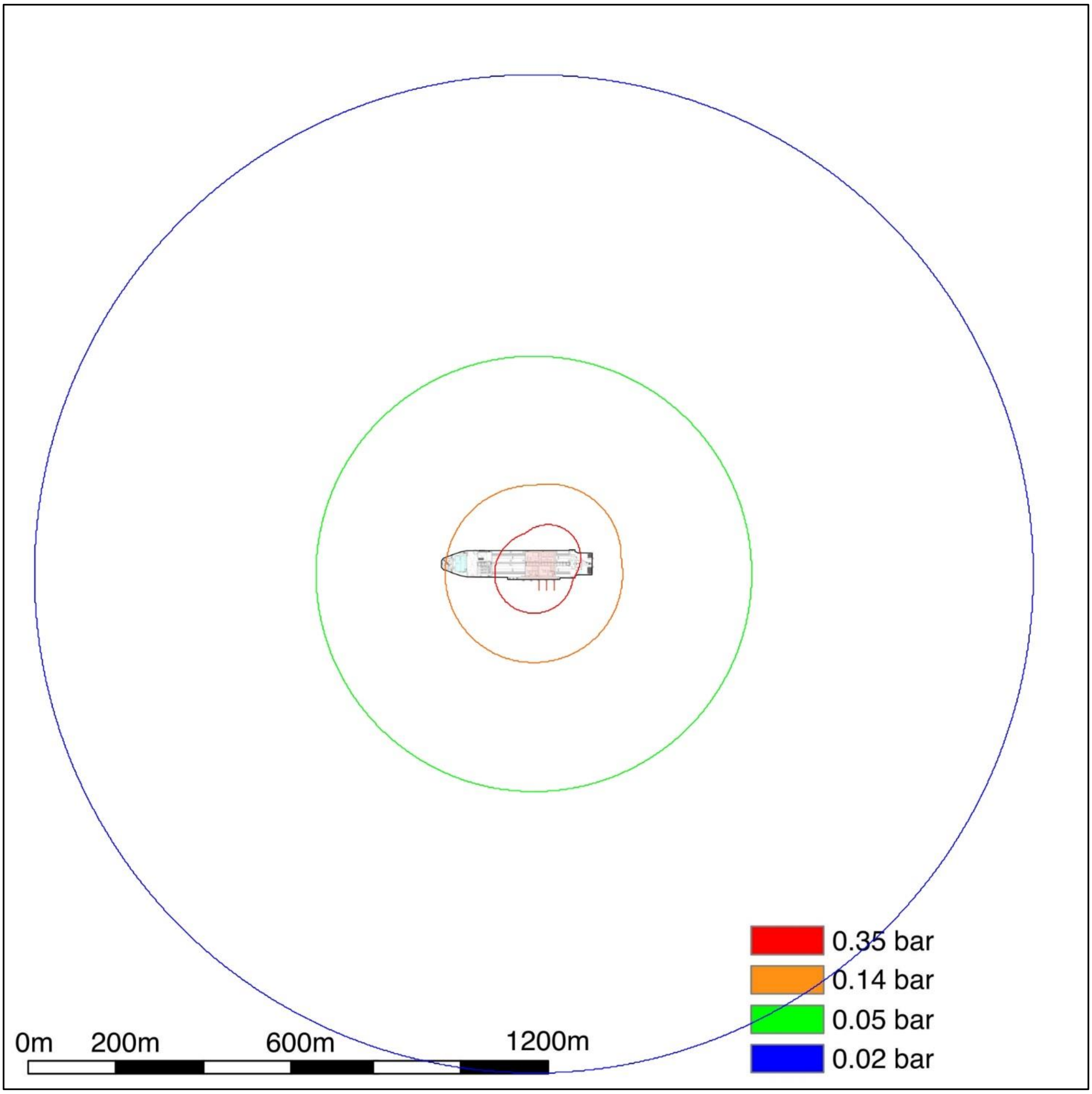


Figure 6-8 Maximum Extent of Overpressure from VCEs on FPSO

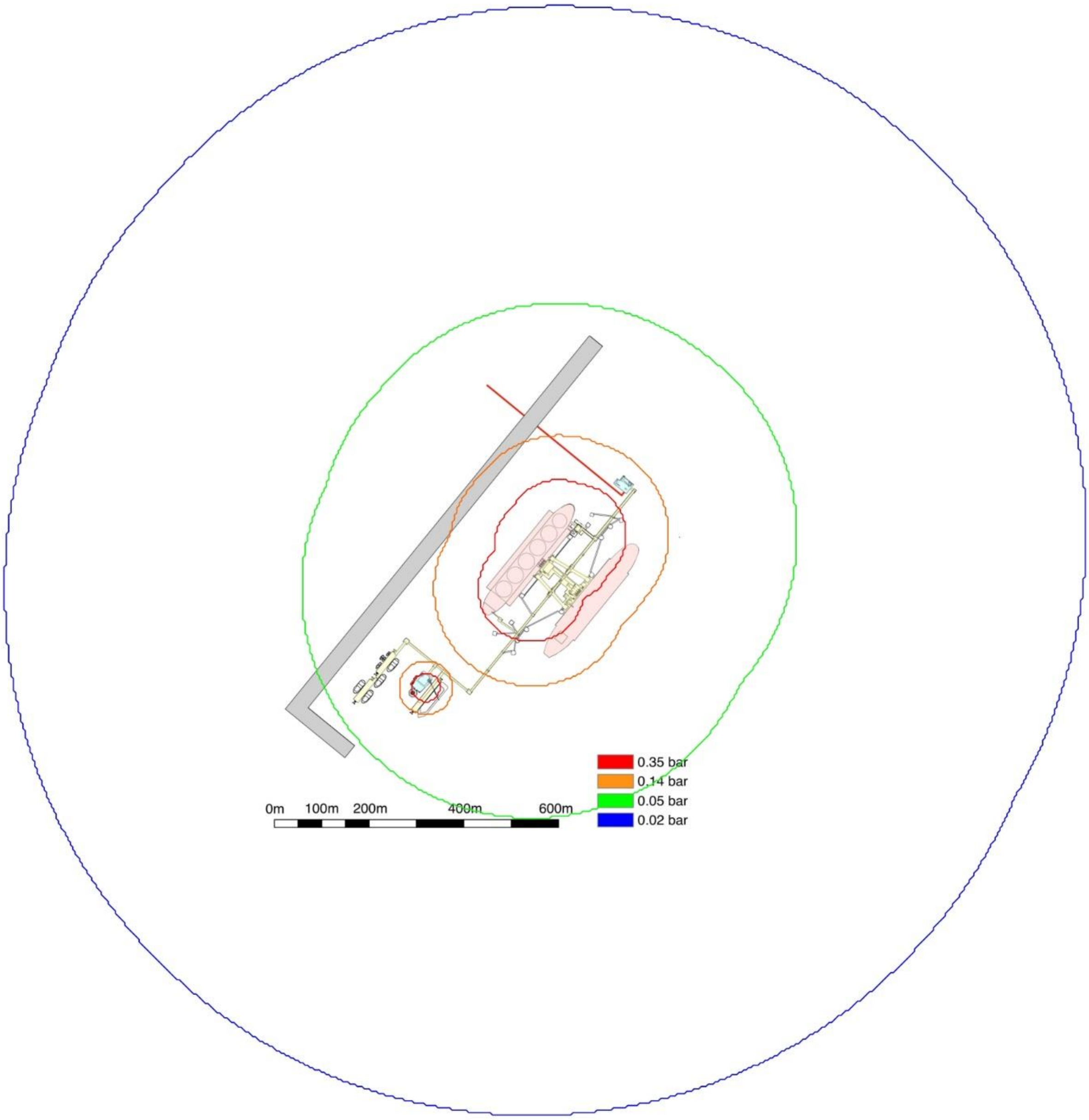


Figure 6-9 Maximum Extent of Overpressure from VCEs on NSH

6.1.6. Cryogenic Spills

The largest cryogenic spills on the FLNG are from catastrophic failures of the LNG flash gas drum (MAE N-11) and the ethylene refrigerant storage vessel (MAE N-15). The largest spill onto the sea surface is from an unrestricted spill from a catastrophic cargo tank failure of the FLNG / LNGC (MAE N-17).

6.2. Recommendations for Further Analysis

It is recommended that further assessment of hazardous effects from hydrocarbon MAEs is completed during the FEED stage of the of Ahmeyim/Guembeul Project. Based on the analysis in this study the following areas are identified for consideration:

- Vapour cloud explosion modelling: Modelling of VCEs has been limited to deflagration however, ethylene has potential for detonation which can result in significantly higher overpressures, although impulse durations are generally lower. It is recommended that assessment of detonation of ethylene is considered as part of the next stage of the design.
- Assessment of cryogenic sprays: modelling of cryogenic releases has been considered the extent of cryogenic pools on the process / hull deck of the FLNG however, high pressure releases in the liquefaction and refrigeration units are likely to result in sprays which may also threaten structures and personnel within the process modules. Assessment of this hazard should be completed in the next design stage.
- Assessment of escalation impact: A detailed analysis of escalation potential should be completed to determine the likelihood for impairment of equipment and structures leading to significant escalation of an initial event – e.g. a cargo tank fire or rupture of a riser. Such scenarios may threaten the integrity of the TR or the FPSO / FLNG and require an evacuation. Escalation may be caused by overpressure impact, fire engulfment for a sustained period or embrittlement of structures due to cryogenic impact. Escalation analysis can also be used to determine the benefit of fire, explosion and cryogenic spill protection for key structures.
- Position of refrigerant storage vessels: Sustained engulfment by fire of the refrigerant vessels will result in a BLEVE – generating significant overpressure and a large fireball (as shown in MAE N12). It is recommended that consideration is given to the position of the refrigerant storage vessels so that potential for escalation impact is minimised.
- Inclusion of SSIVs: modelling of riser failures on the FPSO have been completed assuming provision of SSIVs on the production and gas export riser. While modelling for the import gas riser at the NSH modelling is completed assuming no SSIV. It is recommended that assessment of the benefit of SSIV on the gas import riser at the NSH is completed – this would act to limit the release duration and hence lower the impact of escalation.

7. References

1. Heat and Material Balance Phase 1A, BP Project Internal, MS002-PR-LST-010-03004 (Rev. A01), October 2017.
2. ACDS (1991), Major Hazard Aspects of the Transport of Dangerous Substances: Report and Appendices, Advisory Committee on Dangerous Substances, H.M Stationery Office, HSE Books, 1991.
3. Pitblado, CCPS Paper Consequence of LNG Marine Incidents, Jun 18 2004.
4. SANDIA, Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water 2004.
5. CPR 18E - Guidelines for Quantitative Risk Assessment (‘Purple Book’), Publication Series on Dangerous Substances (PGS 3), VROM, December 2005
6. Risk Study Guide, Ministry of the Environment and of Protection of Nature Department of Environment and Classified Establishments, Republic of Senegal, October 2005

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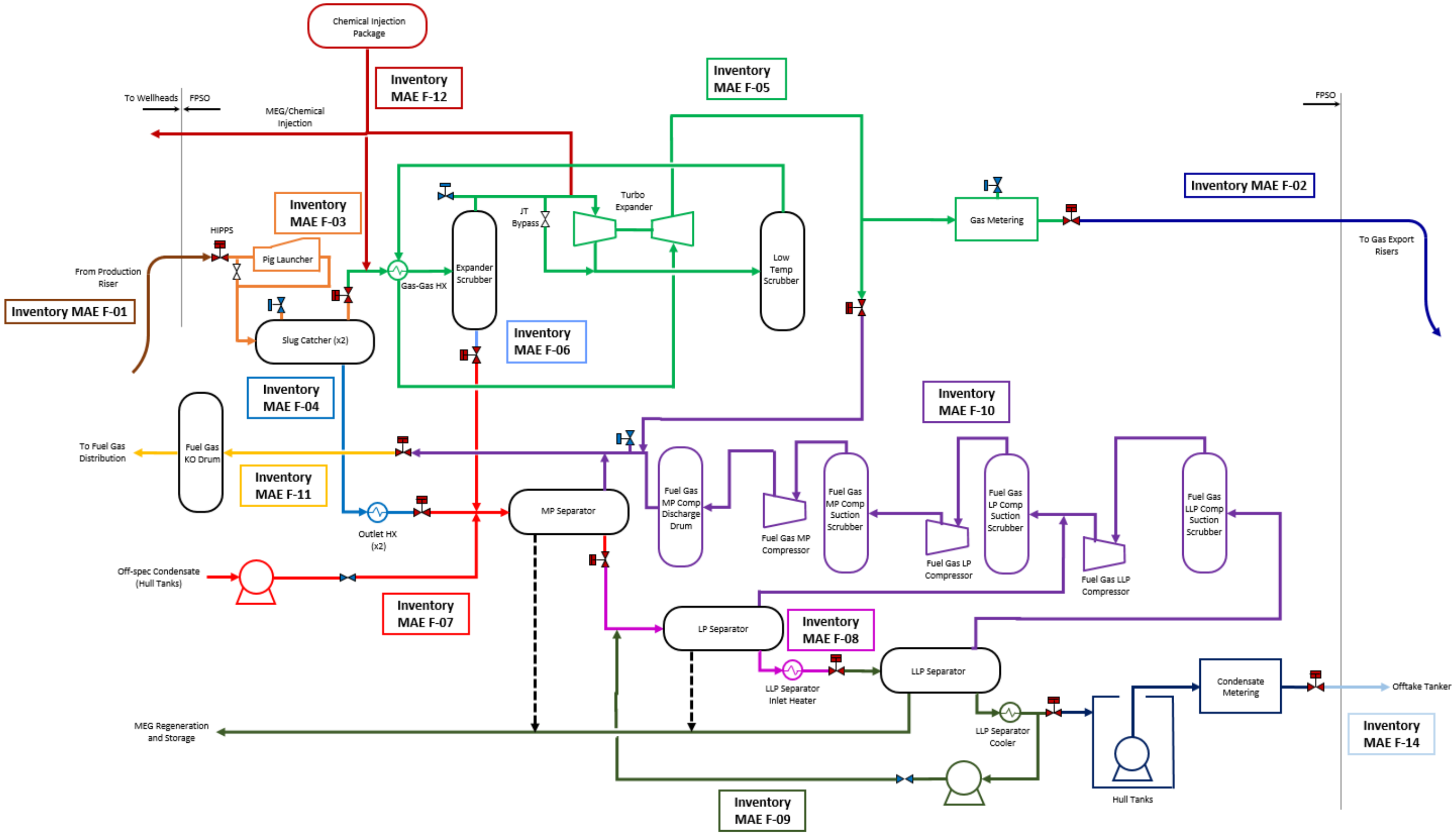
Appendices

Appendix A. Process Flow Diagrams

A.1. FPSO



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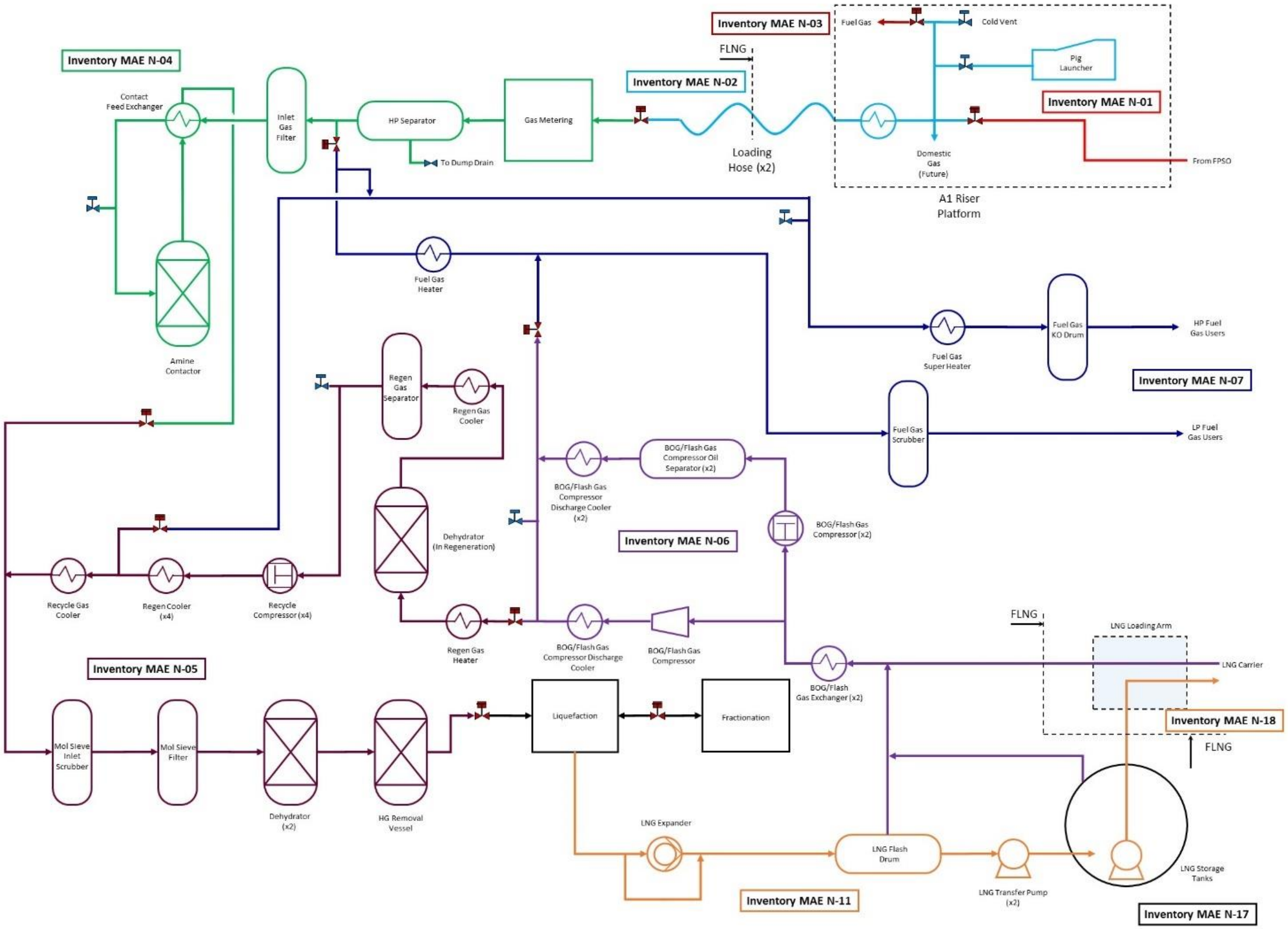
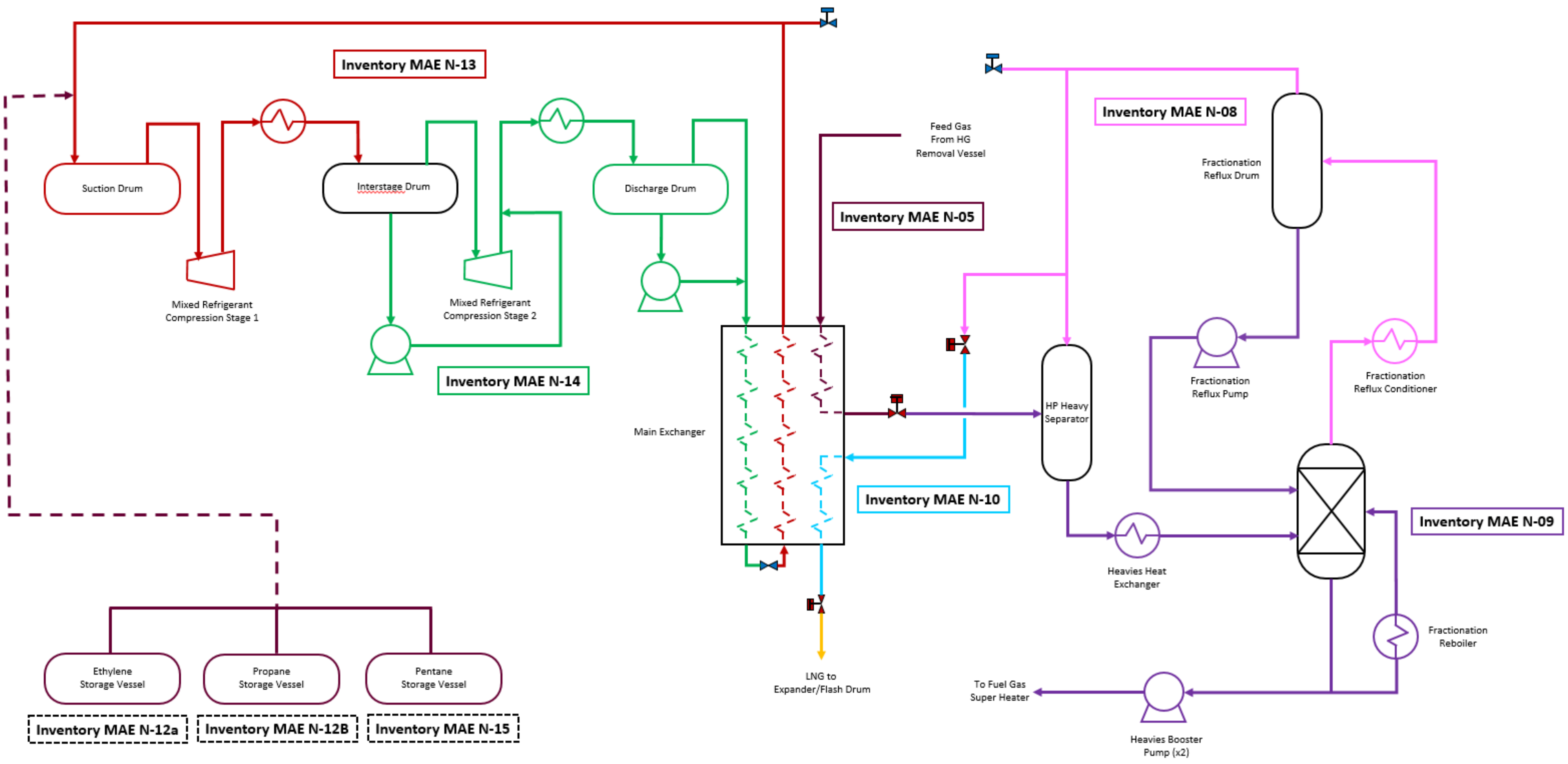
A.2. FLNG


Inventory MAE N-03
Fuel Gas
Cold Vent
FLNG
Pig Launcher
Inventory MAE N-02
Inventory MAE N-01
Inventory MAE N-04
Contact Feed Exchanger
Inlet Gas Filter
HP Separator
Gas Metering
To Dump Drain
Loading Hose (x2)
Domestic Gas (Future)
From FPSO
A1 Riser Platform
Amine Contactor
Fuel Gas Heater
Fuel Gas Super Heater
Fuel Gas KO Drum
HP Fuel Gas Users
Inventory MAE N-07
Regen Gas Separator
Regen Gas Cooler
Fuel Gas Scrubber
LP Fuel Gas Users
BOG/Flash Gas Compressor Oil Separator (x2)
BOG/Flash Gas Compressor Discharge Cooler (x2)
Dehydrator (In Regeneration)
Inventory MAE N-06
BOG/Flash Gas Compressor (x2)
Recycle Gas Cooler
Regen Cooler (x4)
Recycle Compressor (x4)
Regen Gas Heater
BOG/Flash Gas Compressor Discharge Cooler
BOG/Flash Gas Compressor
FLNG
LNG Loading Arm
LNG Carrier
BOG/Flash Gas Exchanger (x2)
Inventory MAE N-05
Liquefaction
Fractionation
Inventory MAE N-18
FLNG
Mol Sieve Inlet Scrubber
Mol Sieve Filter
Dehydrator (x2)
HG Removal Vessel
LNG Expander
LNG Flash Drum
LNG Transfer Pump (x2)
LNG Storage Tanks
Inventory MAE N-11
Inventory MAE N-17

A.3. FLNG – Liquefaction/Fractionation



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Appendix B. Ahmeyim/Guembeul Project MAE Listing & Inventories

B.1.1. FLNG MAR Inventories

Location	MAE ID	Major Accident Event	Release Type	Material	Pressure (bar)	Temp ('C)	Volume m^3	Mass kg
FLNG	N-01	Gas Release from Import Gas Riser (S5)	Gas	Methane	74	16	15,733	1,101,329
FLNG	N-02	Gas Release from Trestle Feed Gas Flowline / Hose to FLNG (S4)	Gas	Methane	74	16	46	2,919
FLNG	N-03	Gas Release from Trestle Fuel Gas Flowline to QU Platform (S4)	Gas	Methane	74	16	2	95
FLNG	N-04	Gas Release from FLNG Inlet Metering and Amine Treatment (S4)	Gas	Methane	60	44	-	28,670
FLNG	N-05	Gas Release from FLNG Dehydration and Regeneration (S4)	Gas	Methane	60	40	-	19,962
FLNG	N-06	Gas Release from FLNG Boil Off Gas / Flash Gas Compression (S4)	Gas	Methane	60	36	-	131
FLNG	N-07	Fuel Gas Release from FLNG HP Fuel Gas System (S4)	Gas	Methane	38	45	4	191
FLNG	N-08	Gas Release from FLNG Fractionation (S4)	Gas	Methane	30	-40	290	7,250
FLNG	N-09	Light Hydrocarbon Liquid Releases from FLNG Fractionation (S4)	Liquid	Propane	30	20	20	12,000
FLNG	N-10	LNG Release from FLNG Liquefaction Process (S4)	Liquid	Methane	18	-109	25	11,750
FLNG	N-11	LNG Release from FLNG Flash Gas Drum (S4)	Liquid	Methane	6	-158	64	30,143
FLNG	N-12	BLEVE of Vessel on FLNG Containing Refrigerant (S4)	Liquid	Ethylene	3	-83	20	11,400
FLNG	N-12	BLEVE of Vessel on FLNG Containing Refrigerant (S4)	Liquid	Propane	9	25	50	25,500
FLNG	N-12	BLEVE of Vessel on FLNG Containing Refrigerant (S4)	Liquid	Pentane	1.5	48	75	46,200
FLNG	N-13	Gas Release from FLNG SMR Refrigerant Closed Loop (S4)	Gas	Propane	10.4	45	115	1,725
FLNG	N-14	Liquid / Two Phase Release from FLNG SMR Refrigerant Closed Loop (S5)	Liquid	Propane	40	55	33	15,624

Location	MAE ID	Major Accident Event	Release Type	Material	Pressure (bar)	Temp ('C)	Volume m^3	Mass kg
FLNG	N-15	Refrigerant Release from FLNG Refrigerant Storage (S5)	Liquid	Propane	9	25	50	25,500
FLNG	N-15	Refrigerant Release from FLNG Refrigerant Storage (S5)	Liquid	Ethylene	3	-83	20	11,400
FLNG	N-15	Refrigerant Release from FLNG Refrigerant Storage (S5)	Liquid	Pentane	1.5	48	75	46,200
FLNG	N-16	Gas Release (Fuel Gas) in QU Platform Utility Space / Area (S4)	Gas	Methane	38	45	2	95
FLNG	N-17	LNG Release from FLNG / LNGC Storage Tanks (S5)	Liquid	Methane	1	-158	20,833	9,791,667
FLNG	N-18	LNG Release during LNGC Loading (S4)	Liquid	Methane	7	-158	40	18,800

B.1.2. FPSO Major Hazard Inventory

Location	MAE ID	Major Accident Event	Release Type	Inventory Description	Material	Pressure (bar)	Temp ('C)	Volume m^3	Mass kg
FPSO	F-01	Hydrocarbon Release from Production Riser	Gas	Production Riser	Wellfluids	97	3	437.1	48,523
FPSO	F-02	Gas Release from Export Gas Risers	Gas	Gas Export Riser	Methane	79	15	437.1	30,600
FPSO	F-03	Gas Release from Reception Facilities (Slug Catchers)	Gas	Reception Facilities (Gas)	Methane	93	1.4	143.2	13,319
FPSO	F-04	Liquid Release from Reception Facilities (Slug Catchers)	Liquid	Reception Facilities (Liquid)	*Condensate*	93	1.4	47.7	36,807
FPSO	F-05	Gas Release from Gas Processing	Gas	Gas Treatment and Metering (Gas)	Methane	91	15	34.8	3,063
FPSO	F-06	Liquid Release from Gas Processing	Liquid	Gas Treatment (Liquid)	*Condensate*	91	-3.5	1.5	1,384
FPSO	F-07	Liquid Release from MP Separator	Liquid	Condensate Separation - MP (Liquid)	*Condensate*	40	45	31.0	23,906
FPSO	F-08	Liquid Release from LP Separator	Liquid	Condensate Separation - LP (Liquid)	*Condensate*	45	12	18.4	14,417
FPSO	F-09	Liquid Release from LLP Separator	Liquid	Condensate Stabilisation - LLP (Liquid)	*Condensate*	65	1.6	25.7	20,267
FPSO	F-10	Gas Release from Flash Gas Compression	Gas	Flash Gas Compression	Methane	39	46	8.2	154
FPSO	F-11	Gas Release from Fuel Gas System	Gas	Fuel Gas System	Methane	38	45	2.1	95
FPSO	F-12	Injection Chemical Release Topsides	Liquid	Production Chemical Emulsion Breaker	*Solution including petroleum distillate and mineral spirits*	1	20	7.4	7,326
FPSO	F-14	Condensate Storage Tank Fire	Liquid	Condensate Storage Tank 2C/3C	*Condensate*	1	20	32,884.0	26,405,852

APPENDIX O RISK STUDY SUPPORT MATERIAL

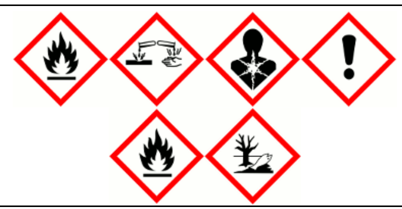
Appendix O
Risk Study Support Material

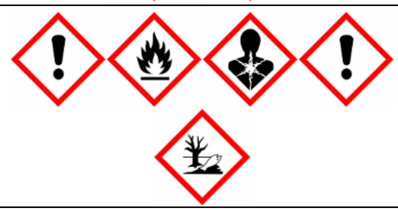
APPENDIX CONTENTS

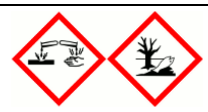
APPENDIX O-1 : PROVISIONAL LISTING OF HAZARDOUS SUBSTANCES AND MATERIALS

PROVISIONAL LISTING OF HAZARDOUS SUBSTANCES AND MATERIALS

Product Name	Function	Phase	Hazard Pictogram(s) – Globally Harmonized System (GHS) Hazard Classes	Hazard Statement	Hazardous Decomposition Products	Incompatible Materials	Indicative Inventory to be Completed at a Later Stage of the Project Design for ICPE Requirements					
							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Chemical Products (General)												
Acetone	Solvent	Liquid	Not provided in MSDS	Extremely flammable. Eye irritant. Inhalation of fumes may cause drowsiness and dizziness	Carbon oxides	No specific detail provided in MSDS	2x18 L drums					
Acetylene	Welding gas	Gas		H220 Extremely flammable gas. H231 May react explosively even in the absence of air at elevated pressure and/or temperature. H280 Gas under pressure, may explode if heated	Carbon monoxide, carbon dioxide and hydrogen	Copper, silver and mercury	16x1.42 m3 bottles					
Ambertron	Precision cleaners	Liquid		H222 Extremely flammable aerosol. H229 Pressurised container: May burst if heated. H315 Causes skin irritation. H336 May cause drowsiness or dizziness. H411 Toxic to aquatic life with long lasting effects	Carbon monoxide and carbon dioxide	Strong oxidisers	12x500 mL aerosol containers					
Anti-static Foam Cleanser	Cleaning product	Liquid	Not provided in MSDS	H229 Pressurised container: may burst if heated	Toxic fumes	None identified in MSDS	24x500 mL aerosol containers					
Brake Cleaner	Washing and cleaning products	Liquid		H222 Extremely flammable aerosol. H229 Pressurised container: May burst if heated. H304 May be fatal if swallowed and enters airways. H315 Causes skin irritation. H336 May cause drowsiness or dizziness. H411 Toxic to aquatic life with long lasting effects	Toxic fumes	Strong oxidisers	24x500 mL aerosol containers					
CRC 2049	Electrical sheathing clear urethane sealing coat	Liquid		H222 Extremely flammable aerosol. H302 Harmful if swallowed. H312 Harmful in contact with skin. H332 Harmful if inhaled. H315 Causes skin irritation. H319 Causes serious eye irritation. H361 Suspected of damaging fertility or the unborn child. H336 May cause drowsiness or dizziness. H373 May cause damage to organs through prolonged or repeated exposure. H402 Harmful to aquatic life	Carbon monoxide and carbon dioxide	None identified in MSDS	24x500 mL aerosol containers					
CRC Lectra Clean	Cleaning product / degreaser for electrical equipment	Liquid		Extremely flammable aerosol. Contains gas under pressure; may explode if heated. May be fatal if swallowed and enters airways. Causes skin irritation. Causes serious eye irritation. May cause drowsiness or dizziness	None identified in MSDS	Strong oxidisers	48x50 mL aerosol containers					
CRC Marine Fuel Stabiliser	Diesel fuel stabilizer	Liquid		Flammable liquid and vapor. May be fatal if swallowed and enters airways. Causes severe skin burns and eye damage. May cause an allergic skin reaction. Causes serious eye damage. May cause respiratory irritation. Suspected of causing cancer. Suspected of damaging the unborn child. May cause damage to organs (central nervous system, ears, kidney, liver, peripheral nervous system) through prolonged or repeated exposure. Toxic to aquatic life. Harmful to aquatic life with long lasting effects	Carbon oxides	Strong acids, strong oxidisers and halogens	25 L					
Dichlorodifluoro-methane	Coolant fluid, propulsion/ expansion agent	Liquefied gas		Contains gas under pressure, may explode if heated	Halogens, halogen acids and possibly carbonyl halides	Freshly abraded aluminium surfaces and chemically reactive metals	900 kg (R 12) 70 kg (R 310)					
Diesel	Fuel for engines	Liquid		Combustible liquid. Causes mild skin irritation. Suspected of causing cancer. May be fatal if swallowed and enters airways. Toxic to aquatic life with long lasting effects	Carbon oxides	Oxidisers	8,458 m3			4,266 m3	4,266 m3	400 m3

Product Name	Function	Phase	Hazard Pictogram(s) – Globally Harmonized System (GHS) Hazard Classes	Hazard Statement	Hazardous Decomposition Products	Incompatible Materials	Indicative Inventory to be Completed at a Later Stage of the Project Design for ICPE Requirements					
							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Ecolab Quik Fill Magnum 34 Cleaner	Pipe nipple cleaner	Liquid		Harmful if inhaled. Causes eye irritation	Carbon dioxide, carbon monoxide, sulfur oxides and metal oxide/oxides	None identified in MSDS	24 L					
Ecolab Quik Fill Neutral 34 Cleaner	Pipe nipple cleaner	Liquid	Not provided in MSDS	Causes eye irritation	Carbon oxides and nitrogen oxides	None identified in MSDS	12 L					
EMC Plus	Heavy duty, alkaline floor cleaner	Liquid		H315 Causes skin irritation. H318 Causes serious eye damage	Irritating gases or vapours	None identified in MSDS	24 L					
EVO-STIK 528	Adhesive	Liquid		H225 Highly flammable liquid and vapour. H315 Causes skin irritation. H319 Causes serious eye irritation. H336 May cause drowsiness or dizziness. H411 Toxic to aquatic life with long lasting effects	Carbon dioxide and carbon monoxide	None identified in MSDS	24x500 mL drums					
HDC-ALK-002	Basic Alkaline Cleaner	Liquid	Not provided in MSDS	Harmful if ingested. Skin irritant. Risk of severe eye injury	Toxic fumes	None identified in MSDS	150 L					
Isopropyl Alcohol (Aqueous Solution)	Antiseptic, surface cleaner	Liquid		H225 Highly flammable liquid and vapour. H319 Causes serious eye irritation. H336 May cause drowsiness or dizziness	None identified in MSDS	Strong oxidisers, acetylene, acids, chlorine, hydrogen peroxide, ethylene oxide, sulfuric acid, isocyanates and aluminium	6x500 mL bottles					
Jet Fuel	Aviation (helicopter) fuel	Liquid		Flammable liquid and vapor. Causes skin irritation. May be fatal if swallowed and enters airways. May cause drowsiness or dizziness.	Nitrogen oxides, carbon oxides and aromatic hydrocarbons	Acids and oxidisers	2,900 L					
Jotacote Universal Comp A	Coatings, various: solvent phase	Liquid	Not provided in MSDS	Flammable liquid and vapour. Slightly irritating to the eyes and skin	Carbon dioxide, carbon monoxide, halogenated compounds and metal oxide / oxides	None identified in MSDS	40 L					
Jotamastic 87 Aluminum Comp A	Coatings, various: epoxy/ solvent phase	Liquid		Flammable liquid and vapour. Causes serious eye irritation. Causes skin irritation. May cause an allergic skin reaction. May cause damage to organs through prolonged or repeated exposure - central nervous system. Toxic to aquatic life with long lasting effects	Carbon dioxide, carbon monoxide, halogenated compounds and metal oxide / oxides	Oxidisers, strong alkalis, strong acids	280 L					
Jotun Thinner No. 10	Diluant/ cleaning solvent	Liquid		Flammable liquid and vapour. Harmful in contact with skin or if inhaled. Causes serious eye irritation. Causes skin irritation. May be fatal if swallowed and enters airways. May cause damage to organs through prolonged or repeated exposure	Carbon dioxide and carbon monoxide	Oxidisers, strong alkalis and strong acids	160 L					
Jotun Thinner No. 17	Diluant / cleaning solvent	Liquid		Flammable liquid and vapour. Causes serious eye damage. Causes skin irritation. May be fatal if swallowed and enters airways. May cause respiratory irritation. May cause drowsiness or dizziness. Toxic to aquatic life with long lasting effects	Carbon dioxide and carbon monoxide	Oxidisers	180 L					
Loctite 1 Gasket Sealant	Sealing	Paste		Causes skin irritation. May cause an allergic skin reaction. Causes serious eye damage. May cause allergy or asthma symptoms or breathing difficulties if inhaled	Aldehydes, carbon oxides, carboxylic acids and irritating vapours	Nitric acid, strong oxidsers, amines, ammonia, sulfuric acid and strong acids	10x40 mL					

Product Name	Function	Phase	Hazard Pictogram(s) – Globally Harmonized System (GHS) Hazard Classes	Hazard Statement	Hazardous Decomposition Products	Incompatible Materials	Indicative Inventory to be Completed at a Later Stage of the Project Design for ICPE Requirements					
							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Loctite 222 Threadlocker	Sealing	Liquid		Causes skin and eye irritation. May cause damage to organs through prolongued or repeated exposure	Carbon oxides, sulfur oxides, nitrogen oxides and irritating organic vapours	Strong oxidisers	12x50 mL					
Loctite 242C Threadlocker	Glue	Liquid		Cases serious eye irritation	Carbon oxides, nitrogen oxides and irritating organic vapors	None identified in MSDS	12x50 mL					
Loctite 406	Glue	Liquid		H227 Combustible liquid. H315 Causes skin irritation. H319 Causes serious eye irritation. H335 May cause respiratory irritation	Carbon monoxide, carbon dioxide and nitrogen oxides	Water, amines, alkalis and alcohols	10x40 mL					
Loctite 542	Anaerobic sealant	Liquid		Causes skin irritation. May cause an allergic skin reaction. Causes serious eye irritation. May cause damage to organs through prolongued or repeated exposure	Carbon oxides and irritating organic vapours	Peroxides	10x10 mL					
Loctite C5-A	Lubricant, anti-seize	Paste		Causes skin irritation. May cause an allergic skin reaction. Causes serious eye damage	Carbon oxides	Strong acids, strong bases and oxidisers	6 kg					
Loctite Super Glue Control Gel	Glue	Liquid		Bonds in seconds. Combustible liquid. Causes eye irritation. May cause respiratory irritation	Carbon oxides. Irritating and toxic fumes	Water, amines, alkalis and alcohols	24x50 mL					
Lube Oil	Lubrication for engines	Liquid	Not provided in MSDS	Combustible liquid. Toxic to aquatic life. Harmful to aquatic life with long lasting effects	None identified in MSDS	None identified in MSDS	190 m3					
Marine Grade Anti-Seize	Lubricant	Paste		Causes severe skin burns and eye damage	Carbon oxides and nitrogen	Strong acids, strong bases, strong oxidisers agents and strong reducing agents	12 kg					
Methyl alcohol	Cleaner and disinfectant	Liquid		Highly flammable liquid and vapour. May displace oxygen and cause rapid suffocation. Corrosive to the respiratory tract	Carbon dioxide and carbon monoxide	Oxidisers	6x500 mL					
Multi-purpose Precision Lubricant	Multi-purpose lubricant	Liquid		Extremely flammable aerosol. Contains gas under pressure; may explode if heated. May be fatal if swallowed and enters airways. Toxic to aquatic life with long lasting effects	Carbon oxides	Strong oxidisers	6x500 mL aerosol containers					
NALCOOL 2000	Cooling-water treatment	Liquid	Not provided in MSDS	Harmful if swallowed. Irritating to eyes and skin. Harmful to aquatic organisms	Carbon oxides and nitrogen	Reducing agents, amines and strong acids	250 L					
Oven Cleaner	Oven cleaner	Liquid		Causes severe skin burns and eye damage	Carbon oxides, nitrogen oxides, sulfur oxides and phosphorus oxides	Acids	54x0.5 L					
Oxygen	Welding gas	Gas		H270 May cause or intensify fire (oxidizer). H280 Gas under pressure, may explode if heated	None identified in MSDS	Combustible materials and reducing agents	34x1.42 m3 bottles					
Penguard Tie Coat 100 Comp B	Coatings. Various: Hardener	Liquid		Flammable liquid and vapour. Harmful if inhaled. Causes severe skin burns and eye damage. May cause an allergic skin reaction. May cause drowsiness or dizziness. May cause damage to organs through prolonged or repeated exposure. Harmful to aquatic life with long lasting effects	Carbon dioxide, carbon monoxide and nitrogen oxides	Oxidisers, strong alkalines and strong acids	22x12.5 L drum					

Product Name	Function	Phase	Hazard Pictogram(s) – Globally Harmonized System (GHS) Hazard Classes	Hazard Statement	Hazardous Decomposition Products	Incompatible Materials	Indicative Inventory to be Completed at a Later Stage of the Project Design for ICPE Requirements					
							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Povidone iodine solution	Cleaner and disinfectant	Liquid	Not provided in MSDS	Causes eye irritation. May cause chronic toxic effects	Carbon oxides, nitrogen oxides and iodine	Caustics, oxidisers and reducing agents	15x500 mL					
Protective Lacquer	Equipment protection	Liquid		H222 Extremely flammable aerosol. H229 Pressurised container: may burst if heated. H317 May cause an allergic skin reaction. H319 Causes serious eye irritation. H336 May cause drowsiness or dizziness	Toxic fumes	Oxidisers	24x500 mL aerosol containers					
Saf-Acid	Cleaning of mineral deposits in boilers, conduits, heat exchangers, etc.	Powder		H290 May be corrosive to metals. H314 Causes severe skin burns and eye damage. H318 Causes serious eye damage. H412 Harmful to aquatic life with long lasting effects	Carbon dioxide, hydrogen chloride, phosgene, nitrogen oxides, sulfur oxides and other pyrolysis products	Alkalies, oxidisers and chemicals readily decomposed by acids	4x25 kg pails					
Sigma Thinner 21-06	Diluant, cleaning solvent	Liquid	Not provided in MSDS	Flammable liquid. Harmful by inhalation and in contct with skin. Irriating to skin	Carbon dioxide, carbon monoxide and nitrogen oxides	Oxidisers, strong alkalines and strong acids	12 L					
Soda ash	pH modifier	Solid	Not provided in MSDS	Causes eye irritation	Carbon dioxide	Acids and oxidisers	240x5 gal container					
Sodium Bisulfite (40%)	Dechlorination, deionization, dechromatation, and deoxygenation of water	Liquid		H302 Harmful if swallowed	Sulphurous gases. Contact with acids liberates toxic fumes	Oxidisers and acids	250 L					
Sodium Hydroxide Solution (30-54%)	Neutralizing agent, industrial cleaner, pulping agent	Powder		May be corrosive to metals. Harmful if swallowed. Causes severe skin burns and eye damage	None identified in MSDS	Water, reducing sugars, acids, glycols, halogenated organics and organic nitro compounds	240x5 gal jugs					
Sodium Hypochlorite	Surface cleaning, bleaching, odor removal and water disinfection	Liquid		H290 May be corrosive to metals. H314 Causes severe skin burns and eye damage. H400 Very toxic to aquatic life	Oxygen and chlorine	Acids, amines, reducing agents and hydrocarbons						
Strip-A-Way	Descaling agent	Liquid		H314 Causes severe skin burns and eye damage	Nitrogen oxides and phosphorus oxides	Alkalis	12 L					
UNITOR Foam Cleaner	Cleaner	Liquid		Risk of severe eye injury. Corrosive to the skin	None identified in MSDS	Acids	24x50 mL					
Various Coatings/ Hardeners: e.g. Hardtop AS HB Comp B	Coating/ solvent/ paint	Liquid		Flammable liquid and vapour. Harmful if inhaled. May cause allergy or asthma symptoms or breathing difficulties if inhaled. May cause an allergic skin reaction. May cause respiratory irritation	Carbon dioxide, carbon monoxide, nitrogen oxides and sulfur oxides	Oxidisers, strong alkalis, strong acids, amines, alcohols and water	40 L					
Various Coatings/ Hardeners: e.g. Hardtop XP Comp A	Coating/solvent/ paint	Liquid		Flammable liquid and vapor. Causes serious eye irritation. Causes skin irritation. May cause an allergic skin reaction. May cause damage to organs through prolonged or repeated exposure	Carbon dioxide, carbon monoxide and metal oxide / oxides	Oxidisers	40 L					

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							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Waste Oil	Waste product	Liquid	Not provided in MSDS	Product may burn, but does not ignite readily. May be harmful if inhaled. May be harmful if absorbed through the skin. May be harmful or fatal if swallowed. May irritate the respiratory tract (nose, throat, and lungs), eyes, and skin. Suspect cancer hazard Contains material which can cause cancer. Risk of cancer depends on duration and level of exposure. Contains material that may cause central nervous system damage. Product may be toxic to fish, plants, wildlife and/or domestic animals	Burning may produce phosgene gas, nitrogen oxides, carbon monoxide and unidentified compounds	Acids, alkalies, oxidisers, reducing agents, reactive halogens and reactive metals	90 m3					
WD-40 Multi-Use Product Bulk Liquid	Corrosion protection, lubricant	Liquid		H226 Flammable liquid and vapour. H304 May be fatal if swallowed and enters airways. H336 May cause drowsiness and dizziness	Carbon oxides and toxic pyrolysis products	Strong oxidisers	100x500 mL					
Chemical Drilling Mud Products												
Calcium Chloride	Water phase salinity agent	Solid		H319 Causes severe eye irritation	Chlorine	Metals	640x25 kg sacks					
Caustic Soda (Sodium Hydroxide)	Alkalinity control	Solid		May be corrosive to metals. Harmful if swallowed. Causes severe skin burns and eye damage	None identified in MSDS	Acids, glycols, halogenated organics and organic nitro compounds	52x25 kg cans					
Drilling Detergent	Drilling detergent	Liquid		H318 Causes serious eye damage	Irritating gases and vapors	None identified in MSDS	7x55 gal drums					
Duo-VIS	Viscosifying agent	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon monoxide and carbon dioxide	Strong oxidisers	219x25 kg sacks					
Ecotrol RD	Fluid loss control agent	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon monoxide and carbon dioxide	None identified in MSDS	196x25 kg sacks					
Encore Base Oil	Oil based drilling mud	Liquid	Not provided in MSDS	May cause lung damage if swallowed	Carbon monoxide and carbon dioxide	Strong oxidisers	815 m3					
Escaid 110	Mineral-based oil	Liquid		H304 May be fatal if swallowed and enters airways	Smoke, fumes, incomplete combustion products, Carbon oxides	Strong oxidisers	1,439x55 gal drums					
G-SEAL	Lost circulation material	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides	Strong oxidisers	71x25 kg bags					
Lime	Alkalinity control	Solid		H315 Causes skin irritation. H318 Causes severe eye injuries. H335 May irritate respiratory pathways	In case of heating and fire, harmful vapors / gases may occur	Acids and water	430x25 kg sacks					
M-I Cide	Biocide	Liquid		H302 Harmful if swallowed. H317 May cause an allergic skin reaction. H330 Fatal if inhaled	Carbon monoxide, carbon dioxide, nitrous oxides and sulphur oxides	Acids, strong oxidisers and strong reducing agents	96x25 liter cans					
MI Gel (Bulk)	Viscosifying agent	Solid	Not provided in MSDS	May cause eye, skin, and respiratory tract irritation. Long term inhalation of particulates may cause lung damage. Cancer hazard Contains crystalline silica which may cause cancer	None identified in MSDS	None identified in MSDS	34 MT					

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							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
MI WATE Barite	Weighting agent	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Thermal decomposition can lead to release of irritating gases and vapours	None identified in MSDS	2,676 MT					
Mix II Medium	Lost circulation material	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Thermal decomposition can lead to release of irritating gases and vapors	Oxidisers	95x11 kg bags					
Polypac UL	Fluid loss control agent	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides and sodium oxides	Strong oxidisers	335x25 kg sacks					
Rheflat NS	Rheology modifier	Liquid	Not provided in MSDS	Irritating to eyes and skin	Toxic fumes	Strong oxidisers and flammable / combustible materials	5x55 gal drums					
Rhethik	Rheology modifier	Liquid	 	H302 Harmful if ingested. H373 May cause harm to bodily organs in case of prolonged or repeated exposure	Carbon oxides and nitrous oxides	Acids, ketones, aldehydes and copper alloys	19x55 gal drums					
Safe Carb 20	Lost circulation material	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon monoxide and carbon dioxide	Strong acids	308x25 kg bags					
Safe Carb 250	Lost circulation material	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon monoxide and carbon dioxide	Strong acids	290x25 kg bags					
Safe Carb 40	Lost circulation material	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon monoxide and carbon dioxide	Strong acids	458x25 kg bags					
Sodium Bicarbonate	Hardness control agent	Powder		H319 Causes serious eye irritation. H332 Harmful if inhaled. H335 May cause respiratory irritation	Carbon oxides	Acids	58x25 kg sacks					
Suremul Plus	Oil based mud emulsifier	Liquid	Not provided in MSDS	Eye irritant	None identified in MSDS	Strong acids and strong oxidisers	41x55 gal drums					
Surewet	Oil based mud emulsifier	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	In case of heating and fire, harmful vapors / gases may occur	Strong oxidisers	23x55 gal drums					
Truvis	Oil based mud emulsifier	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	None identified in MSDS	None identified in MSDS	121x25 kg sacks					
VG-69	Oil based mud emulsifier	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	In case of heating and fire, harmful vapors / gases may occur	Strong oxidisers, organic peroxides / hydroperoxides	11x25 kg sacks					
VG-Plus	Oil based mud emulsifier	Powder	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon monoxide, nitrous gases and hydrogen chloride	Strong oxidisers	453x25 kg sacks					
VG-Supreme	Oil based mud emulsifier	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon monoxide, carbon dioxide, nitrous gases and hydrogen chloride	Strong oxidisers	150x25 kg sacks					
Water Based Mud	Drilling Mud	Liquid	Not provided in MSDS	May cause eye, skin, and respiratory tract irritation. Cancer hazard. Contains crystalline silica which may cause lung cancer	None identified in MSDS	None identified in MSDS	10,804 bbl					
Chemical Drilling Cementing Products												
B275	Cement additive, dye	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	Toxic fumes	Strong oxidisers and strong acids	100 gal					

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							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Cement G	Cement (general purpose)	Powder		H315 Causes skin irritation. H318 Causes serious eye damage. H371 May cause damage to organs (respiratory). H373 May cause damage to organs (respiratory) through prolonged or repeated exposure	None identified in MSDS	Acids	160 MT					
Cement G + 35 % silica	Cement	Powder	Not provided in MSDS	May cause eye, skin, and respiratory irritation. Breathing crystalline silica can cause lung disease, including silicosis and lung cancer. Crystalline silica has also been associated with scleroderma and kidney disease	None identified in MSDS	Hydrofluoric acid	160 MT					
D081	Cement additive, self timer	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	None identified in MSDS	None identified in MSDS	267 gal					
D095 CemNET (LCM)	Cement additive	Solid	Not provided in MSDS	May cause skin irritation	None identified in MSDS	None identified in MSDS	500 bbl					
D097 Losseal W/O	Fracturing additive	Solid	Not provided in MSDS	May cause lung cancer if inhaled. May cause eye irritation	None identified in MSDS	None identified in MSDS	480 bbls					
D110	Cement additive, self timer/retarder	Liquid	Not provided in MSDS	Repeated or prolonged exposure may cause eye and skin irritation. Ingestion of large amounts may cause nausea, vomiting and diarrhea	Carbon oxides and harmful organic fumes	Oxidisers	160 gal					
D145A	Cement additive, dispersing agent	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	None identified in MSDS	Oxidisers	3 gal					
D153	Cement additive, stabilizer agent	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides and harmful organic fumes	None identified in MSDS	250 lb					
D155	Cement additive, extender	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	None identified in MSDS	None identified in MSDS	4,500 gal					
D168 UNIFLAC	Control of fluid loss	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides, sulphur oxides, nitrogen oxides, ammonia and harmful organic fumes	Oxidisers	439 gal					
D182 Barite MUDPUSH II		Solid	Not provided in MSDS	May cause irritation if inhaled. May cause eye irritation	Carbon oxides, sulphur oxides and harmful organic fumes	None identified in MSDS	2,225 lb					
D185	Dispersing agent at low temperature	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides and harmful organic fumes	None identified in MSDS	483 gal					
D186	Setting accelerator of the cement	Liquid		May cause eye irritation. Harmful if swallowed. May cause or intensify fire (oxidizer).	Ammonia, nitrogen oxides and carbon oxides	Strong acids, strong bases, reducing agents and organics	90 gal					
D191	Cement additive, surfactant	Liquid		H318 May cause severe eye injuries	None identified in MSDS	None identified in MSDS	576 gal					
D199 Losseal W	Cement additive	Solid	Not provided in MSDS	May cause skin irritation	Carbon oxides, nitrogen oxides, ammonia, harmful organic fumes, cyanide and aldehyde	Oxidisers, strong acids and strong bases	480 bbls					

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							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
D206	Anti-foaming agent	Liquid	Not provided in MSDS	May cause eye irritation	Carbon oxides, sulphur oxides, nitrogen oxides, silicone oxides, ammonia and harmful organic fumes	Oxidisers	399 gal					
D500 GASBLOK LT Emergency	Cement additive	Liquid		Toxic material. May cause sensitization in case of skin contact. Risk of slight eye irritation	Carbon oxides, nitrogen oxides, ammonia and harmful organic fumes	None identified in MSDS	2,480 gal					
D600G GASBLOK	Gas migration control additive	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides and harmful organic fumes	Oxidisers	5,000 gal					
U066	Cement additive, mutual solvent	Liquid	Not provided in MSDS	Combustible liquid. Irritating to eyes and skin. Toxic by inhalation and in contact with skin. Toxic by ingestion	Carbon oxides and harmful organic fumes	Oxidisers	576 gal					
Drilling Well Monitoring Radioactive Isotopes												
Am-241/Be	Well logging and bottom-hole monitoring	Solid	N/A	Contained in sealed, leakproof container. Sealed sources pose no internal radiation hazard	None identified in MSDS	None identified in MSDS	2 GBq					
Co-60	Well logging and bottom-hole monitoring	Solid	N/A	Contained in sealed, leakproof container. Sealed sources pose no internal radiation hazard	None identified in MSDS	None identified in MSDS	5 GBq					
Cs-137	Well logging and bottom-hole monitoring	Solid	N/A	Contained in sealed, leakproof container. Sealed sources pose no internal radiation hazard	None identified in MSDS	None identified in MSDS	1 KBq					
Na-22	Well logging and bottom-hole monitoring	Solid	N/A	Contained in sealed, leakproof container. Sealed sources pose no internal radiation hazard	None identified in MSDS	None identified in MSDS	2 KBq					
Th-323	Well logging and bottom-hole monitoring	Solid	N/A	Contained in sealed, leakproof container. Sealed sources pose no internal radiation hazard	Smoke may be radioactive	None identified in MSDS	1 KBq					
Drilling Well Testing Chemical Products												
Calcium Bromide Brine	Completion fluid	Liquid		318 Causes serious eye damage	Bromhydric acid and bromine	Strong acids	6000 bbls					
Defoam-X EH	Anti-foaming agent	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides	None identified in MSDS	3x5 gal					
Defoamer AF340	Anti-foaming agent	Liquid		H304 May be fatal if swallowed and enters airways	Carbon oxides	Strong acids, strong bases and strong oxidisiers	10x 200L					
Emulsotron CC3344-G	Demulsifier	Liquid		H315 Causes skin irritation. H319 Causes serious eye irritation. H332 Harmful if inhaled. H335 May cause respiratory irritation	Carbon oxides	Strong acids, strong bases and strong oxidisers	10x 200 L					
HEC (hydroxymethyl-cellulose)	Viscosifier; fluid loss reducer	Powder	N/A	Not classified. Not regarded as a health or environmental hazard	None identified in MSDS	None identified in MSDS	500x25 kg sacks					
Methanol	Hydrate inhibitor	Liquid	  	H225 Highly flammable liquid and vapour. H301+H311+H331 Toxic if swallowed, in contact with skin or if inhaled. H370 Causes damage to organs (liver, kidneys, central nervous system, optic nerve) (Dermal, oral)	Formaldehyde, carbon monoxide and carbon dioxide	Strong oxidisers, strong bases, strong acids, peroxides, acid anhydrides and acid chlorides	20 bbls					

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							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Monoethylene Glycol (MEG)	Hydration inhibitor	Liquid		H302 Harmful if swallowed	Toxic fumes	None identified in MSDS	15x1000 L					
Oceanic HW 443	Line-control fluid	Liquid		Harmful if swallowed. Causes serious eye irritation. May cause damage to organs through prolonged or repeated exposure.	Carbon dioxide, carbon monoxide and nitrogen oxides	None identified in MSDS	10x200 L					
Oceanic HW 540	Line-control fluid	Liquid		Harmful if swallowed. May cause damage to organs through prolonged or repeated exposure.	Carbon dioxide and carbon monoxide	None identified in MSDS	10x200 L					
One-Trol HT	Loss-reducing fluid	Solid		H304 May be fatal if swallowed and enters airways. H314 Causes severe skin burns and eye damage. H373 May cause damage to organs under prolonged or repeated exposure. H410 Very toxic to aquatic life with long lasting effects	Carbon oxides, nitrous oxides, ammonia and amines	Acids	500x50 lb sacks					
Safe-Cide	Biocide	Liquid		H302 Harmful if swallowed. H315 Causes skin irritation. H317 May cause an allergic skin reaction. H318 Causes serious eye damage. H330 Fatal if inhaled. H372 Causes damage to organs through prolonged or repeated exposure	Carbon oxides, nitrogen oxides and sulphur oxides	Strong oxidisers, nitrites and strong acids	5x25 L containers					
Safe-Cor	Corrosion inhibitor	Liquid	Not provided in MSDS	Irritating to eyes and skin. May cause sensitisation by skin contact.	Carbon monoxide, carbon dioxide and nitrous gases	Acids and oxidisers	5x55 gal drums					
Safe-Link 110	Completion-fluid additive	Paste and/or Gel	Not provided in MSDS	May cause severe eye and skin irritation. Prolonged contact may cause burns. Vapors and mists may be irritating if inhaled.	Chlorides and Carbon oxides	Water, zinc, methyl vinyl ether, boric acid plus calcium oxide and bromine trifluoride	20x25 L container					
Safe-Link 135	Completion-fluid additive	Gel		H318 Causes serious eye damage	Carbon oxides and bromine	Strong oxidisers and acids	20x25 L container					
Safe-Link Pill	Completion-fluid additive	Liquid		H315 Causes skin irritation. H319 Causes serious eye irritation	Irritating gases and vapors	None identified in MSDS	150 bbls					
Safe-Scav CA	Oxygen cleaner	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides	Metals, strong bases and strong Oxidisers	10x15 lb sacks					
Safe-Vis E	Completion-fluid additive	Liquid		H315 Causes skin irritation. H319 Causes serious eye irritation. H335 May irritate the respiratory tract	Irritating gases and vapors	Nitrates, strong acids, strong bases, and strong oxidisers	100x25L container					
Transaqua HT2	Hydraulic fluid	Liquid		H302 Harmful if swallowed. H373 May cause damage to organs through prolonged or repeated exposure	Carbon oxides and nitrogen oxides	None identified in MSDS	10x242 L					
Versagel HT	Viscosity enhancer	Solid	Not provided in MSDS	May be irritating to the respiratory tract if inhaled. May cause gastric distress, nausea and vomiting if ingested. May be irritating to the skin. May be irritating to the eyes	Carbon oxides	None identified in MSDS	120x50 lb sacks					
Drilling Explosives												
CDC Cutter Type 1	Explosive	Solid	Not provided in MSDS	Explosive. Danger of fire	Nitrous fumes	No specific detail provided in MSDS	6x3.3 kg					
CDC Cutter Type 2	Explosive	Solid	Not provided in MSDS	Explosive. Danger of fire	Nitrous fumes	No specific detail provided in MSDS	2x1.1 kg					
CDC Cutter Type 3	Explosive	Solid	Not provided in MSDS	Explosive. Danger of fire	Nitrous fumes	No specific detail provided in MSDS	6x5.4 kg					

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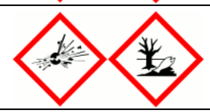
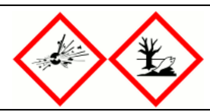
							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
CDC Cutter Type 4	Explosive	Solid	Not provided in MSDS	Explosive. Danger of fire	Nitrous fumes	No specific detail provided in MSDS	2x1.8 kg					
CDC Cutter Type 5	Explosive	Solid	Not provided in MSDS	Explosive. Danger of fire	Nitrous fumes	No specific detail provided in MSDS	2x0.40 kg					
HMX Super Booster	Explosive component	Solid	Not provided in MSDS	Explosive. May cause eye irritation, including corneal injury. Capable of causing irritation, allergic skin reaction and eczema. Ingestion ia poisonous and may cause cardiovascular collapse. May result in respiratory tract irritation and soreness in the nose and throat together with coughing. Inhalation or penetration through the skin may cause cardiovascular collapse, may also cause severe nasal and respiratory system irritation	Carbon dioxide, carbon monoxide and nitrogen oxide	No specific detail provided in MSDS	100x0.07 kg					
Igniter	Igniter	Solid		H204 Fire or projection hazard. H412 Harmful to aquatic life with long lasting effects	Toxic fumes	Oxidisers	20x0.06 kg					
Igniter Needle	Igniter	Solid		H204 Fire or projection hazard. H412 Harmful to aquatic life with long lasting effects	Toxic fumes	Oxidisers	240x0.02 kg					
L Powder Cartridge	Explosive	Solid		H204 Fire or projection hazard. H412 Harmful to aquatic life with long lasting effects	Toxic fumes	Oxidisers	120x0.96 kg					
Nobel Detonator	Detonator	Solid		H201 Explosive; mass explosion hazard. H301 Toxic if swallowed. H312+H332 Harmful in contact with skin or if inhaled. H319 Causes serious eye irritation. H315 Causes skin irritation	Nitrogen oxides	Reducing agents, strong oxidisers, strong alkalis and strong acids	50x0.14 kg					
Powder Charge	Explosive	Solid		H204 Fire or projection hazard. H412 Harmful to aquatic life with long lasting effects	Toxic fumes	Oxidisers	120x1.23 kg					
Powerjet Omega	Perforating charge	Solid	Not provided in MSDS	Explosive. Inhalation can cause headaches, dizziness and nervous system irregularity. Poison by ingestion, intraperitoneal, and intravenous routes. Inhalation of zinc oxide fume may cause “metal fume fever”. Vasodilator and can lower blood pressure	Nitrogen oxides and carbon oxides	No specific detail provided in MSDS	90x3.48 kg					
Primacord – 80 gr FEP	Detonator cord	Solid	Not provided in MSDS	Explosive. May cause eye irritation, redness and tearing, PYX is a known eye irritant. May cause skin irritation. Moderately toxic if ingested	Nitrogen oxides and carbon monoxide	No specific detail provided in MSDS	500ft @ 1.95 kg/ft (975 kg)					
Primacord – Reboxed	Detonator cord	Solid		H201 Explosive; mass explosion hazard. H301 Toxic if swallowed. H312+H332 Harmful in contact with skin or if inhaled. H315 Causes skin irritation. H319 Causes serious eye irritation	None identified in MSDS	No specific detail provided in MSDS	500 ft @ 2.7 kg/ft (1350 kg)					
Puncher 1606, L	Perforating charge	Solid	Not provided in MSDS	Explosive. Inhalation of explosive powders can cause headaches, dizziness and nervous system irregularity. Poison by ingestion, intraperitoneal, and intravenous routes. Inhalation of zinc oxide fume may cause “metal fume fever”. Vasodilator and can lower blood pressure	Nitrogen oxides and carbon oxides	No specific detail provided in MSDS	90x0.27 kg					
Puncher 1606, M	Perforating charge	Solid	Not provided in MSDS	Explosive hazard. Inhalation of explosive powders can cause headaches, dizziness and nervous system irregularity. Poison by ingestion, intraperitoneal, and intravenous routes. Inhalation of zinc oxide fume may cause “metal fume fever”. Vasodilator and can lower blood pressure	Nitrogen oxides and carbon oxides	No specific detail provided in MSDS	90x0.21 kg					

Product Name	Function	Phase	Hazard Pictogram(s) – Globally Harmonized System (GHS) Hazard Classes	Hazard Statement	Hazardous Decomposition Products	Incompatible Materials	Indicative Inventory to be Completed at a Later Stage of the Project Design for ICPE Requirements					
							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Puncher 1606, S	Perforating charge	Solid	Not provided in MSDS	Explosive. Inhalation of explosive powders can cause headaches, dizziness and nervous system irregularity. Poison by ingestion, intraperitoneal, and intravenous routes. Inhalation of zinc oxide fume may cause “metal fume fever”. Vasodilator and can lower blood pressure	Nitrogen oxides and carbon oxides	No specific detail provided in MSDS	60x0.22 kg					
Puncher 1606, XL	Shaped Charge	Solid		H201 Explosive; mass explosion hazard. H302 Harmful if swallowed. H370 Causes damage to organs. H373 May cause damage to organs through prolonged or repeated exposure. H400 Very toxic to aquatic life. H410 Very toxic to aquatic life with long lasting effects	None identified in MSDS	Strong acids, strong bases, strong oxidisers	60x0.18 kg					
Secure 2 Detonator	Detonator	Solid	Not provided in MSDS	Explosive. Inhalation of explosive powders can cause headaches and dizziness. Poison by ingestion, intraperitoneal, and intravenous routes	Nitrogen oxides	No specific detail provided in MSDS	20					
Secure 2 Exposed Detonator	Detonator	Solid		H201 Explosive; mass explosion hazard. H312 Harmful in contact with skin	Carbon oxides, nitrogen oxides and lead fumes	Strong acids, strong bases, strong oxidisers	24x0.05 kg					
Secure 2 Igniter	Igniter	Solid	Not provided in MSDS	Explosive. Inhalation of explosive powders can cause headaches and dizziness. Poison by ingestion, intraperitoneal, and intravenous routes	Nitrogen oxides	No specific detail provided in MSDS	10x0.05 kg					
SuperSet Power Cartridge	Peripheral power device	Solid	Not provided in MSDS	The dust is a mild irritant to the eyes, skin and mucous membranes. Vapor of the heated material (above 350ºC) may cause respiratory system irritation. Ingested material can cause convulsions, vomiting, diarrhea and may be fatal. The dust is a mild irritant to eyes, skin and mucous membranes	Carbon monoxide and nitrogen oxides	No specific detail provided in MSDS	10x5.7 kg					
Drilling Mudlogging Chemicals												
0.02N Hydrochloric Acid	Test medium	Liquid		H315 Causes skin irritation. H319 Causes serious eye irritation	Hydrogen chloride	Metals, strong bases and cyanides	3 L					
0.1M Calcium Carbonate	Dehumidifier	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	None identified in MSDS	None identified in MSDS	4x0.5 kg					
1% Benzalkonium Chloride (ROCCAL)	Antiseptic cleaner	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	None identified in MSDS	None identified in MSDS	1x20 cc					
Alizarin Red S Monosodium Salt	Test medium	Liquid		Causes serious eye irritation. Causes skin irritation. May cause respiratory irritation	Carbon oxides and metallic oxides	Oxidisers	2x0.5 L					
Barium Chloride Solution	Test medium	Liquid		H302 Harmful if swallowed	Hydrogen chloride and barium	Strong Oxidisers	1x0.25 L					
Blue Star Antifreeze	Coolant	Liquid		H302 Harmful if swallowed. H373 May cause damage to organs through prolonged or repeated exposure	Carbon oxides and toxic fumes	Strong oxidisers	2x1 L					
Calcium Carbide	Gas test	Solid		In contact with water releases flammable gases which may ignite spontaneously. Causes severe skin burns and eye damage. May cause respiratory irritation	Carbon dioxide, carbon monoxide and metal oxide / oxides	Water	4x0.5 kg					
Chlorodifluoro-methane (R22)	Refrigerant gas	Gas		Contains gas under pressure; may explode if heated. May cause frostbite. Harms public health and the environment by destroying ozone in the upper atmosphere	Carbon dioxide, carbon monoxide, halogenated compounds and carbonyl halides	None identified in MSDS	2x1 L					

Product Name	Function	Phase	Hazard Pictogram(s) – Globally Harmonized System (GHS) Hazard Classes	Hazard Statement	Hazardous Decomposition Products	Incompatible Materials	Indicative Inventory to be Completed at a Later Stage of the Project Design for ICPE Requirements					
							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Cyclohexane	Solvent	Liquid		H225 Highly flammable liquid and vapor. H304 May be fatal if swallowed and enters airways. H315 Causes skin irritation. H319 Causes serious eye irritation. H335 May cause respiratory irritation. H336 May cause drowsiness or dizziness. H361 Suspected of damaging fertility or the unborn child. H370: May cause damage to organs (Vasculature). H400 Very toxic to aquatic life	Carbon dioxide and carbon oxides	Oxygen and strong oxidisers	2x0.5 L					
Electrical Solvent Cleaner Plus	Electrical cleaner	Liquid Aerosol		H222 Extremely flammable aerosol. H280 Contains gas under pressure; may explode if heated. H315 Causes skin irritation. H336 May cause drowsiness or dizziness. H411 Toxic to aquatic life with long lasting effects	Carbon dioxide	Strong acids, bases and oxidisiers	2x500 mL					
Isceon MO79 Coolant (R-428A)	Refrigerant	Gas	Not provided in MSDS	Contact with liquid or refrigerated gas can cause cold burns and frostbite. May cause skin and eye irritation. May cause discomfort, itching, redness, or swelling. May cause eye tearing, redness, or discomfort	Toxic fumes	Alkali metals, alkaline earth metals, powdered metals, and powdered metal salts	2x5 gal					
Lubriplate 630-AA	Lubricating grease	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon dioxide, carbon monoxide, nitrogen oxides, sulfur oxides and metal oxide / oxides	Oxidisers, acids and chlorine	2x10 oz					
Magnesium Hydroxide Carbonate Light Extra Pure	Drying agent	Solid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides	Acids	1x500 g					
Methylene Blue	Analytical reagent	Liquid		H226 Flammable liquid and vapour. H332 Harmful if inhaled. H370 Causes damage to organs	Carbon dioxide, carbon monoxide, nitrous gases and hydrocarbons	Acids, alkalis and oxidisers	1x0.5 L					
Phenolphthalein	Solvent	Liquid		H351 Suspected of causing cancer	Carbon dioxide and carbon monoxide	Strong oxidisers and strong bases	1x0.5 L					
Propan-2-OL	Solvent	Liquid		H225 Highly flammable liquid and vapour. H319 Causes serious eye irritation. H336 May cause drowsiness or dizziness	Carbon oxides	Strong oxidisers, strong acids, alkali metals, amines, aluminium and iron	2x1 L					
Silver Nitrate Solution 0.1N	Test medium	Liquid		H315 Causes skin irritation. H319 Causes serious eye irritation. H412 Harmful to aquatic life with long lasting effects	Nitrogen oxides	Chlorides, strong acids and strong bases	2x1 L					
Dispersants												
Corexit 9500	Dispersant	Liquid		Causes serious eye irritation. May cause drowsiness or dizziness.	Carbon oxides nitrogen oxides, sulphur oxides and phosphorus oxides	Strong oxidisers			8,000 L			

Product Name	Function	Phase	Hazard Pictogram(s) – Globally Harmonized System (GHS) Hazard Classes	Hazard Statement	Hazardous Decomposition Products	Incompatible Materials	Indicative Inventory to be Completed at a Later Stage of the Project Design for ICPE Requirements					
							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
Subsea Commissioning (Offshore Storage) Chemicals												
Combined hydrotest chemical cocktail (RX-5254)	Biocide, oxygen scavenger, corrosion inhibitor	Liquid		H314 Causes severe skin burns and eye damage	In combustion emits toxic fumes	Acids		0.09 m3	35 m3			
Combined hydrotest chemical sticks (RX-9034A)	Leak detection dye	Solid		H290 May be corrosive to metals. H314 Causes severe skin burns and eye damage. H335 May cause respiratory irritation	Toxic fumes	Strong oxidisers, strong acids and bases						
MEG	Hydration inhibitor	Liquid		H302: Harmful if swallowed	Toxic fumes	None identified in MSDS		210.5 m3	2,741 m3			
RX-9022	Liquid dye	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	Toxic fumes	None identified in MSDS		0.01 m3	2.3 m3			
FPSO MEG Chemicals												
Defoamer AF400	Anti-foam			H312 + H332 Harmful in contact with skin or if inhaled. H315 Causes skin irritation. H319 Causes serious eye irritation	Carbon oxides	Oxidisers					5 m^3	
EC6804A	Oxygen scavenger			H315 Causes skin irritation. H319 Causes serious eye irritation	Sulphur oxides	None identified in MSDS					46 m^3	
MEG	Lean MEG			H302 Harmful if swallowed	Toxic fumes	None identified in MSDS					55,300 m3	
Monoethanolamine	pH stabiliser			H302 Harmful if swallowed. H312 Harmful in contact with skin. H314 Causes severe skin burns and eye damage. H332 Harmful if inhaled. H335 May cause respiratory irritation	Carbon monoxide, carbon dioxide and nitrogen oxides	Acids, oxidisers, and chemically active metals					23 m^3	
FPSO Production and Subsea Injection Chemicals												
Cortron RN-629	Corrosion inhibitor top-up	Liquid		H302 Harmful if swallowed. H315 Causes skin irritation. H317 May cause an allergic skin reaction. H318 Causes serious eye damage. H373 May cause damage to organs through prolonged or repeated exposure	Carbon oxides, nitrogen oxides and hydrogen sulfide	None identified in MSDS					64 m^3	
Defoamer AF400	Anti-foam	Liquid		H312 + H332 Harmful in contact with skin or if inhaled. H315 Causes skin irritation. H319 Causes serious eye irritation	Carbon oxides	Oxidisers					5 m^3	
EC6029A	Flocculants or coagulants (PW treatment system)	Liquid	N/A	Not classified. Not regarded as a health or environmental hazard	Carbon oxides, nitrogen oxides, sulphur oxides and phosphorus oxides	None identified in MSDS					5 m^3	
EC6527G	Biocide	Liquid		H302 Harmful if swallowed. H317 May cause an allergic skin reaction. H318 Causes serious eye damage. H331 Toxic if inhaled. H361 Suspected of damaging the unborn child. H400 Very toxic to aquatic life	Carbon oxides, nitrogen oxides, sulphur oxides and phosphorus oxides	None identified in MSDS					11.5 m^3	
FX2140	Emulsion breaker	Liquid		H226 Flammable liquid and vapour. H304 May be fatal if swallowed and enters airways. H336 May cause drowsiness or dizziness. H351 Suspected of causing cancer. H411 Toxic to aquatic life with long lasting effects	Carbon oxides	Oxidisers					7.4 m^3	

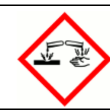
Product Name	Function	Phase	Hazard Pictogram(s) – Globally Harmonized System (GHS) Hazard Classes	Hazard Statement	Hazardous Decomposition Products	Incompatible Materials	Indicative Inventory to be Completed at a Later Stage of the Project Design for ICPE Requirements					
							Drillship	Supply Base(s)	Support Vessels	FLNG	FPSO	QU Platform
FX2589	Scale inhibitor top-up	Liquid		H302 Harmful if swallowed. H315 Causes skin irritation. H317 May cause an allergic skin reaction. H318 Causes serious eye damage. H373 May cause damage to organs through prolonged or repeated exposure. H411 Toxic to aquatic life with long lasting effects	Carbon oxides, nitrogen oxides, sulphur oxides, phosphorus oxides and hydrogen sulfide	None identified in MSDS					5 m^3	
Methanol	Hydrate inhibitor	Liquid		H225 Highly flammable liquid and vapour. H301+H311+H331 Toxic if swallowed, in contact with skin or if inhaled. H370 Causes damage to organs (liver, kidneys, central nervous system, optic nerve) (Dermal, oral)	Formaldehyde, carbon monoxide and carbon dioxide	Strong oxidisers, strong bases, strong acids, peroxides, acid anhydrides and acid chlorides					254 m^3	
PARA16592A	Wax inhibitor	Liquid		H304 May be fatal if swallowed and enters airways. H336 May cause drowsiness or dizziness. H351 Suspected of causing cancer. H411 Toxic to aquatic life with long lasting effects	Carbon oxides	Oxidisers					160 m3	
Transaqua HT2	Hydraulic fluid	Liquid		H302 Harmful if swallowed. H373 May cause damage to organs through prolonged or repeated exposure	Carbon oxides and nitrogen oxides	None identified in MSDS					5 m^3	
FLNG Production Chemicals												
Amine	Gas scrubbing, sweetening and acid gas removal	Liquid		H302 Harmful if swallowed. H316 Causes mild skin irritation. H319 Causes serious eye irritation	Carbon oxides and nitrogen oxides	Oxidisers and acids				25 m3		
Defoamer AF400	Anti-foam	Liquid		H312 + H332 Harmful in contact with skin or if inhaled. H315 Causes skin irritation. H319 Causes serious eye irritation	Carbon oxides	Oxidisers				240 m3		
Ethylene	LNG refrigerant	Liquid		Extremely flammable gas. May form explosive mixtures with air. Contains gas under pressure; may explode if heated. May cause frostbite. May displace oxygen and cause rapid suffocation. May cause drowsiness or dizziness	Carbon dioxide and carbon monoxide	Oxidisers				3x20 m3		
Iso-pentane	LNG refrigerant	Liquid		Extremely flammable liquid and vapor. May form explosive mixtures with air. May cause drowsiness and dizziness. Toxic to aquatic life with long lasting effects	Carbon dioxide and carbon monoxide	Oxidisers				12x25 m3		
Propane	LNG refrigerant	Liquid		Extremely flammable gas. May form explosive mixtures with air. Contains gas under pressure; may explode if heated. May cause frostbite. May displace oxygen and cause rapid suffocation	Carbon dioxide and carbon monoxide	Oxidisers				6x25 m3		
Sodium hypochlorite	Surface cleaning, bleaching, odor removal and water disinfection	Liquid		H290 May be corrosive to metals. H314 Causes severe skin burns and eye damage. H400 Very toxic to aquatic life	Oxygen and chlorine	Acids, amines, reducing agents, and hydrocarbons						

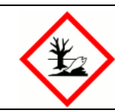
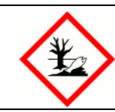
CLASSIFICATION AND LABELLING OF CHEMICALS

Meaning of the hazard icons (according to the Globally Harmonized System of Classification and Labelling of Chemicals – GHS.
http://www.unece.org/trans/danger/publi/ghs/ghs_rev07/07files_e0.html#c61353

Flammable	Explosive	Oxidising	Compressed Gas	Corrosive	Toxic	Harmful	Health	Environmental

Hazard Class	Hazard Statement Code	Hazard Statement	Hazard Category	Signal Word	Pictogram
Explosive	H200	Unstable explosive	Unstable explosive	Danger	
	H201	Explosive: mass explosion hazard	Division 1.1	Danger	
	H202	Explosive: severe projection hazard	Division 1.2	Danger	
	H203	Explosive: fire, blast or projection hazard	Division 1.3	Danger	
	H204	Fire or projection hazard	Division 1.4	Warning	
Explosive	H205	May mass explode in fire	Division 1.5	Danger	None
Explosive	None	None	Division 1.6	None	None
Desensitized explosives	H206	Fire, blast projection hazard: increased risk of explosion if desensitizing agent is reduced	1	Danger	
	H207	Fire or projection hazard: increased risk of explosion if desensitizing agent is reduced	2 3	Danger Warning	
	H208	Fire hazard: increased risk of explosion if desensitizing agent isreduced	4	Warning	
Flammable Gases	H220	Extremely flammable gas	1A	Danger	
	H221	Flammable gas	1B 2	Danger Warning	 None
Aerosols	H222	Extremely flammable aerosol	1	Danger	
	H223	Flammable aerosol	2	Warning	
Flammable Liquids	H224	Extremely flammable liquid and vapour	1	Danger	
	H225	Highly flammable liquid and vapour	2	Danger	
	H226	Flammable liquid and vapour	3	Warning	
	H227	Combustible liquid	4	Warning	None
Flammable Solids	H228	Flammable solid	1 2	Danger Warning	
Aerosols	H229	Pressurized container: may burst if heated	1, 2 or 3	Warning	None
Flammable Gases	H230	May react explosively even in the absence of air	1A	Danger	
	H231	May react explosively even in the absence of air at elevated pressure and/or temperature	1A	Danger	
	H232	May ignite spontaneously if exposed to air	1A	Danger	
Self-reactive substances and mixtures Organic Peroxides	H240	Heating may cause an explosion	Type A	Danger	
	H241	Heating may cause a fire or explosion	Type B	Danger	
	H242	Heating may cause a fire	Types C & D Types E & F	Danger Warning	
	None	None	Type G	None	None
Pyrophoric liquids Pyrophoric solids	H250	Catches fire spontaneously if exposed to air	1	Danger	
Self-heating substances and mixtures	H251	Self-heating: may catch fire	1	Danger	
	H252	Self-heating in large quantities: may catch fire	2	Warning	
	H260	In contact with water releases flammable gases which may ignite spontaneously	1	Danger	

Hazard Class	Hazard Statement Code	Hazard Statement	Hazard Category	Signal Word	Pictogram
Substances and mixtures, which in contact with water, emit flammable gases	H261	In contact with water releases flammable gases	2 3	Danger Warning	
Oxidising Gases	H270	May cause or intensify fire; oxidizer	1	Danger	
Oxidising liquids	H271	May cause fire or explosion; strong oxidizer	1	Danger	
Oxidising solids	H272	May intensify fire; oxidizer	2 3	Danger Warning	
Gases under pressure	H280	Contains gas under pressure; may explode if heated	Compressed, liquefied or dissolved gas	Warning	
	H281	Contains refrigerated gas; may cause cryogenic burns or injury	Refrigerated liquefied gas	Warning	
Corrosive to metals	H290	May be corrosive to metals	1	Warning	
Acute toxicity	H300	Fatal if swallowed	1 or 2	Danger	
	H301	Toxic if swallowed	3	Danger	
	H302	Harmful if swallowed	4	Warning	
	H303	May be harmful if swallowed	5	Warning	None
Aspiration hazard	H304	May be fatal if swallowed and enters airways	1	Danger	
	H305	May be harmful if swallowed and enters airways	2	Warning	
Acute toxicity	H310	Fatal in contact with skin	1 or 2	Danger	
	H311	Toxic in contact with skin	3	Danger	
	H312	Harmful in contact with skin	4	Warning	
	H313	May be harmful in contact with skin	5	Warning	None
Skin corrosion/irritation	H314	Causes severe skin burns and eye damage	1	Danger	
	H315	Causes skin irritation	2	Warning	
	H316	Causes mild skin irritation	3	Warning	None
Skin sensitizer	H317	May cause an allergic skin reaction	1, 1A or 1B	Warning	
Serious eye damage/eye irritation	H318	Causes serious eye damage	1	Danger	
	H319	Causes serious eye irritation	2/2A	Warning	
	H320	Causes eye irritation	2B	Warning	None
Acute toxicity	H330	Fatal if inhaled	1 or 2	Danger	
	H331	Toxic if inhaled	3	Danger	

Hazard Class	Hazard Statement Code	Hazard Statement	Hazard Category	Signal Word	Pictogram
	H332	Harmful if inhaled	4	Warning	
	H333	May be harmful if inhaled	5	Warning	None
Respiratory sensitizer	H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled	1, 1A or 1B	Danger	
Specific target organ toxicity following single exposure	H335 H336	May cause respiratory irritation May cause drowsiness or dizziness	3	Warning	
Germ cell mutagenicity	H340	May cause genetic defects (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	1A or 1B	Danger	
	H341	Suspected of causing genetic defects (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	2	Warning	
Carcinogenicity	H350	May cause cancer (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	1A or 1B	Danger	
	H351	Suspected of causing cancer (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	2	Warning	
Toxic to reproduction	H360	May damage fertility or the unborn child (state specific effect if known) (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	1A or 1B	Danger	
	H361	Suspected of damaging fertility or the unborn child (state specific effect if known) (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	2	Warning	
	H362	May cause harm to breast-fed children	Additional category for effects on or via lactation	None	None
Specific target organ toxicity following single exposure	H370	Causes damage to organs (or state all organs affected, if known) (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	1	Danger	
	H371	May cause damage to organs (or state all organs affected, if known) (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	2	Warning	
	H372	Causes damage to organs (state all organs affected, if known) through prolonged or repeated exposure (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	1	Danger	
Specific target organ toxicity following repeated exposure	H373	May cause damage to organs (state all organs affected, if known) through prolonged or repeated exposure (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)	2	Warning	
Hazardous to the aquatic environment, short-term (acute)	H400	Very toxic to aquatic life	Acute 1	Warning	
	H401	Toxic to aquatic life	Acute 2	None	None
	H402	Harmful to aquatic life	Acute 3		
Hazardous to the aquatic environment, long-term (chronic)	H410	Very toxic to aquatic life with long lasting effects	Chronic 1	Warning	
	H411	Toxic to aquatic life with long lasting effects	Chronic 2	None	
	H412	Harmful to aquatic life with long lasting effects	Chronic 3	None	None
	H413	May cause long lasting harmful effects to aquatic life	Chronic 4		
Hazard to the ozone layer	H420	Harms public health and the environment by destroying ozone in the upper atmosphere	1	Warning	

INCOMPATABILITY OF PRODUCTS

The storage of products at the various Ahmeyim/Guembeul project facilities will be done in accordance with industry recognised standards and accepted good practice to reduce the risk of dangerous physico-chemical reactions that can lead to accidents. This includes never storing in the same place products that may react violently with each other. Incompatability of materials are identified within MSDS and the listing of hazardous materials and substances above.

In addition, the table below summarises general compatibility and storage rules for the different types of products (Ecole Polytechnique Fédérale de Lausanne (EPFL), Institut des Sciences et Ingénierie Chimiques (ISIC), Section de Chimie et Génie Chimique (SCGC) - Règles d'Hygiène de Sécurité et de Protection de l'Environnement, Octobre 2014).

					 Acid	 Base			
	Yes	No	No	No	No	No	-	Yes	Yes
	No	Yes	No	No	No	No	No	No	No
	No	No	Yes	No	-	-	No	-	No
	No	No	No	Yes	No	No	No	No	No
 Acid	No	No	-	No	Yes	No	No	No	No
 Base	No	No	-	No	No	Yes	No	No	No
	-	No	No	No	No	No	Yes	Yes	Yes
	Yes	No	-	No	No	No	Yes	Yes	Yes
	Yes	No	No	No	No	No	Yes	Yes	Yes

Notes

Yes	Can be stored together
No	Must be stored separately
-	Should only be stored together if certain special provisions are applied

Do not store toxic products with flammable products (risk of fire and dangerous reactions in case of accidental mixing)

If a product has more than one hazard pictogram, it will be stored in the following order of precedence:

That is, the oxidising property of a product is more important than the flammable property. Therefore, if a product has both these hazards, it should be stored with Oxidisers rather than flammables.

APPENDIX O-2 : PRELIMINARY RISK ANALYSIS WORKSHEETS

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.02.01	Well blowout during drilling, or completion (subsea or surface flow)	• Hydrostatic pressure of the well is greater than the pressure exerted by the weight of the drilling mud • Human error (mistake in the make-up of the drilling muds, failure to detect a kick etc.) • Rupture of the marine riser	• Hydrocarbon blowout on or below the drill floor of the drillship • Explosion and / or jet fire on the drillship • Toxic smoke and high levels of thermal radiation capable of causing severe or fatal injuries (more than 3) to exposed persons • Damage to the drillship resulting in possible foundering • Oil spill and marine pollution over a significant distance	2	5	U	• Well planning and program addresses well specific aspects and design / drilling requirements • Training and competence of personnel • Kick and well control procedures • Continuous monitoring of drilling activities including mud returns to detect and control kick • Subsea BOP at the wellhead can safely divert (using choke and kill system) or isolate flow (using rams) from the well • Inspection, testing and maintenance of equipment	• Control / contain the blowout using emergency response services and equipment (e.g., ROV to manually close subsea BOP, containment caps to collect oil, relief wells to kill blowout) • Option to disconnect the drillship from the well / BOP at the LMRP (lower marine riser package) • Fire and gas detection with associated alarms • Topsides emergency shutdown with strict control of ignition sources • Control of ignition sources through hazardous area classifications (ATEX compliant) • Multiple escape routes leading to the primary safe muster area and the alternate safe muster area • Active fire protection (e.g., deluge sprinklers / fire hydrants) in the derrick / drilling areas provides cooling • Multiple redundant fire pumps to supply firewater / foam • Support / supply vessels equipped with firefighting facilities • Safe muster and evacuation systems (lifeboats, life rafts, and lifesaving appliances) • BP Cap & Containment Plan • Oil spill contingency plans	1	5	S	R	D-01
			• Hydrocarbon blowout on the seabed with dispersion to the surface (density of the well fluids is less than the density of seawater) • Oil spill and marine pollution over a significant distance	2	5	U		• Water depths result in low flammable gas concentrations at the surface (<<LFL) • Control / contain the blowout using emergency response services and equipment (e.g., ROV to manually close subsea BOP, containment caps to collect oil, relief wells to kill blowout) • Option to disconnect the drillship from the well / BOP at the LMRP (lower marine riser package) • BP Cap & Containment Plan • Oil spill contingency plans	1	5	S	R	D-01

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.06.01	Hydrocarbon release from drillship mud/gas separator or degasser	• Gas cut mud • Poor kick / well control • Mechanical failure (e.g., corrosion, erosion, flange failure, weld defect) • Failure of ventilation system	• Fire or explosion that might cause severe or fatal injuries (3 or less) to the personnel exposed • Possible escalation and damage to well control equipment leading to blowout	2	4	S	• Training and competence of personnel • Kick and well control procedures • Monitoring of mud returns (e.g. volumes, flammable gas) • ESD and use of choke and kill system • Ventilation of shaker and mud pit areas to limit potential for significant gas build up	• Topsides emergency shutdown with strict control of ignition sources • Fire and gas detection with associated alarms • Control of ignition sources through hazardous area classifications (ATEX compliant) • Escape and safe muster of personnel in response to gas detection alarms, and prior to ignition • Multiple escape routes leading to the primary safe muster area and the alternate safe muster area • Active fire protection including foam system for mud pits • Support / supply vessels equipped with firefighting facilities • Safe muster and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	D-02
H-01.06.02	Fire or explosion in the drilling-mud return areas (shale shakers)	• Gas cut mud • Well release • Poor kick / well control • Failure of ventilation system	• Fire or explosion that might cause severe or fatal injuries (3 or less) to the personnel exposed • Possible escalation and damage to well control equipment leading to blowout	2	4	S	• Monitoring of mud returns (e.g. volumes, flammable gas) • Training and competence of personnel • Kick and well control procedures • ESD and use of choke and kill system and mud / gas separator to divert / contain flammable gas and safely vent • Ventilation of shaker and mud pit areas to limit potential for significant gas build up	• Topsides emergency shutdown with strict control of ignition sources • Fire and gas detection with associated alarms • Control of ignition sources through hazardous area classifications (ATEX compliant) • Escape and safe muster of personnel in response to gas detection alarms, and prior to ignition • Multiple escape routes leading to the primary safe muster area and the alternate safe muster area • Active fire protection including foam system for mud pits • Support / supply vessels equipped with firefighting facilities • Safe muster and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	D-02
H-01.02.02	Hydrocarbon leaks or spills during well testing	• Mechanical failure (e.g., corrosion, erosion, flange failure, weld defect)	• Fire or explosion that might cause severe or fatal injuries (3 or less) to the personnel exposed • Possible escalation and damage to well control equipment leading to blowout	2	4	S	• Certified well testing equipment that is appropriately designed and regularly tested, inspected and maintained as part of the drillship preventive maintenance system • Training and competence of personnel • Well test area open, well ventilated and away from critical well control equipment • Well tests conducted during daylight hours, to minimize potential for errors	• Well test area located towards the stern of the drillship, in an open area and remote from the drillfloor and primary muster area • Gas and fire detection in the well test area • Emergency shutdown and isolation of flow from the well • Control of ignition sources through hazardous area classifications (ATEX compliant)	1	4	S	R	D-03

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
								• Escape and safe muster of personnel in response to gas detection alarms, and prior to ignition, or upon fire alarm • Immediate isolation of equipment and depressurization by means of the burner rails • Multiple escape routes leading to the primary safe muster area and the alternate safe muster area • Active fire protection systems (e.g., firewater and foam) • Support / supply vessels equipped with firefighting facilities • Safe muster and evacuation systems (lifeboats, life rafts, and lifesaving appliances)					
H-01.02.03	Well blowout during production (subsea flow)	• Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object impacts wellhead	• Hydrocarbon blowout on the seabed with dispersion to the surface (density of the well fluids is less than the density of seawater) • Oil spill and marine pollution over a significant distance	2	5	U	• Well planning and program addresses well specific aspects and design requirements • Inspection, testing and maintenance of subsea equipment • Cathodic protection (sacrificial anodes) • Wellheads remote from FPSO with no lifting over live wellheads	• Water depths result in low flammable gas concentrations at the surface (<<LFL) • Pressure monitoring of production and gas flowlines from wellheads • Isolation of the well downhole at the surface controlled sub-surface safety valve (SCSSV) • Control / contain the blowout through use of emergency response services and equipment (e.g., containment caps to collect oil, relief wells to kill blowout)	1	5	S	R	D-01
H-01.06.03	Well fluid release from subsea wells wellheads (9) – inboard the tree wing valve	• Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object	• Hydrocarbon well fluid release to sea • Gas migration to sea surface (low concentration due to water depth) • Oil spill and marine pollution over a significant distance	2	5	U	• Inspection, testing and maintenance of subsea production infrastructure • Use of corrosion inhibitors • Subsea paint coating • Wellheads remote from FPSO with no lifting over live wellheads	• Water depths result in low flammable gas concentrations at the surface (<<LFL) • Pressure monitoring of production and gas flowlines from wellheads • Isolation of the well downhole at the surface controlled sub-surface safety valve (SCSSV) • Oil spill contingency plans	1	5	S	R	D-01
H-01.06.04	Well fluid release from subsea wells Xmas trees – outboard of the tree wing valve	• Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object	• Hydrocarbon well fluid release to sea • Gas migration to sea surface (low concentration due to water depth) • Oil spill and marine pollution over a significant distance	2	5	U	• Inspection, testing and maintenance of subsea production infrastructure • Corrosion resistant alloy cladding • Use of corrosion inhibitors • Cathodic protection • Subsea paint coating • Wellheads remote from FPSO with no lifting over live wellheads	• Water depths result in low flammable gas concentrations at the surface (<<LFL) • Isolation of the well and shutdown of flow at the tree wing valve or downhole at the surface controlled subsurface safety valve (SCSSV) • Oil spill contingency plans	1	3	A	S	

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.06.05	Well fluid release from subsea wells flowlines to manifolds	• Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object • Flowline expansion	• Hydrocarbon well fluid release to sea • Gas migration to sea surface (low concentration due to water depth) • Oil spill and marine pollution over a significant distance	2	5	U	• Inspection, testing and maintenance of subsea production infrastructure • Material selection (NACE compliant carbon steel) • Use of corrosion inhibitors • Cathodic protection • Subsea paint coating • Well flowlines to manifolds remote from FPSO with no lifting over live well flowlines	• Water depths result in low flammable gas concentrations at the surface (<<LFL) • Isolation of the well and shutdown of flow at the tree wing valve or downhole at the surface controlled subsurface safety valve (SCSSV) • Oil spill contingency plans	1	3	A	S	
H-01.06.06	Well fluid release from manifolds	• Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object	• Hydrocarbon well fluid release to sea • Gas migration to sea surface (low concentration due to water depth) • Oil spill and marine pollution over a significant distance	2	5	U	• Inspection, testing and maintenance of subsea production infrastructure • Corrosion resistant alloy cladding • Use of corrosion inhibitors • Cathodic protection • Subsea paint coating • Manifolds remote from FPSO with no lifting over live manifolds	• Water depths result in low flammable gas concentrations at the surface (<<LFL) • Isolation of the well and shutdown of flow at the tree wing valve or downhole at the surface controlled subsurface safety valve (SCSSV) • Oil spill contingency plans	1	3	A	S	
H-01.06.07	Well fluid release from flowline from DC-3 to DC-1	• Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object • Flowline expansion	• Hydrocarbon well fluid release to sea • Gas migration to sea surface (low concentration due to water depth) • Oil spill and marine pollution over a significant distance	2	5	U	• Inspection, testing and maintenance of subsea production infrastructure • Riser and pipeline integrity management plans • Material selection (NACE compliant carbon steel) • Use of corrosion inhibitors • Cathodic protection • Subsea paint coating • Well flowlines from DC-3 to DC-1 remote from FPSO with no lifting over live flowlines	• Water depths result in low flammable gas concentrations at the surface (<<LFL) • Isolation of the well and shutdown of flow at the tree wing valve or downhole at the surface controlled subsurface safety valve (SCSSV) • Oil spill contingency plans	1	3	A	S	
H-01.06.08	Well fluid release from flowline from DC-1 to PLEM	• Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object • Flowline expansion • Over-pressurisation	• Hydrocarbon well fluid release to sea • Gas migration to sea surface (low concentration due to water depth) • Oil spill and marine pollution over a significant distance	2	5	U	• Inspection, testing and maintenance of subsea production infrastructure • Riser and pipeline integrity management plans • Material selection (NACE compliant carbon steel) • Use of corrosion inhibitors • Cathodic protection • Subsea paint coating • HIPPS	• Water depths result in low flammable gas concentrations at the surface (<<LFL) • Isolation of the well and shutdown of flow at the tree wing valve or downhole at the surface controlled subsurface safety valve (SCSSV) • Oil spill contingency plans	1	3	A	S	
H-01.06.09	Well fluid release from or near the PLEM	• Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object • Fishing vessel trawling • Over-pressurisation	• Hydrocarbon well fluid release to sea • Gas migration to sea surface (possible flammable concentration at the surface as nominal water depth 120m at the FPSO) • Flammable gas can disperse towards FPSO and create a flash-fire that could cause severe or fatal injuries (less than 3) to personnel exposed	2	4	S	• Inspection, testing and maintenance of pipelines including periodic pigging • Riser and pipeline integrity management plans • Cathodic protection • Lifting restrictions over pipelines • Over trawl protection on pipeline to nominal water depth of 800 meters	• PLEM and production pipeline remote from FPSO • Over trawl protection protects from impacts and large releases • Isolation of the well and shutdown of flow at the tree wing valve or downhole at the surface controlled subsurface safety valve (SCSSV) • Control of FPSO ignition sources through hazardous area classifications (ATEX compliant)	1	3	A	S	

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
			• Oil spill and marine pollution					• Oil spill contingency plans					
H-01.06.10	Well fluid release from production riser to FPSO	• Vessel collision • Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object • Fishing vessel trawling • Over-pressurisation	• Hydrocarbon well fluid release to sea • Oil spill and marine pollution • Gas migration to sea surface • Flammable gas release at or above sea surface, explosion, and / or jet fire that could cause severe or fatal injuries (more than 3) to personnel exposed • Long duration event with potential for escalation, depending upon size of the release and riser / pipeline inventory	2	5	U	• Inspection, testing and maintenance of subsea production infrastructure • Riser and pipeline integrity management plans • Use of corrosion inhibitors • Cathodic protection • Lifting restrictions over pipelines • Exclusion zone around the near shore hub and FPSO • Risers located away from areas where vessel operations take place • Riser guards and impact protection	• FPSO Subsea Isolation Valve (SSIV) on the PLEM isolates flow from the import pipelines • Risers located amidships and remote from the TR with significant separation • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances) • Oil spill contingency plan	1	5	S	R	F-01
H-01.06.11	Gas (including well fluid) release from FPSO inlet header or slug catcher tops (95 barg, 0ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Gas explosion and/or jet fire that could cause severe or fatal injuries (more than 3) to personnel exposed	2	5	U	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Isolation / emergency shutdown of flow (at the wellhead for import risers) • FPSO Subsea Isolation Valves (SSIV) – requirements for SSIVs will be determined as part of engineering design • Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection with associated alarms • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	F-03

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.05.01	Flammable Liquid release from FPSO slug catcher bottoms or heat exchanger (2 x 50%) (90 barg)	• Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Pool fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Prior to stabilisation, there will may be some vapour generation, with risk of explosion (refer to H-01.06.11)	2	4	S	• Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Oil spill contingency plans • Fire and gas detection with associated alarms • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	S	F-04
H-01.06.12	Flammable gas release from FPSO condensate separation medium pressure separator tops (39 barg, 45ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Gas explosion and/or jet fire that could cause severe or fatal injuries (more than 3) to personnel exposed	2	5	U	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection with associated alarms • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	F-10

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.05.02	Flammable liquid release from FPSO condensate separation medium pressure separator bottoms (39 barg, 45ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Pool fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Prior to stabilisation, there will may be some vapour generation, with risk of explosion (refer to H-01.06.12)	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Fire and gas detection with associated alarms • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	S	F-07
H-01.06.13	Flammable Gas release from FPSO condensate separation low pressure separator tops (10 barg, 43ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Gas explosion and/or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection with associated alarms • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	F-10
H-01.05.03	Flammable liquid release from FPSO condensate separation low pressure separator bottoms and/or heater (10 barg, 43ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Pool fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Prior to stabilisation, there will may be some vapour generation, with risk of explosion (refer to H-01.06.13)	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Fire and gas detection with associated alarms • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities	1	4	S	S	F-08

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
								• Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)					
H-01.06.14	Flammable gas release from FPSO condensate stabilization low low pressure separator tops (0.8 barg, 74ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Gas release or flash-fire could cause severe or fatal injuries (3 or less) to personnel exposed	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Low pressure system (0.8 bar) • Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection with associated alarms • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	3	A	R	
H-01.05.04	Condensate release from FPSO condensate stabilization low low pressure separator bottoms and / or heater (0.8 barg, 74ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Pool fire that could cause severe or fatal injuries (3 or less) to personnel exposed	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Low pressure system (0.8 bar) • Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Fire and gas detection with associated alarms • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	S	F-09

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.05.05	Condensate release from FPSO condensate stabilization recycle pump (10 barg, 40ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Spreading pool fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Condensate spill to the sea	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Low pressure system (0.8 bar) once pumps shutdown • Pump used infrequently • Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Fire and gas detection with associated alarms • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	3	A	S	
H-01.07.01	Condensate release from FPSO coaming or drip pan overflow	• Condensate spill exceeds drip pan capacity • Vessel motions • Deluge overflows drip pan following activation	• Small spreading pool fire • Small condensate spill on the sea	2	3	S	• Maintenance procedures • Drain tanks	• Spill would occur from a manual operation which would be quickly detected • Spill clean-up equipment onboard	1	2	A	S	
H-01.07.02	Condensate release from FPSO storage tank	• Overfilling of cargo tanks • Operator error • Hull structural failure • Vessel collision (passing, attendant, offtake tanker)	• Sea surface pool fire (sustained fire on the sea surface is considered unlikely) • Oil spill and marine pollution over a significant distance if large spill	2	5	U	• Training and competence of personnel • Cargo tank level detection and alarms • Deck coaming prevents condensate spilling overboard • Exclusion zone around the FPSO • Double hull • Marine operating procedures for attendant vessels and offtake tankers • Facility location clearly identified on marine navigation charts • Navigation aids	• Lighter condensate may wither quickly reducing potential environmental impact • Oil spill contingency plans	1	5	S	M/S	F-13
H-01.07.03	FPSO condensate storage tank fire	• Failure of the inert gas system • Air ingress to tanks • Improper tank entry • Long duration jet fire impinging on tank tops	• Explosion and / or fire in the tank that could cause severe or fatal injuries (more than 3) to personnel exposed • Damage to tanks and hull • Sea surface pool fire • Oil spill and marine pollution over a significant distance	2	5	U	• Training and competence of crew • Inspection, testing and maintenance of tank inert gas system • Monitoring of inert gas composition • Infrequent tank entry • Confined space entry procedures • Fire detection, isolation and blowdown limit impinging jet fire duration	• Active fire protection systems (e.g., firewater and foam) • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind	1	5	S	R	F-14

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR L	Initial RR S	Initial RR R	Prevention	Control and Mitigation	Final RR L	Final RR S	Final RR R	Kinetic	MAE No.
								• TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)					
H-01.07.04	FPSO cargo vapour in the ballast tanks	• Corrosion of adjacent bulkheads • Ship collision	• Fire or explosion in ballast tank / storage tanks • Potential extensive damage to ballast or cargo tanks • Condensate release resulting in Sea surface pool fire (sustained fire on the sea surface is unlikely) • Oil spill and marine pollution over a significant distance if large spill	2	5	U	• Tank integrity and coatings • Tank inspections and maintenance • Gas monitoring of ballast tanks with gas detection and alarm on HLL	• Active fire protection systems (e.g., firewater and foam) • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster areas and the alternate safe muster areas • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	5	S	R	F-14
H-01.07.05	FPSO cargo tanks are over / under pressurized	• Malfunction of pressure relief valve at tank tops • Blocked cargo tank vent • Inert gas system failure • Operator error	• Rupture of cargo tank • Tank fire • Potential extensive damage to vessel structure • Condensate release resulting in Sea surface pool fire (sustained fire on the sea surface is unlikely) • Oil spill and marine pollution over a significant distance if large spill	2	5	U	• Pressure indication and monitoring for each cargo tank • Inspection, testing and maintenance of tank inert gas system and associated pressure relief systems • Pressure relief valves on each tank	• TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances) • Lighter condensate may wither quickly reducing potential environmental impact • Oil spill contingency plans	1	5	S	M	F-13 F-14
H-01.07.06	FPSO tank vent releases gas during low wind conditions	• Excessive tank vapours	• Tank vents routed to the flare boom by design, so no hazardous consequence	2	1	A							
H-01.07.07	Lightning strikes FPSO tank vent	• Adverse weather	• Tank vents routed to the flare boom by design, so no hazardous consequence	1	1	A							
H-01.07.08	FLNG / LNGC tank vent releases gas during low wind conditions	• Excessive tank vapours • LNGC arrives 'warm'	• LNGC boil off gas sent to FLNG	2	1	A							
H-01.07.09	Lightning strikes FLNG / LNGC tank vent	• Adverse weather	• Small diffuse fire from vent	1	1	A							
H-01.06.15	Gas ingress into FPSO safe areas (e.g. living quarters, electrical rooms etc.)	• Process gas or LNG release • Delay in detection or shutdown	• Gas accumulation resulting in explosion • Explosion that could cause severe or fatal injuries (more than 3) to personnel exposed	2	5	U	• Gas detection on HVAC intakes • ESD and closure of HVAC dampers • HVAC maintains positive pressure in space • Internal recirculation of air in the accommodation	• FPSO accommodation is upwind of prevailing wind • Process gas detection and shutdown with depressurisation • Methane is usually lighter than air and would disperse quickly • Evacuation of TR prior to build of flammable above LFL	1	3	A	R / M	
H-01.06.16	Gas ingress into FLNG and QU safe areas (e.g. living quarters, FLNG control room, electrical rooms etc.)	• Large LNG release (e.g. FLNG or LNGC tank failure) • Delay in detection or shutdown	• Gas accumulation resulting in explosion • Explosion that could cause severe or fatal injuries (more than 3) to personnel exposed	2	5	U	• Gas detection on HVAC intakes • ESD and closure of HVAC dampers • HVAC maintains positive pressure in space • Internal recirculation of air in the accommodation	• QU platform remote from process • Process gas detection and shutdown with depressurisation • Evacuation of TR prior to build of flammable above LFL	1	5	S	S	N-17

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.05.06	Condensate release from FPSO condensate metering	• Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Spreading pool fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Condensate spill on the sea	2	4	S	• Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Infrequent offloads (3-4 per year) • Initial transfer rate is kept low while system is inspected for leaks • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Fire and gas detection systems • Offloading emergency shutdown systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Oil spill contingency plans	1	3	A	S	
H-01.05.07	Condensate release from FPSO condensate loading hose	• Hose coupling failure • Hose failure from high tension, overpressure or flange leak • Incorrect hose makeup • Shuttle tanker inadequately maintained	• Condensate spill to sea • Sea surface pool fire (sustained fire on the sea surface is considered very unlikely)	2	4	S	• Training and competence of crew • Safe offloading procedures • Pressure testing of hose and transfer equipment	• Infrequent offloads (3-4 per year) • Initial transfer rate is kept low while system is inspected for leaks • Dry release coupling limits quantity of condensate spilt • Oil spill contingency plans	1	3	A	S	
H-01.06.17	Gas release from FPSO flash gas compression (LP flash gas scrubber, compressor, MP flash gas scrubber, compressor)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion and/or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	F-10
H-01.06.18	Gas release from FPSO fuel gas system	• Mechanical failure (e.g., corrosion, erosion, flange failure, weld defect) on HP Fuel Gas System	• Explosion and/or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage • Impairment of escape route to QU Platform	2	4	S	• Inspection, testing and maintenance of equipment	• Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area	1	4	S	R	F-11

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
								• FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)					
H-01.05.08	Condensate release from FPSO expander scrubber bottoms	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Pool fire that could cause severe or fatal injuries (3 or less) to personnel exposed	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Fire and gas detection systems • Process emergency shutdown and blowdown to minimize released inventory • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	S	F-06
H-01.06.19	Gas release from gas treatment (expander scrubber inlet cooler, expander scrubber tops, turbo expander (81 barg, -2.8ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion and/or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances	1	4	S	R	F-05

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.06.20	Gas release from low temperature separator (75 barg, -13ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion and/or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances	1	4	S	R	F-05
H-01.06.21	Gas release from export gas metering packages (78 barg, -4.3ºC)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	F-05
H-01.06.22	Gas release from export gas risers from FPSO (x2)	• Vessel collision • Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object	• Gas migration to sea surface • Gas release most likely in the splash zone with, explosion, and / or jet fire that could cause severe or fatal injuries (more than 3) to personnel exposed • Long duration event with potential for escalation, depending upon size of the release and riser / pipeline inventory	2	5	U	• Inspection, testing and maintenance of subsea production infrastructure • Riser and pipeline integrity management plans • Use of corrosion inhibitors • Cathodic protection • Lifting restrictions over pipelines • Exclusion zone around the near shore hub and FPSO • Risers located away from areas where vessel operations take place • Riser guards and impact protection	• FPSO Subsea Isolation Valve (SSIV) on the PLEM isolates flow from the export gas pipeline • Risers located amidships and remote from the TR with significant separation • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind	1	5	S	R	F-02

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR L	Initial RR S	Initial RR R	Prevention	Control and Mitigation	Final RR L	Final RR S	Final RR R	Kinetic	MAE No.
								• TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)					
H-01.06.23	Gas release from gas pipeline (far shore PLEM to A1 riser platform)	• Mechanical failure (e.g., corrosion, erosion, weld defect) • Dropped object • Fishing vessel trawling • Flowline expansion	• Hydrocarbon gas release to sea and marine pollution • Gas migration to sea surface (possible flammable concentration at the surface as nominal water depth 120m at the FPSO) • Flammable gas can disperse towards FPSO and create a flash-fire that could cause severe or fatal injuries (less than 3) to personnel exposed	2	4	S	• Inspection, testing and maintenance of pipelines including periodic pigging • Riser and pipeline integrity management plans • Cathodic protection • Lifting restrictions over pipelines • Over trawl protection on pipeline to nominal water depth of 800 meters	• PLEM and export gas pipeline remote from FPSO • Over trawl protection protects from impacts and large releases • Shutdown of flow at the PLEM SSIV and FPSO • Control of FPSO ignition sources through hazardous area classifications (ATEX compliant)	1	3	A	S	
H-01.06.24	Gas release from gas pipeline (near shore hub)	• Mechanical failure (e.g., corrosion, erosion) • Dropped object • Fishing vessel trawling • Flowline expansion • Dragged anchor	• Hydrocarbon gas release to sea • Gas migration to sea surface (gas concentration at surface may be high given the shallow water depth) • Flammable gas can disperse towards FLNG and create a flash-fire that could cause severe or fatal injuries (less than 3) to personnel exposed	2	4	S	• Inspection, testing and maintenance of pipelines including periodic pigging • Riser and pipeline integrity management plans • Cathodic protection • Lifting restrictions over pipelines • Exclusion zone around the near shore hub • Over trawl protection on pipeline to nominal water depth of 800 meters • Dragged anchor and impact protection on pipeline at the A1 riser platform	• A1 riser platform import gas pipeline remote from FLNG and QU platform • Over trawl, dropped object and dragged anchor protection protects from impacts and large releases • Shutdown of flow at the PLEM SSIV, FPSO and A1 riser platform	1	3	A	M	
H-01.06.25	Gas release from near shore hub riser (A1 riser platform)	• Vessel collision • Dropped object • Mechanical failure (e.g., corrosion, erosion, fatigue, weld defect)	• Gas release, explosion, and / or jet fire that could cause severe or fatal injuries (more than 3) to personnel exposed • Long duration event with potential for significant damages to the riser platform, depending upon size of the release and riser / pipeline inventory	2	5	U	• Inspection, testing and maintenance of risers and support structures • Riser and pipeline integrity management plans • Cathodic protection • Lifting restrictions over pipelines • Exclusion zone around the near shore hub • Risers located away from areas where vessel operations take place • Riser guards and impact protection	• Shutdown of flow at the FPSO and at riser platform • A1 Riser platform remote from other facilities and process • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the safe muster area on the A1 Riser Platform or to the TR / safe muster area on QU platform • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	5	S	R	N-01
H-01.06.26	Gas release from piping / flexible hose between A1 riser platform and FLNG	• Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect)	• Jet fire could cause severe or fatal injuries (more than 3) to personnel exposed	2	5	U	• Inspection, testing and maintenance of piping and flexible hose • Dry gas – limited potential for corrosion	• Not normally manned area • Process emergency shutdown with limited inventory between isolation on A1 riser platform and FLNG • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the	1	4	S	R	N-02

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
								alternate safe muster area on the A1 Riser Platform • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)					
H-01.06.27	Gas release from FLNG gas metering or HP separator	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion or jet fire that could cause severe or fatal injuries (more than 3) to personnel exposed • Equipment damage	2	5	U	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	N-04
H-01.05.09	Liquid release from FLNG HP separator	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Small vessel inventory resulting in small fire with potential minor impact on personnel	2	3	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Bunding and drainage to contain liquid spill • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas	1	3	A	S	
H-01.06.28	Gas release from FLNG gas filter, contactor feed exchanger or amine contactor	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	N-04

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.06.29	Gas release from FLNG mol sieve inlet scrubber, filter, dehydrator or HG removal vessel	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	N-05
H-01.06.30	Flammable gas release from FLNG fractionation	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Flammable gas explosion and/or jet fire that could cause numerous severe or fatal injuries (more than 3) to personnel exposed	2	5	U	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	N-08
H-01.03.01	Light Hydrocarbon Liquid (LPGs) Releases from FLNG fractionation	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Release of light hydrocarbons (LPGs) that will flash rapidly and generate a flammable gas release and eventually an evaporating liquid pool • Flammable gas explosion and/or jet fire that could cause numerous severe or fatal injuries (more than 3) to personnel exposed	2	5	U	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Limited inventory fractionating column • Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain smaller liquid spill • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the	1	4	S	R	N-09

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
								alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)					
H-01.04.01	LNG release from FLNG liquefaction train	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion and / or pool fire that could cause severe or fatal injuries (more than 3) to personnel exposed • Embrittlement and cracking / failure of metal structure, hull or deck plating that LNG contacts • Equipment damage	2	5	U	• Material selection for cryogenic service • Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain smaller liquid spill • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	N-10
H-01.04.02	LNG release from FLNG expander, LNG flash drum or transfer pump	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion and / or pool fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Embrittlement and cracking / failure of metal structure, hull or deck plating that LNG contacts • Equipment damage	2	4	S	• Material selection for cryogenic service • Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain smaller liquid spill • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	N-11

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-01.03.02.1	LNG refrigerant (LPG) release from drum, compressors or exchangers - Gas	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation • Dropped tank during transfer to refill refrigerant	• Severe explosion (potential for detonation with ethylene) and/or jet fire that could cause severe or fatal injuries (more than 3) to personnel exposed • Overpressure effects covering a significant distance	2	5	U	• Material selection for cryogenic service • Training and competence of personnel • Equipment start-up procedure • Material selection for cryogenic service • Inspection, testing and maintenance of equipment • Managed lifts • Lifted tanks provided with protection in case of impact • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	5	S	R	N-13
H-01.03.02.2	LNG refrigerant (LPG) release from drum, compressors or exchangers – Liquid / Two Phase	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation • Dropped tank during transfer to refill refrigerant	• Severe explosion (potential for detonation with ethylene) and/or jet fire that could cause severe or fatal injuries (more than 3) to personnel exposed • Overpressure effects covering a significant distance • Embrittlement and cracking / failure of metal structure, hull or deck plating	2	5	U	• Material selection for cryogenic service • Training and competence of personnel • Equipment start-up procedure • Material selection for cryogenic service • Inspection, testing and maintenance of equipment • Managed lifts • Lifted tanks provided with protection in case of impact • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain smaller liquid spill • Fire and gas detection systems • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	5	S	R	N-14
H-01.03.03	Boiling liquid expanding vapour explosion (BLEVE) from the vessel containing liquefied gas (LPG)	Hot BLEVE • Long duration jet fire impinging on refrigerant vessel	• Explosive vaporisation that could generate overpressure blast waves and projection of solid materials • Ascending fireball that could cause severe or fatal injuries (more than 3) to personnel exposed Material damage	2	5	U	• Pressure relief system • Fire and gas detection systems • FLNG cooling system with firewater • Support / supply vessels equipped with firefighting facilities to cool down impinged vessel	• Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	M	N-12

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
		Cold BLEVE • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation • Dropped tote tank containing LPG during transfer to refill refrigerant	• Explosive vaporisation that could generate overpressure blast waves and projection of solid materials • Flash fire or explosion that could cause severe or fatal injuries (more than 3) to personnel exposed • Material damage	2	5	U	• Inspection, testing and maintenance of equipment • Managed lifts • Training and competence of personnel • Lifted tanks provided with protection in case of impact • Pressure relief system	• Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • FLNG cooling system with firewater • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	N-12
H-01.03.04	Refrigerant Release (LPG) from FLNG Refrigerant Storage (Make-up Ethylene, Propane, & Iso-pentane)	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation • Dropped tote tank containing LPG during transfer to refill refrigerant	• Severe explosion (potential for detonation with ethylene) and/or jet fire that could cause severe or fatal injuries (more than 3) to personnel exposed • Overpressure effects covering a significant distance • Embrittlement and cracking / failure of metal structure, hull or deck plating	2	5	U	• Material selection for cryogenic service • Training and competence of personnel • Equipment start-up procedure • Material selection for cryogenic service • Inspection, testing and maintenance of equipment • Managed lifts • Lifted tanks provided with protection in case of impact • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain smaller liquid spill • Fire and gas detection systems • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	5	S	R	N-15
H-01.04.03	LNG release from storage tank (FLNG or LNGC)	• Collision of LNGC with near shore hub facilities (e.g., berth) • Rollover (rapid release of LNG vapours from the storage tank due to stratification • Sloshing	• Damage to tanks • Pool or flash fire that might cause severe or fatal injuries (more than 3) to the personnel exposed • Dispersion of flammable gas at significant distances • Embrittlement and cracking / failure of metal structure, hull or deck plating that LNG contacts • Tank overpressuring venting • Rapid vapour expansion and overpressure if spill on water	2	5	U	• Training and competence of personnel • Tugs used to manoeuvre LNGC during berthing (managed low speed operation) • Moss type LNG storage tanks not prone to high sloshing effects • Rollover unlikely since LNG has consistent density • FLNG on opposite side of berth, protected by the trestle structure • QU platform remote from berth • LNG transfer procedures • Tank venting • Double hull FLNG and LNGC	• LNG readily evaporates and disperses • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances) • Emergency response plans	1	5	S	M	N-17
H-01.04.04	LNG release during transfer from FLNG to LNGC (loading arm)	• Mechanical failure (e.g., corrosion, flange failure, weld defect) • Operator error during transfer	• Pool fire and/or flash fire that might cause severe or fatal injuries (3 or less) to the personnel exposed	2	4	S	• Material selection for cryogenic service • Inspection, testing and maintenance of equipment • LNG transfer procedures	• LNG readily evaporates and disperses • Loading arm emergency disconnect system	1	4	S	R	N-18

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR L	Initial RR S	Initial RR R	Prevention	Control and Mitigation	Final RR L	Final RR S	Final RR R	Kinetic	MAE No.
			• Embrittlement and cracking / failure of metal structure, hull or deck plating that LNG contacts • Rapid vapour expansion and overpressure if spill on water				• Training and competence of personnel	• Limited quantity of LNG spilt from loading arm disconnect (estimated at approximately 83m^3) • Containment areas / bunding to contain spill • Gas detection and emergency shutdown • Transfer operation monitored by CCTV • Restricted access to transfer area					
H-01.06.31	Gas release from BOG/flash gas compression or exchangers	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Explosion or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Pressure relief system	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	N-06
H-01.06.32	Low pressure gas release (methane return) during transfer from FLNG to LNGC	• Mechanical failure (e.g., corrosion, flange failure, weld defect) • Operator error during transfer	• Low pressure gas release and localised fire that might cause severe injuries to the personnel exposed	2	3	S	• Inspection, testing and maintenance of equipment • LNG transfer procedures • Training and competence of personnel	• Gas detection and emergency shutdown	1	2	A	M	
H-02.03.01	Diesel fuel spill during transfer to / from supply vessel (bulk transfer and / or refuelling)	• Rupture / breakage of the transfer hose • Operator error (valves misaligned) • Mechanical failure of storage tank • Overfilling of storage tank	• Spillage of diesel fuel onto the sea surface • Marine pollution, depending on the flow rate and the duration of the discharge	2	3	S	• Training and competence of crew • Procedures and checks for the transfer of diesel fuel • Inspection, testing and maintenance of equipment • Dry break couplings on hoses • Tank-filling always monitored	• Manned operation with visual detection of any leak • Emergency shutdown (ESD) of diesel pumps and diesel supply • Clean up equipment for small spills • Oil spill contingency plans	2	2	A	S	
H-02.03.02	Diesel / oil fire in an engine room or machinery space	• Overheated equipment, and/or bearing failures • Explosions of a crankcase • Electrical failures • Leakage of ignited diesel / oil • Oil soaked lagging • Fuel gas release	• Heat and toxic fumes in the room or space • Possible escalation if not controlled • Fire that might cause severe or fatal injuries (3 or less) to the personnel exposed	2	4	S	• Inspection, testing and maintenance of equipment • Good housekeeping (e.g. clean up oil / diesel, replace lagging soaked in oil)	• Smoke, gas, and fire detectors in the engine rooms and machinery spaces, with associated alarms • Fire extinguishing systems to flood engine room and machinery spaces to extinguish fire • Fire rated engine room and machinery space bulkheads • Engine shutdown in case of an emergency, and fuel isolation to help limit fuel to feed the fire • Rapid response by the firefighting team with firefighting resources present on board	1	3	A	S	

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-02.03.03	Diesel release from NSH Support Vessel or Storage	• Mechanical failure of storage tank • Mechanical failure of diesel transfer pump • Collision of support vessel and rupture of hull storage tanks	• Spillage of diesel fuel onto the sea surface • Marine pollution, depending on the flow rate and the duration of the discharge	3	3	S	• Implementation of the provisions of the 1972 Convention on International Regulations for Preventing Collisions at Sea • Training and competence of crew • Inspection, testing and maintenance of equipment	• Bunding and drainage to contain smaller liquid spill from storage tank • Emergency shutdown to isolate flow from tank • Marine operating procedures in NSH area limit vessel speeds and therefore the potential for significant / high speed impacts and hull damage • Clean up equipment for small spills • Oil spill contingency plans • Limited inventory on QU platform (400m^3) or in support vessel	1	3	A	M	N-19
			• Large diesel fire on QU platform • Possible escalation and impact on QU accommodation if not controlled • Fire that might cause severe or fatal injuries (3 or less) to the personnel exposed	2	4	S	• Inspection, testing and maintenance of equipment	• Diesel high flash point liquid and difficult to ignite (tank storage at ambient atmospheric conditions) • Bunding and drainage to contain smaller liquid spill from storage tank • Smoke and fire detectors with associated alarms • Emergency shutdown to isolate flow from tank • Accommodation / TR designed for anticiapted fire loads • Smoke detection on QU accommodation HVAC intakes with shutdoen to prevent smoke ingress • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	3	A	S	
H-01.06.33	Fuel gas in QU platform utility space / area	• Mechanical failure (e.g., corrosion, erosion, flange failure, weld defect)	• Possible significant gas accumulation and explosion if confined space • Explosion and / or fire that might cause severe or fatal injuries (3 or less) to the personnel exposed	2	5	U	• Inspection, testing and maintenance of equipment	• Low pressure system with limited inventory that could be released following shutdown • Process emergency shutdown and blowdown to minimize released inventory • Accommodation / TR designed for anticiapted explosion loads • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	2	4	S	M	N-16
H-01.06.34	Fuel Gas Release from NSH Trestle Fuel Gas Flowline to QU Platform	• Mechanical failure (e.g., corrosion, erosion, flange failure, weld defect)	• Explosion and/or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage • Impairment of escape route to QU Platform	2	4	S	• Inspection, testing and maintenance of equipment	• Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the	1	4	S	R	N-03

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
								alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)					
H-01.06.35	Fuel Gas Release from FLNG Fuel Gas System	• Mechanical failure (e.g., corrosion, erosion, flange failure, weld defect) on HP Fuel Gas System	• Explosion and/or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Equipment damage • Impairment of escape route to QU Platform	2	4	S	• Inspection, testing and maintenance of equipment	• Process emergency shutdown and blowdown to minimize released inventory • Control of ignition sources through hazardous area classifications (ATEX compliant) • Fire and gas detection systems	1	4	S	R	N-07
		• Mechanical failure (e.g., corrosion, erosion, flange failure, weld defect) on LP Fuel Gas System	• Explosion and/or jet fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Limited Equipment damage	2	4	S		• Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area on QU platform or the alternate safe muster area on the A1 Riser Platform • QU platform remote from process • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	3	A	R	
H-02.04.01	Fire at or near the helicopter refuelling facilities	• Mechanical failure (e.g., corrosion, erosion, flange failure, weld defect) • Ignition from hot surface (e.g., helicopter engine); hot work; static	• Fire that might cause severe or fatal injuries to the personnel exposed	2	4	S	• Inspection, testing and maintenance of equipment • Grounding of the helicopter during refuelling • No hot work during refuelling • Safe helicopter refuelling procedures • Training and competency of crew	• The helideck is not occupied during refuelling • ESD stop button for the fuel pump isolate fuel supply and shuts down the pump • Heli-fuel is stored remote from the helideck • The helicopter fuel (helifuel) storage unit is protected by a firefighting device that releases an AFFF (aqueous film-forming foam) • Foam monitors at helideck	1	3	A	M	
H-03.00.01	Fire in the chemical storage areas	• Poor storage conditions • Ignition from cigarette butt, - hot work, electrical fault	• Fire and toxic smoke that might cause severe or fatal injuries (3 or less) to the personnel exposed	2	4	S	• Training and competence of crew • Smoking restricted to designated safe areas only • Good housekeeping • "Permit to work" required for all hot work including fire watch with immediate access to fire extinguishing medium • An "authorization prior to work" system for tasks that generate heat and that must be performed near flammable products	• Fire or Smoke detection in chemical storage area • Fire rated storage to prevent fire / smoke spreading • Rapid response by the firefighting team present on board • Firefighting resources (including portable fire extinguishers, fire hydrants, and connecting hoses that make it possible to reach any part of the drillship, FPSO, FLNG)	1	3	A	M	

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-03.00.02	Fire in the accommodation space	• Overheated cooking oil • Lint build up in laundry dryers • Electrical failures • Cigarette or candle	• Fire and toxic smoke that might cause severe or fatal injuries (3 or less) to the personnel exposed	2	4	S	• Training and competence of crew • Smoking restricted to designated safe areas only • Good housekeeping • Regular cleaning and inspections, • Accommodation units, including fixtures and furnishings constructed with non-flammable materials	• Smoke detection in all areas of the accommodations • Fire rated bulkheads to prevent fire / smoke spreading • Accommodation materials fire retardant (e.g. bedding, furniture etc.) • Personal address system, announcements and alarms to direct personnel • Multiple unobstructed and clearly marked evacuation routes allowing the occupants to be directed to a safe muster point • Sprinklers and portable fire extinguishers in the accommodation spaces	1	3	A	M	
H-03.00.03	Flammable chemical injection release on the FPSO	• Equipment start-up • Mechanical failure (e.g., corrosion, erosion, fatigue, flange failure, weld defect) • Dropped object or swinging load • Over-pressurisation	• Fire that could cause severe or fatal injuries (3 or less) to personnel exposed • Potential for flammable vapour cloud due to atomised droplets • Chemical Injection spill to the sea	2	4	S	• Equipment start-up procedure • Inspection, testing and maintenance of equipment • Restrictions on lifting over or near live equipment • Protection where impacts may be possible (e.g. near laydown areas) • Emergency relief and depressuring systems	• Control of ignition sources through hazardous area classifications (ATEX compliant) • Bunding and drainage to contain liquid spill • Fire and gas detection systems • Active and passive fire protection systems (e.g., deluge) covering process areas • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster areas • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances)	1	4	S	R	F-12
H-03.01.01	Ignition of cellulosic materials	• Electrical fault • Poor housekeeping	• Fire with a potential for personnel injury • Impairment of escape routes	3	3	S	• Housekeeping procedures	• Smoke detection systems • Portable fire extinguishers • Multiple escape routes with signage and emergency lighting	2	3	S	M	
H-04.03.01	Accidental discharge of explosives on board the drillship	• Fire in the area where explosives are stored • Criminal act or suicide	• Explosion of the inventory on board the drillship • Potential serious injury / fatality (3 or less) to exposed persons • Physical damage to the interior of the vessel, potentially affecting the vessel's stability	2	4	S	• Use of third party specialist for all operations involving explosives • Explosives loaded onto the drillship only as needed • Explosives stored in steel containers that can be jettisoned in the event of a fire on board • Explosives and detonators completely separated • No storage of flammable products near the explosives • All operations involving the use of explosives are governed strictly by procedures specified by the drilling company		1	3	A	R	
H-05.02.01	Water in gas export riser	• Initial start-up following installation	• Potential to send water downstream	3	2	S	• Installation and commissioning procedures • Start-up procedures	• Pigging operations for water removal	2	2	A	R	

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-05.07.01	Plugged production flowline	• Sand or wax build-up • Hydrate formation • Stuck pig	• Loss of containment • Hydrocarbon release to sea with significant hydrocarbon impact • Gas migration to sea surface	2	5	U	• System rated for full shut-in pressure • Pigging operational procedures	• Isolation of the well and shutdown of flow at the tree wing valve or downhole at the surface controlled subsurface safety valve (SCSSV) • Oil spill contingency plans	1	1	A	M / S	
H-06.03.01	Dropped object from drillship with impact damage to manifold / production flowline	• Human error • Inadequate securing of load • Excessive weight • Equipment failure	• Hydrocarbon release to sea • Gas migration to sea surface (low concentration due to water depth) • Oil spill and marine pollution over a significant distance • Equipment damage	2	4	S	• Training and competency • Lifting procedures • Lifting restrictions over subsea equipment • Subsea facilities not located near FPSO • SIMOPS plan • Crane ratings and safety lock-outs for excessive weight • Crane maintenance • Lifting equipment inspections	• Water depths result in low flammable gas concentrations at the surface (<<LFL) • Isolation of the well and shutdown of flow at the tree wing valve or downhole at the surface controlled subsurface safety valve (SCSSV) • Oil spill contingency plans	1	3	A	R	
H-07.01.01	High load on FPSO risers	• Excessive sea movements • Mooring failure • Structural failure • Vessel collision	• Damage to riser (production and/or export gas) • Potential hydrocarbon release • Ignited jet fire or plume that might cause severe or fatal injuries (more than 3) to the personnel exposed • Hydrocarbon release to sea	2	5	U	• Riser design for maximum site environmental criteria • Riser inspection and surveys • Redundant mooring lines	• FPSO Subsea Isolation Valve (SSIV) on the PLEM isolates flow from the import and export pipelines • Risers located amidships and remote from the TR with sigificant separation • Support / supply vessels equipped with firefighting facilities • Multiple escape routes leading to the TR / safe muster area and the alternate safe muster area • FPSO accommodation upwind of prevailing wind • TR and evacuation systems (lifeboats, life rafts, and lifesaving appliances) • Oil spill contingency plan	1	5	S	M	F-01 F-02
H-08.00.01	Loss of stability of the drillship	• Failure of, or error during, ballasting • Fire or explosion on board • Severe weather / environmental event • Towing error • Violent collision with another vessel	• Potentially significant loss of stability that could lead to foundering / capsizing of the drillship • Loss of the facility • Multiple fatalities (more than 3)	2	5	U	• Selection and use of a new drillship (2014) built to latest standards minimizes the potential for ballasting failures • A high degree of ballast system redundancy in the design of the drillship • 500m safety perimeter around the drillship to prevent collisions (with the diversion of unauthorized vessels) • Use of a Vessel Management System (VMS) on board the drillship, with the inclusion of a stability program whose purpose is to monitor the vessel's stability conditions • Drillship designed to operate under harsh conditions • Regular structural inspections and monitoring	• Watertight doors / compartments and integrity of the drillship • TR and evacuation systems (lifeboats, life rafts, life vests and lifesaving appliances) • Availability of a search and rescue vessel and helicopter • Presence of supply vessels nearby	1	5	S	S	D-04

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-08.00.02	Loss of stability / foundering of a supply vessel	• Poor weather conditions • Reduced visibility, potentially causing a collision with another vessel • Mechanical failures • Fire on board • Human error or a criminal act	• Sinking of the vessel • Loss of the vessel and of its cargo • Possible loss of the occupants (3 or less) of the vessel	2	4	S	• Weather check before each voyage • Vessels piloted by an experienced crew • Continuous presence of mechanical engineers on board.	• Small number of crew onboard should be able to evacuate quickly and safely • Life saving appliances onboard (communications, life rafts, life vests) • Availability of a search and rescue vessel and helicopter • Presence of support vessels nearby • Emergency response plans	1	3	A	S	
H-08.00.03	Loss of stability of the FPSO	• Cargo tank fire / explosion • Extreme weather • Ship collision • Ballast failure • Fatigue • Corrosion	• Loss of stability / foundering • Potential release of hydrocarbons • Personnel injury or fatality (more than 3)	2	5	U	• Stability modelling and assessments • 30-year operational design life • Operating and loading procedures • Weather forecasting and monitoring • Cargo tank blanketing • Corrosion coatings • Cathodic protection	• TR and evacuation systems (lifeboats, life rafts, life vests and lifesaving appliances) • Availability of a search and rescue vessel and helicopter • Presence of support vessels nearby • Emergency response plans • Oil spill contingency plan	1	5	S	S	F-15
H-08.00.04	Loss of stability of the FLNG	• Extreme weather • Ballast failure • Fatigue • Corrosion	• Loss of stability / foundering • Potential release of hydrocarbons • Personnel injury or fatality (more than 3)	2	5	U	• Stability modelling and assessments • 30-year operational design life • Operating and loading procedures • Weather forecasting and monitoring • Corrosion coatings • Cathodic protection • Protected behind sheltered breakwater	• Evacuation via the hub trestle to the QU platform • Relatively shallow water depth at the Near Shore Hub (should not capsize) • Presence of support vessels nearby • Emergency response plans	1	3	A	S	
H-08.00.05	Structural failure of QU platform	• Extreme weather • Failure of suction bucket foundations • Jacket manufacturing defect	• Potential structural failure of QU platform • Potential damage to bridge link • Injury or fatality to personnel (more than 3)	2	5	U	• Metocean data • Seabed surveys prior to install • Material selection • QU platform located behind sheltered breakwater	• Can escape across bridge link onto trestle and A1 platform if slow collapse • TR and evacuation systems (lifeboats, life rafts, life vests and lifesaving appliances) • Availability of a search and rescue vessel and helicopter • Presence of support vessels nearby • Emergency response plans	1	5	S	S	N-20
H-08.03.01	Helicopter crash	• Poor weather conditions • Reduced visibility, potentially causing a collision with another vessel and/or with offshore facilities • Mechanical failures (e.g. gearbox) • Fire on board • Human error or pilot suicide	• Crash of the aircraft, loss of buoyancy, and sinking • Loss of the aircraft and of its cargo • Likely loss of the occupants (more than 3)	3	5	U	• Weather check before each voyage • Helicopter piloted by an experienced crew (Two pilots) • Safety briefing before each departure • Twin engine helicopters • Safe operating procedures, practices and limits	• Fire extinguishers on board helicopter to smother any fires that may have started • Floatation device on helicopter pontoons in case of ditching at sea • Helicopter equipped with 2 life rafts, each of which can carry all occupants • Self inflating life jackets worn • Availability of a search and rescue vessel and helicopter • Presence of support vessels nearby if crash near offshore facilities • Emergency response plans	1	5	S	R	D-05

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-08.04.01	Fast crew boat founders	• Vessel impact • Captain error • Severe weather • Low visibility • Propulsion failure	• Personnel injury or fatality (more than 3) • Damage or loss of crew vessel • Damage to facility	2	5	U	• Seaworthyness of crew boat • Navigation aids • Training and competency of crew • Weather limitations for transit	• Life saving appliances onboard (communications, life rafts, life vests) • Availability of a search and rescue vessel and helicopter • Presence of support vessels nearby if near offshore facilities • Emergency response plans	1	4	S	M	F-16 N-21
H-08.08.01	Dropped Transfer FROG	• Equipment failure • Failure to follow safe work procedures	• Risk of very serious impact / crushing injury or fatality • Multiple fatalities (more than 3)	3	5	U	• Training, competence and certification of lifting equipment operators, and people involved in lifting operations • Regular inspections and preventive maintenance of lifting and materials / manual handling equipment • Use of certified lifting equipment and slings for man-riding	• FROG buoyancy prevents sinking if drop onto water • Spring and hydraulic damping system, and shock absorbing seats mitigate heavy vertical impacts • Frame and buoyancy panels provide protection against side impacts • Harnesses prevent falling / keep personnel in seat • Crew boat and fast rescue craft to effect recovery from water	1	4	S	R	F-16
H-08.04.02	Passing vessel collision with drillship or FPSO	• Poor weather conditions • Vessel propulsion failure • Reduced visibility • Human error • Proximity to traffic / shipping lanes	• Potentially significant loss of stability (depending on the magnitude of the impact) that could lead to foundering / capsizing of the drillship • Loss of the drillship • Multiple fatalities (more than 3)	2	5	U	• Implementation of the provisions of the 1972 Convention on International Regulations for Preventing Collisions at Sea • 500m safety perimeter around the drillship, FPSO to prevent collisions (with the diversion of unauthorized vessels) • Operations and facilities will be announced, using the appropriate communications channels (e.g, notice to mariners) • Facilities fully illuminated at night and visible from a distance • Drillship and FPSO equipped with radar that includes an automatic radar plotting device	• Selection and use of a new drillship (2014) built to latest standards that can withstand certain impacts • Watertight doors / compartments and integrity of the drillship • TR and evacuation systems (lifeboats, life rafts, life vests and lifesaving appliances) • Availability of a search and rescue vessel and helicopter • Presence of supply vessels nearby • Emergency response plans	1	5	S	M	D-06 F-18
H-08.04.03	Support vessel collision with drillship, FPSO, or NSH facilities	• Human error • Poor weather condition • Loss of dynamic positioning of the support vessel	• Possible damage to the hull of drillship, FPSO, FLNG, Hub Trestle, or PU platform	3	3	S	• Implementation of the provisions of the 1972 Convention on International Regulations for Preventing Collisions at Sea • Approach to facilities by support vessels at very low speed • Training and competence of crew • Approach manoeuvres performed in compliance with specific operational instructions (including safe weather limits) for the piloting of support vessels inside safety perimeters • Support vessels and facilities quipped with fenders that reduce the impact of the collisions	• Selection and use of a new drillship (2014) built to latest standards that can withstand certain impacts • Watertight doors / compartments and integrity of the FPSO and FLNG • FPSO and FLNG double hull design can withstand significant impact	2	2	A	M	
H-08.04.05	Condensate tanker impacts FPSO during offload	• Weather event • High entry speed • Propulsion failure • Human error • Hold back tug error	• Damage to FPSO bow offloading area and / or condensate tanker • Release of condensate to sea (hose failure or impact) • Potential damage to storage tanks	2	5	U	• Hold back tug used by tanker during offloading • Crew training and competence • BP offloading carrier requirements • Offloading operating limits	• Shutdown of transfer pumps onboard the FPSO • Emergency response plans • Oil spill contingency plans	1	5	S	M	F-17

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-08.04.06	LNGC collision at breakwater	• Extreme Weather • Carrier drive-off • Captain error • Tug boat loss of power or error	• Potential damage to LNG berth area / loading arms / FLNG • Potential release of LNG during transfer • Damage to LNGC / grounding	3	5	U	• LNGC entry and transfer procedures including use of tugs to control berthing at slow speed • Crew training and competence • BP LNGC carrier requirements • Docking aids	• Berthing instrumentation and monitoring • Emergency response plans	1	5	S	M	N-22
H-09.01.01	Extreme weather event occurs	• Location environment	• Facility motion • Operations cease • Potential loss of containment due to fatigue • Inability to offload from FPSO	2	3	S	• Operations weather limitation • Weather forecasting and monitoring		2	2	A	S	
H-07.01.02	Mooring system failure	• Seismic activity • Scouring • Severe weather • Vessel collision	• Loss of FPSO station keeping • Potential loss of containment from riser damage (production and/or export gas) • Loss/damage to mooring line • Foundering of the FPSO	2	5	U	• Redundancies built into the design of the FPSO mooring system • Design for anticipated enveionmental loads • Design incorporates scouring potential • ROV inspection for scouring	• Mooring line tension monitoring system • Oil spill contingency plans	1	5	S	M	F-01 F-02 F-14 F-15
		• Severe weather • Large LNG spill at jetty • Fire involving large LNG spill	• Damage to FLNG mooring system • Escalation of event	2	5	U	• FLNG and LNGC protected by breakwater from severe environmentall oads • Design for anticipated enveionmental loads • Redundancies built into the design of the FLNG and LNGC mooring systems • Inspections	• Protection of mooring lines from fire and cold spill (to be evalauted as part of design)	1	5	S	M	N-17
H-14.03.01	Liquids sent to the flare tower	• Carryover • Knock out drum failure • Knock out drum incorrectly sized • Instrumentation failure	• Potential rain out on deck • Damage to flare tip • Potential injury to personnel (3 or less)	2	4	S	• Knock out drum and flare system sized based upon maximum flow rates	• Flow control alarms and indications • Flare remote from process and manned areas	1	3	A	R	
H-14.03.02	Flare lightning strike	• Weather event / squall	• Damage to flare • Secondary ignition	2	3	S		• Grounded flare • Flare snuffing system	2	2	A	R	
H-14.03.03	Flare pilot goes out	• Wind • Fuel gas failure	• Vapour cloud released to deck area	2	4	S	• Flow alarms for low or no fuel gas • Backup propane fuel	• Flare remote from process and manned areas • Temperature monitoring in the flare for pilot flame presence	1	3	A	R	
H-08.03.02	Exhaust turbine impacts helicopter operations	• Wind • Temperature variances	• Shutdown of helicopter operations • Potential helicopter crash resulting in serious injuries or multiple fatalities (more than 3)	2	5	U	• Operational limits for helicopter operation • CAP 437 requirements with exhaust turbine location and thermal dispersion assessed during design, exhausts sited accordingly	• Helicopter landing crew • Active firefighting equipment including foam monitors • Support vessels and fast rescue craft for assisting in recovery of personnel at sea	1	3	A	R	

PRA No.	Accident Event	Main Causes	Potential Consequences	Initial RR			Prevention	Control and Mitigation	Final RR			Kinetic	MAE No.
				L	S	R			L	S	R		
H-27.01.01	Attack from terrorists or pirates	• Piracy or terrorism	• Hostage-taking • Serious injury or fatality (3 or less)	1	5	S	• Safety and security plans complying with recognised international standards such as the International Ship and Port Security (ISPS) Code of the International Maritime Organization (IMO) • Areas for boarding of facilities (e.g. boat docks) secured when not in use • Secure fenced area for the support base • Deepwater locations (Drillship and FPSO) far from shore		1	5	S	N/A	G-01
H-28.00.01	Erosion / degradation of breakwater	• Waves • Weather	• Potential damage to sea island foundation • Excessive wave and swell motions on FLNG – impact to production availability	3	3	S	• Siting and feasibility studies including sea state conditions • Accropode concrete armour installed for exposed areas of sea island	• Inspections and surveys	1	2	A	S	

APPENDIX O-3 : BOWTIE DIAGRAMS (SEVERITY RANKING 4)

Figure AO-3.1: Bowtie 08.02 - FLNG LNG Release during LNGC Loading (Left Hand Side)

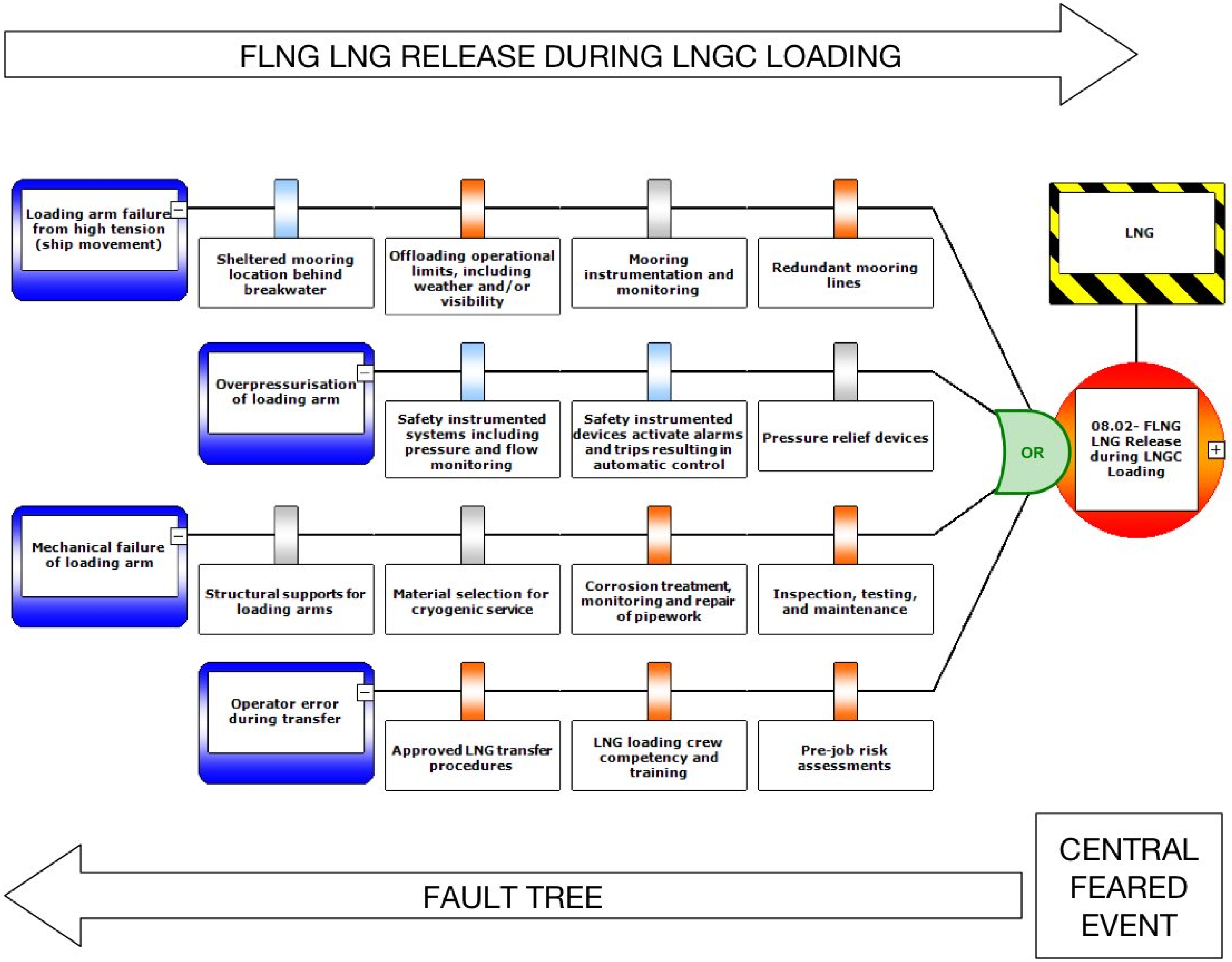


Figure AO-3.2: Bowtie 08.02 - FLNG LNG Release during LNGC Loading (Right Hand Side)

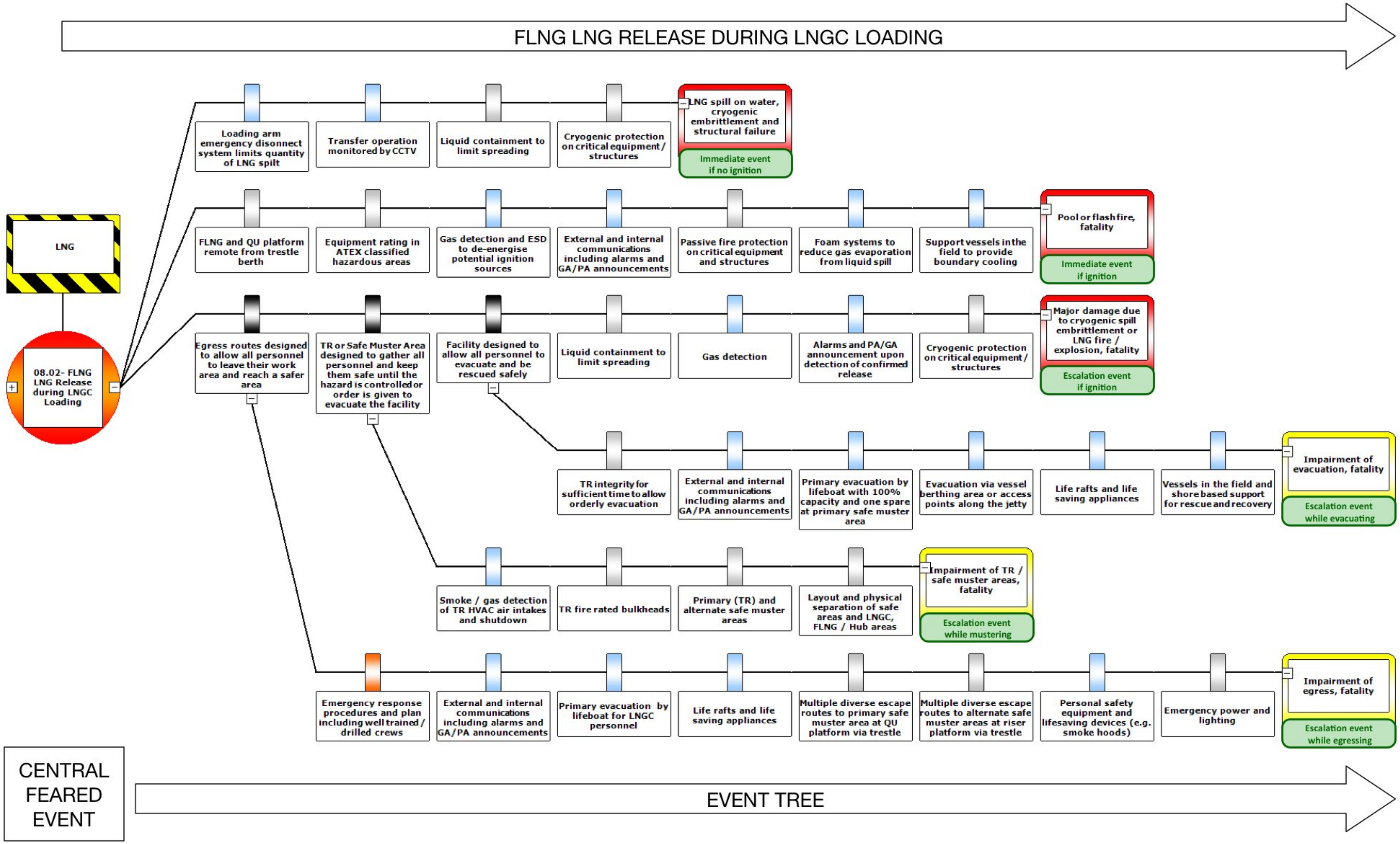


Figure AO-3.3: Bowtie 11 - Drillship Well Testing or Clean-up Hydrocarbon Release (Right Hand Side)

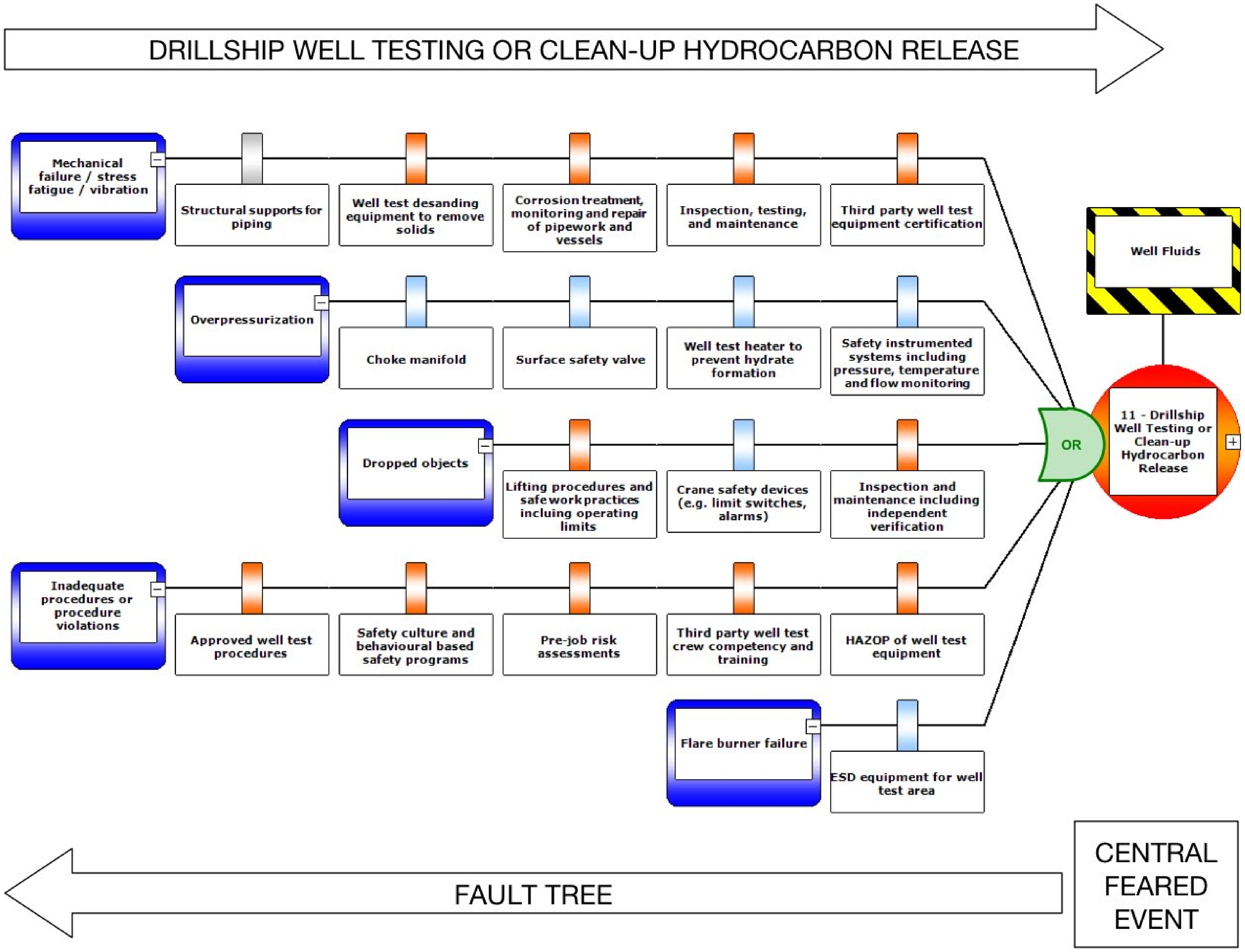


Figure AO-3.4: Bowtie 11 - Drillship Well Testing or Clean-up Hydrocarbon Release (Left Hand Side)

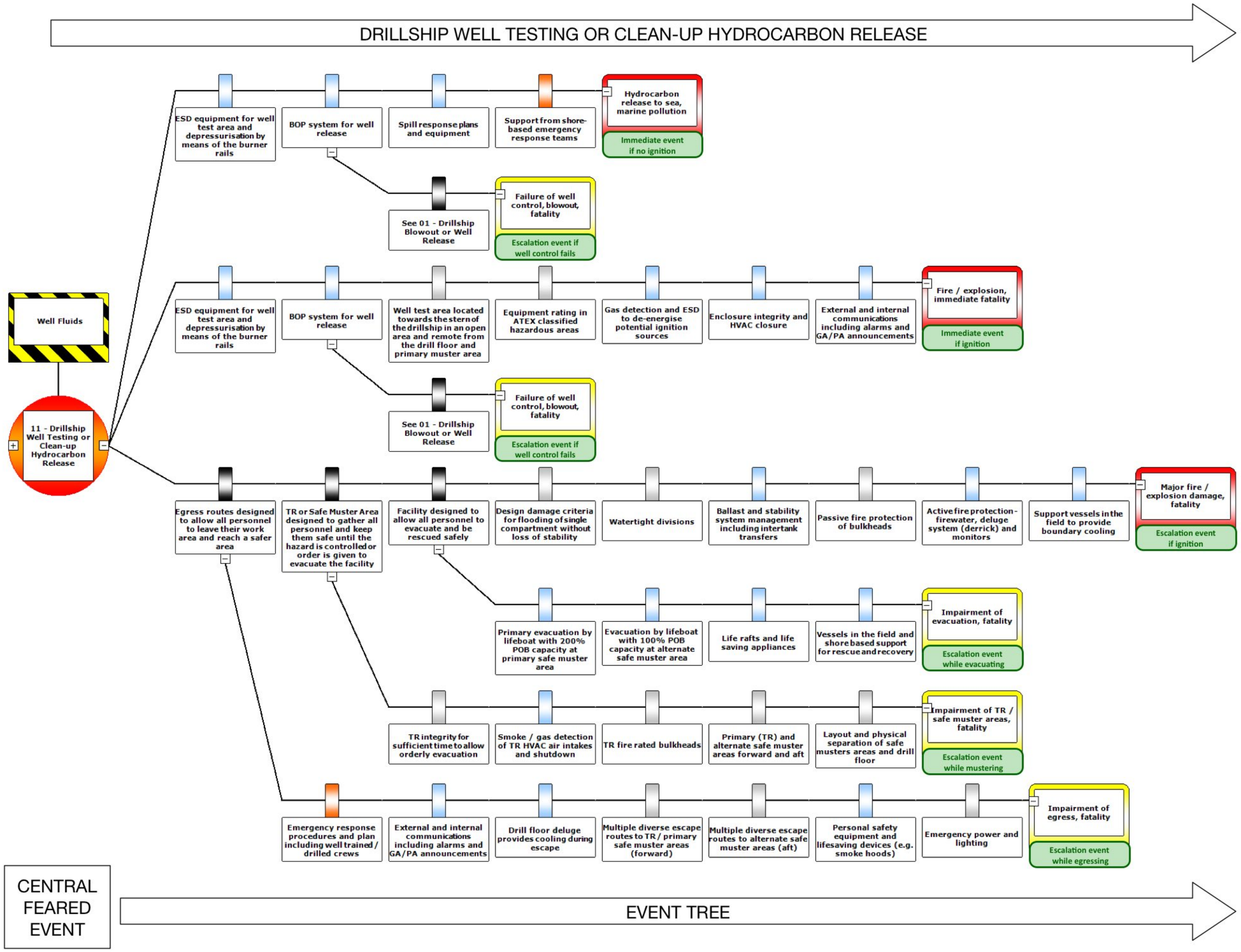


Figure AO-3.5: Bowtie 12.01 - FPSO Hydrocarbon Process Release (Left Hand Side)

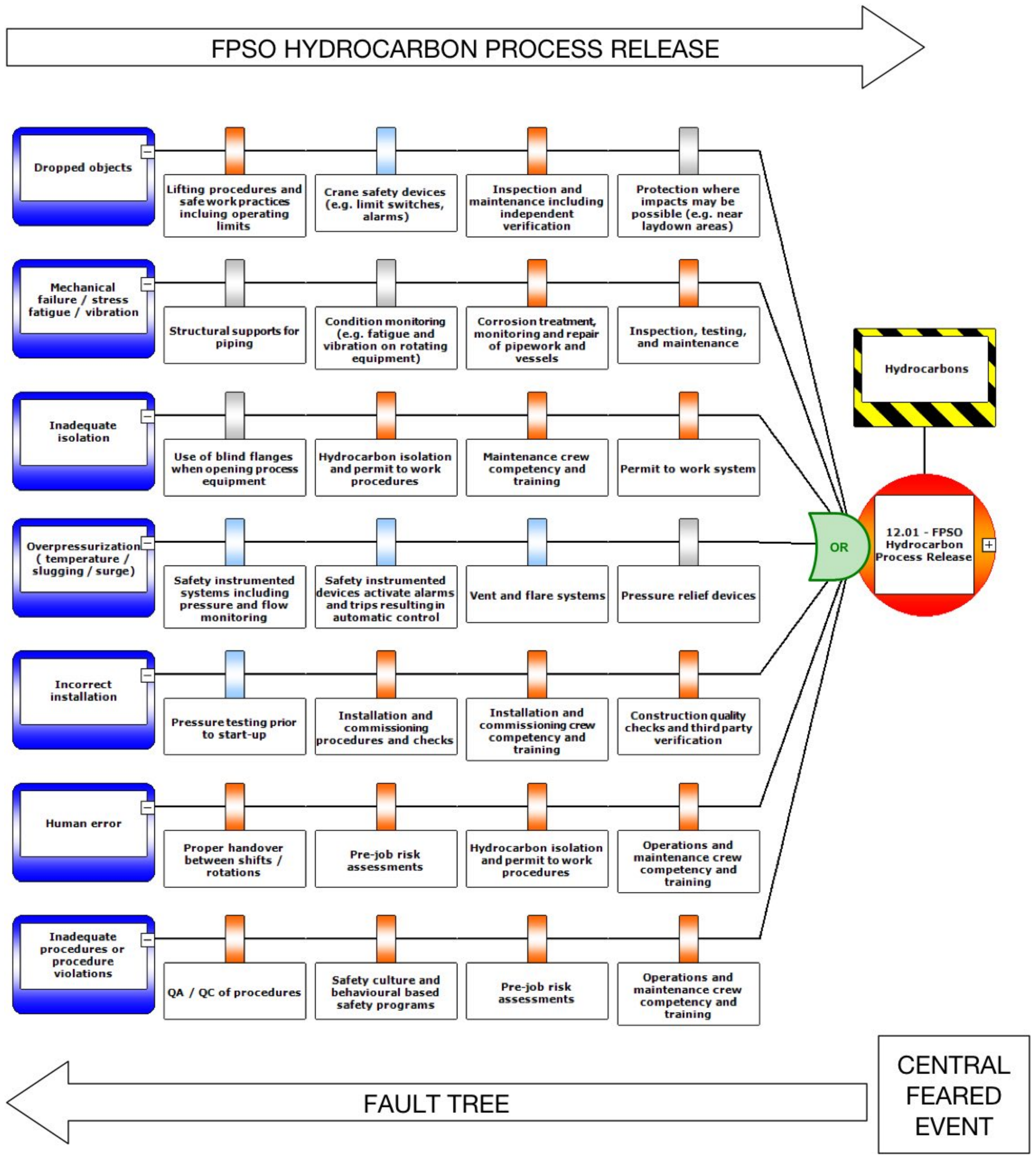


Figure AO-3.6: Bowtie 12.01 - FPSO Hydrocarbon Process Release (Right Hand Side)

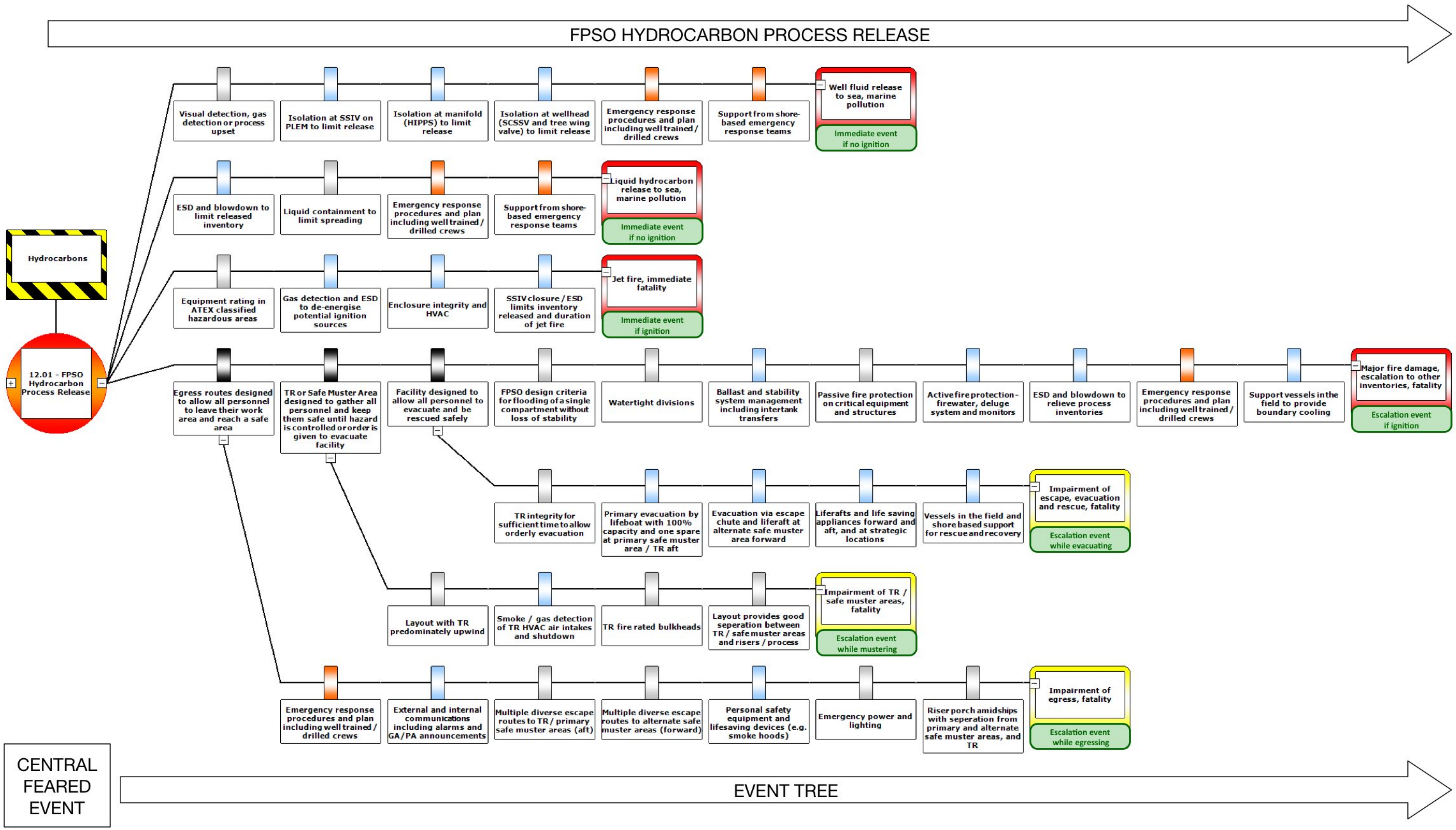


Figure AO-3.7: Bowtie 12.02 - FLNG Hydrocarbon Process Release (Left Hand Side)

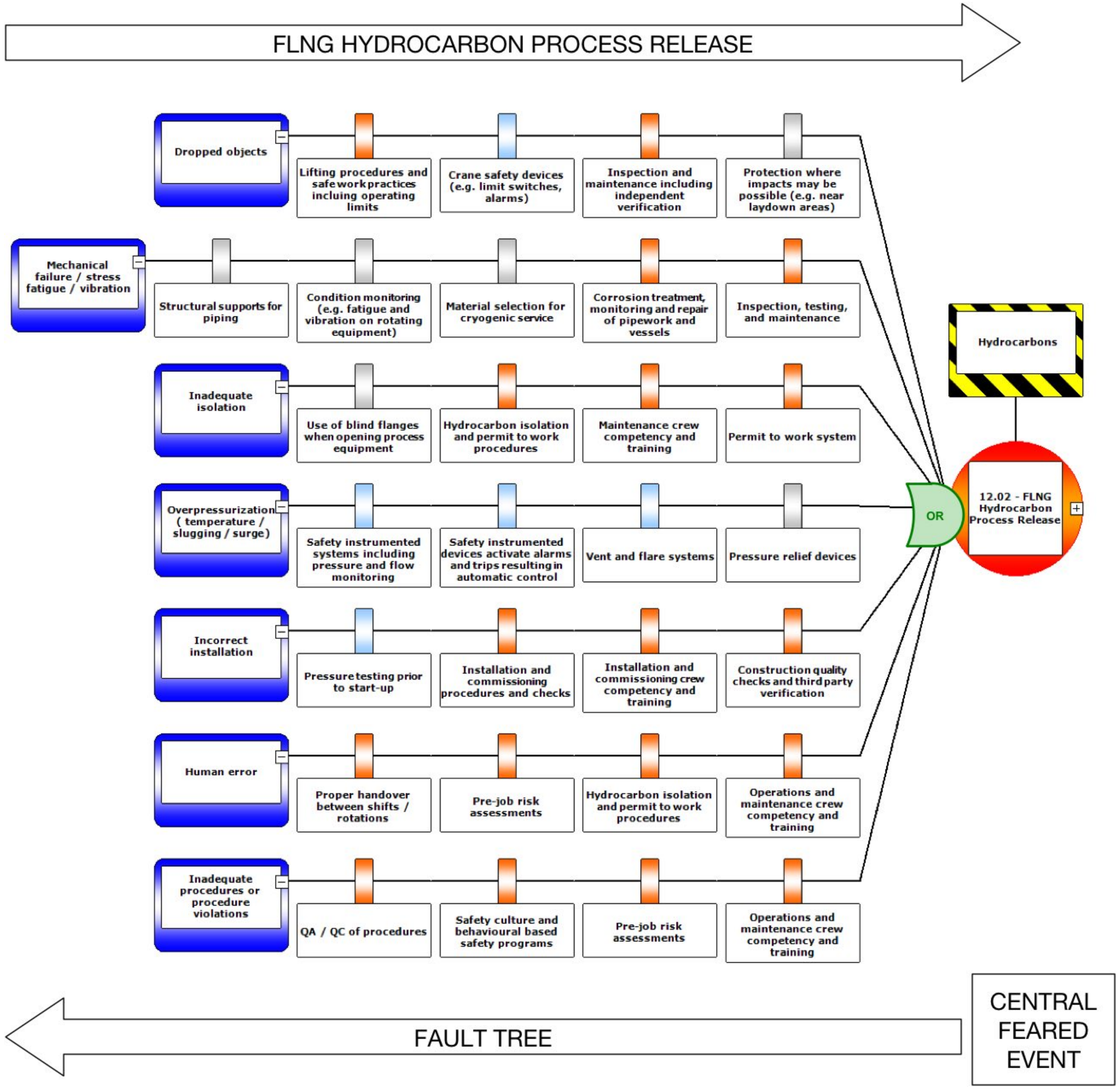


Figure AO-3.8: Bowtie 12.02 - FLNG Hydrocarbon Process Release (Right Hand Side)

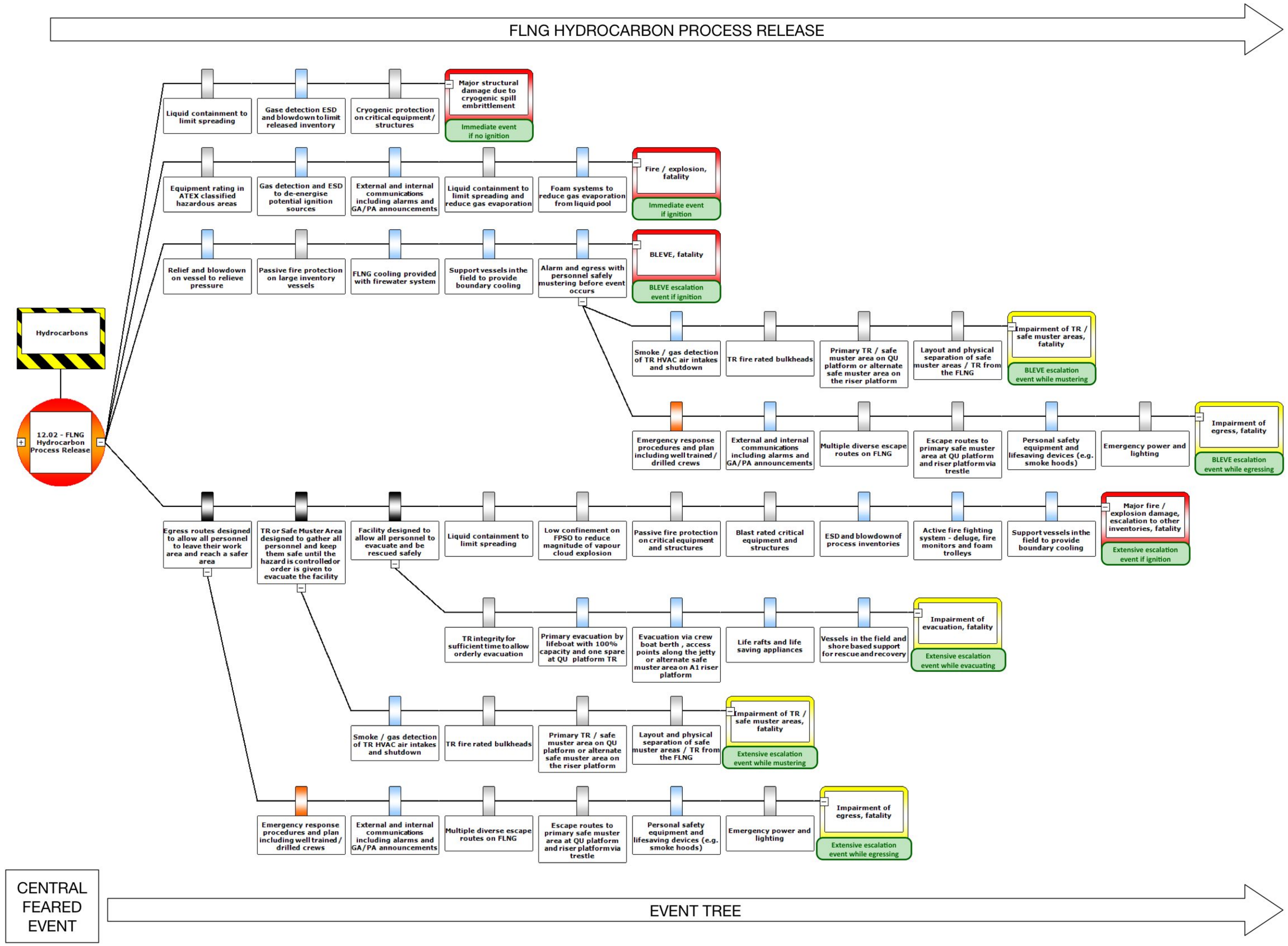


Figure AO-3.9: Bowtie 13 - FPSO Chemical Injection Release (Left Hand Side)

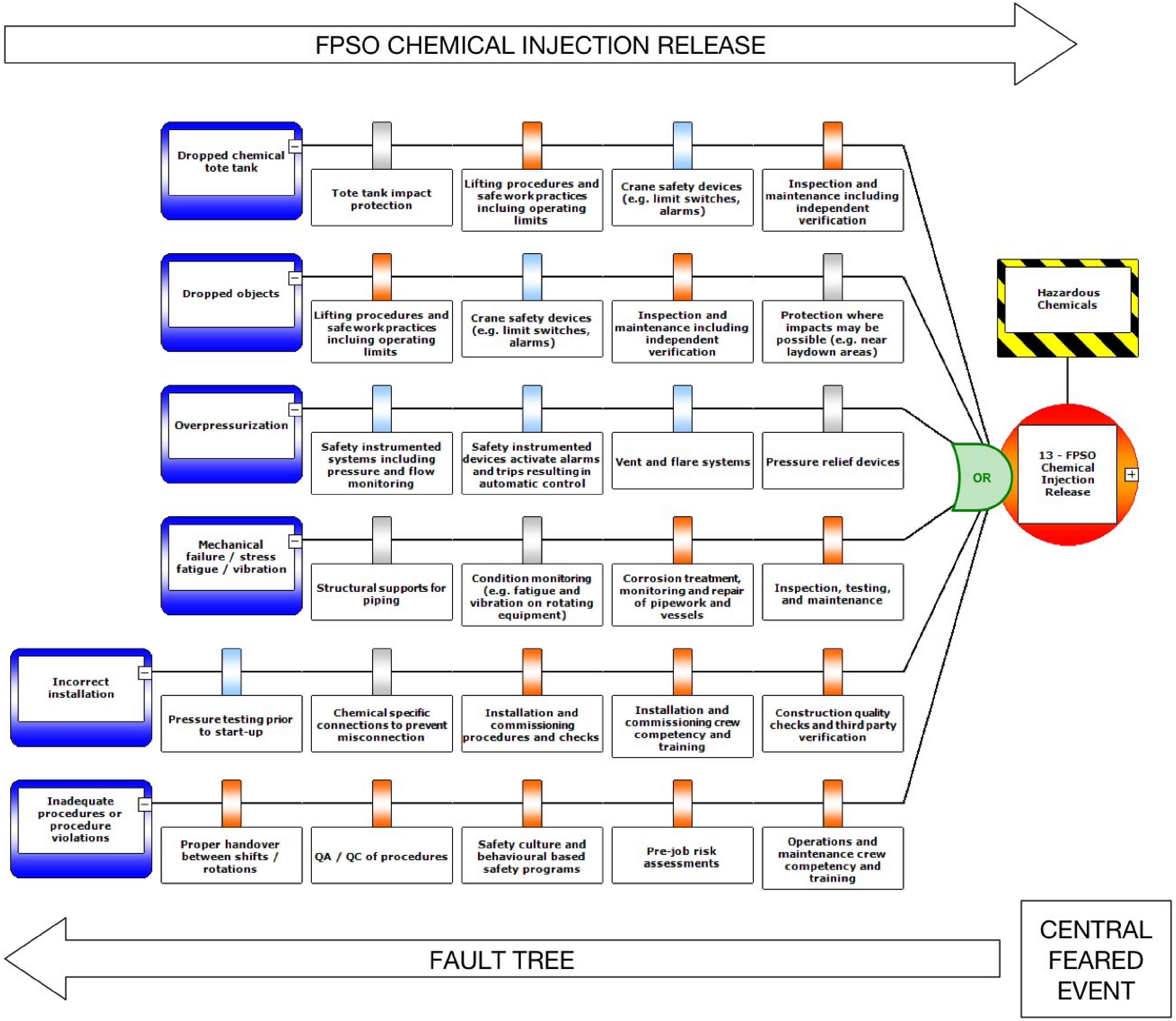


Figure AO-3.10: Bowtie 13 - FPSO Chemical Injection Release (Right Hand Side)

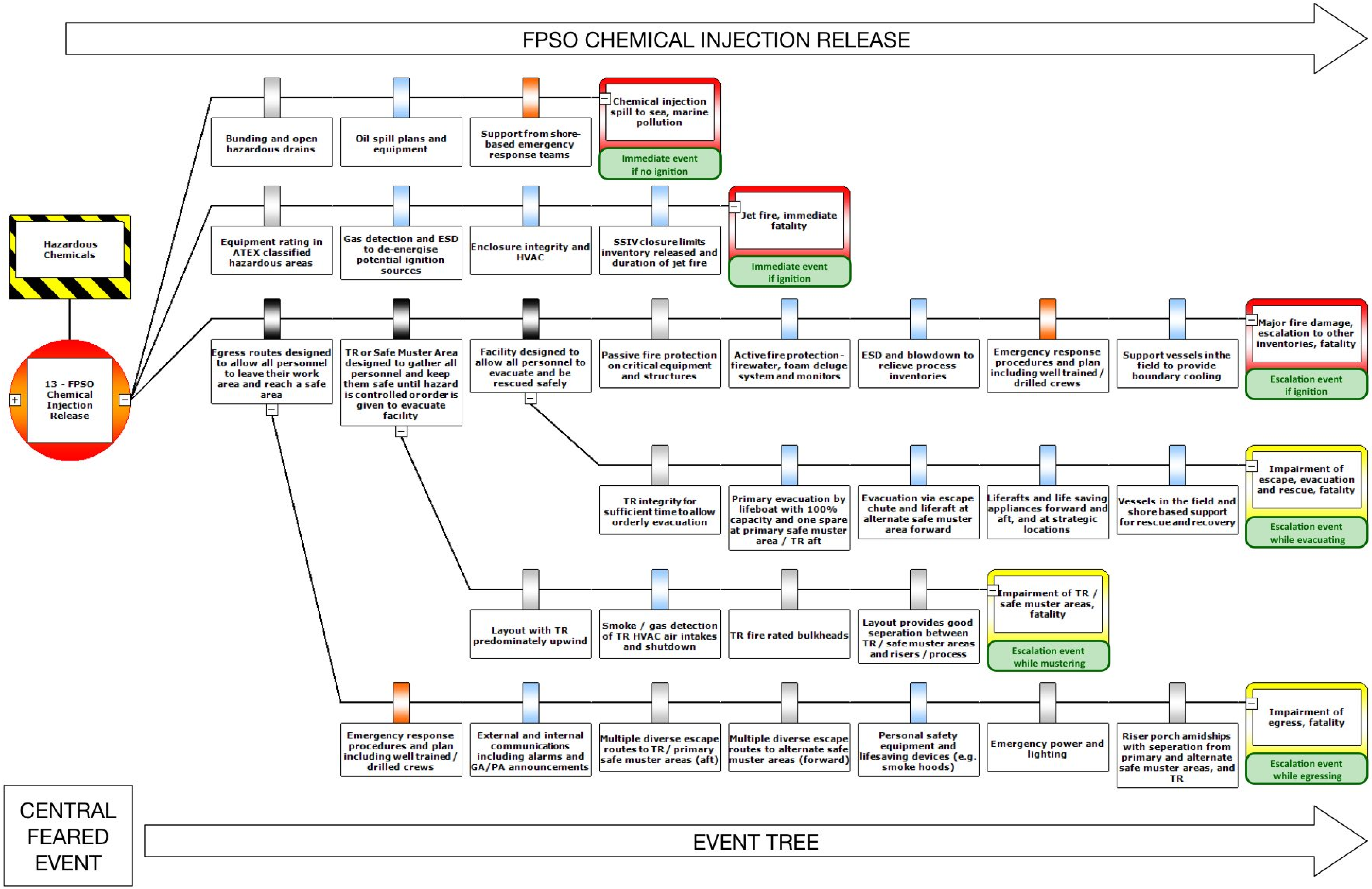


Figure AO-3.11: Bowtie 14.01 - FPSO / NSH Transportation Accident (Crew Boat Founders) (Left Hand Side)

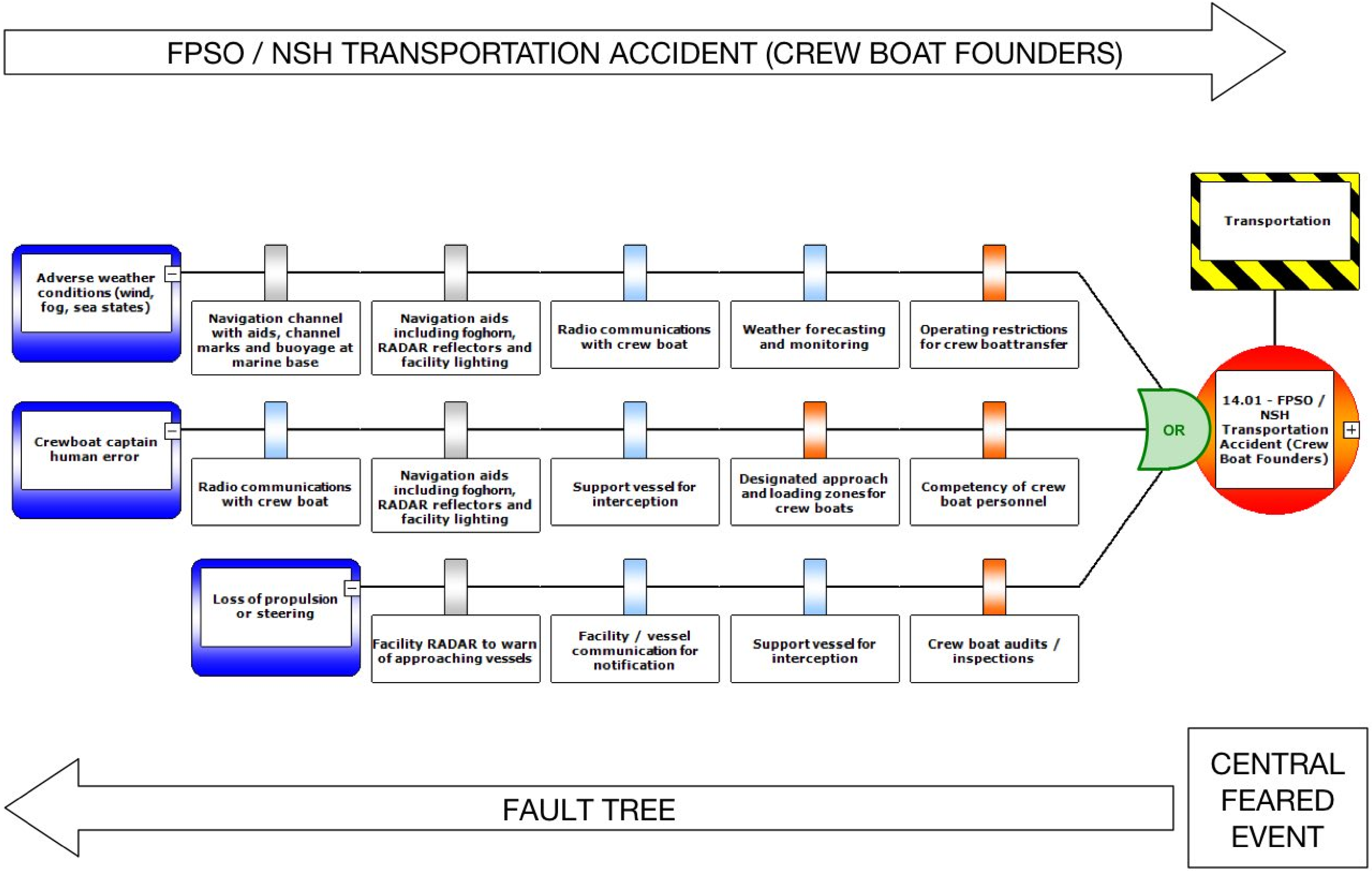


Figure AO-3.12: Bowtie 14.01 - FPSO / NSH Transportation Accident (Crew Boat Founders) (Right Hand Side)

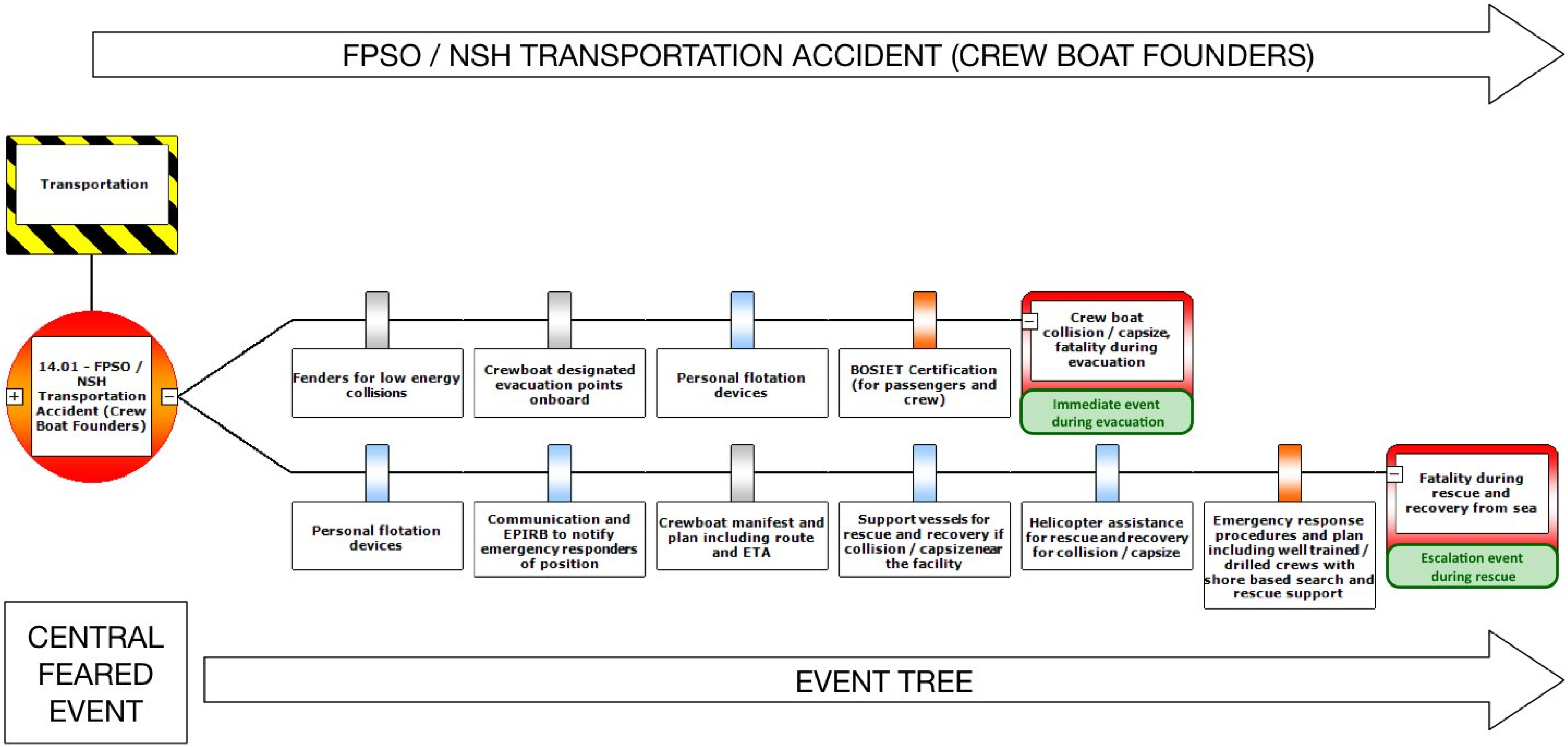


Figure AO-3.13: Bowtie 14.02 - FPSO Transportation Accident (Dropped FROG) (Left Hand Side)

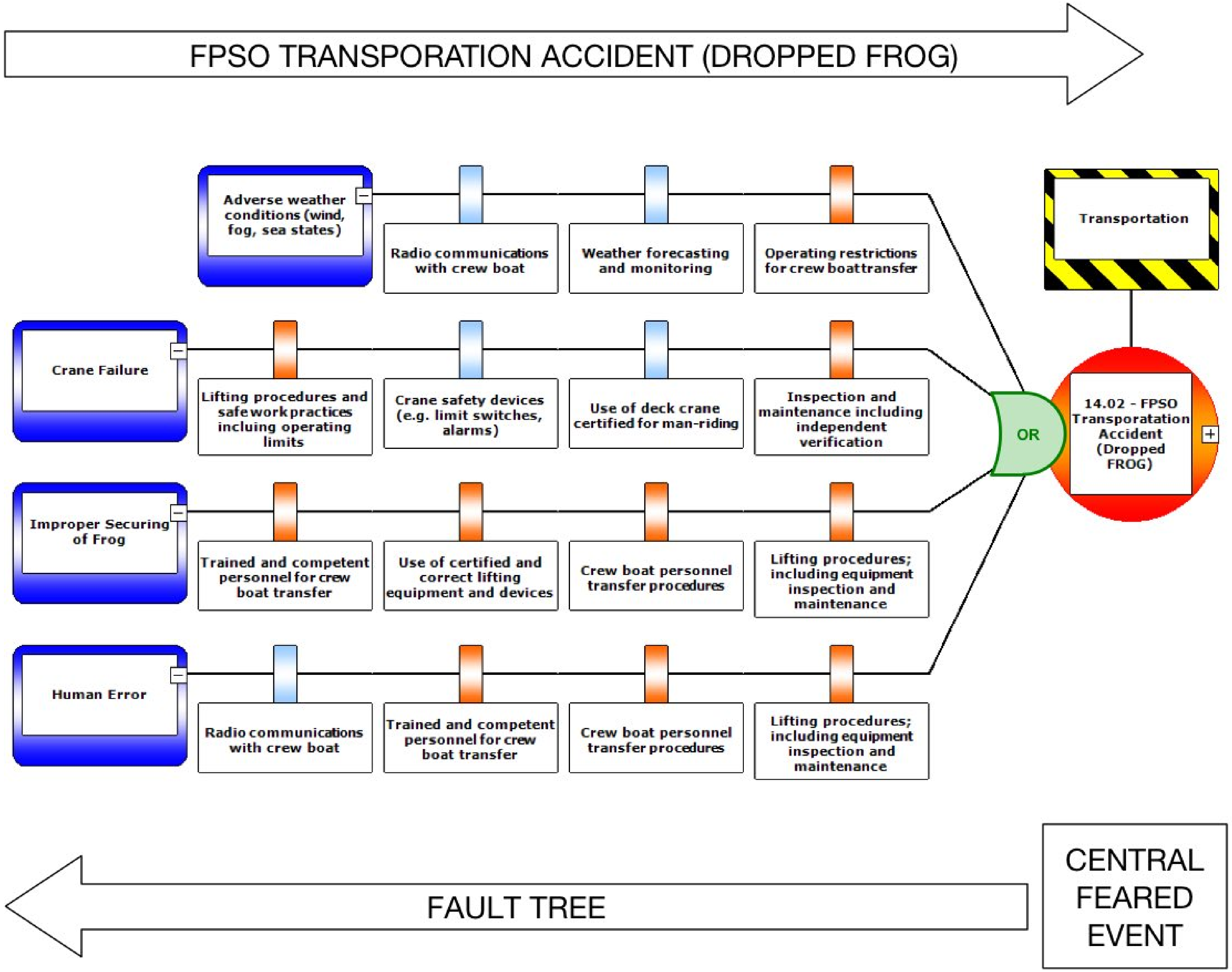


Figure AO-3.14: Bowtie 14.02 - FPSO Transportation Accident (Dropped FROG) (Right Hand Side)

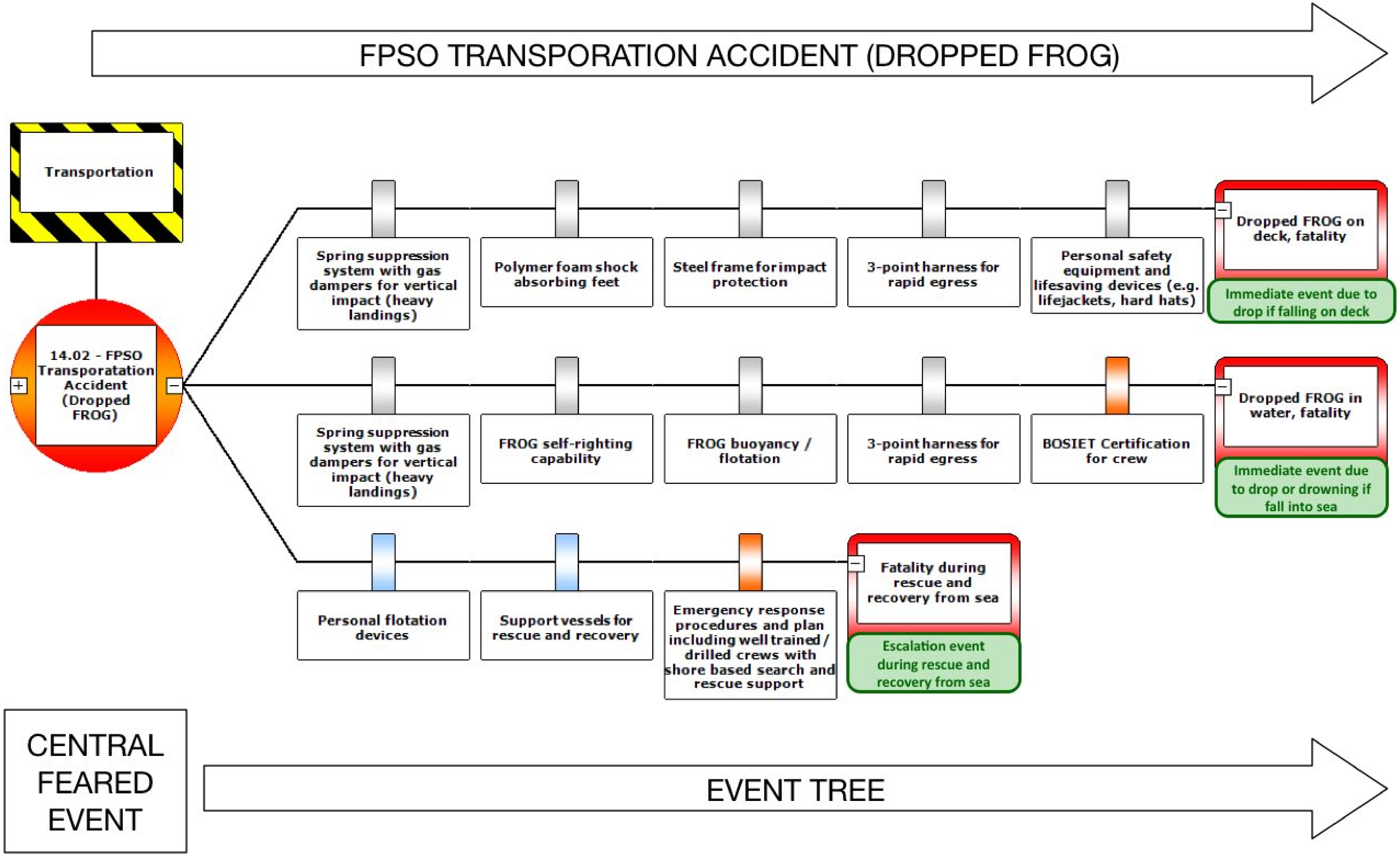


Figure AO-3.15: Bowtie 16 - QU Platform Fuel Gas Release (Left Hand Side)

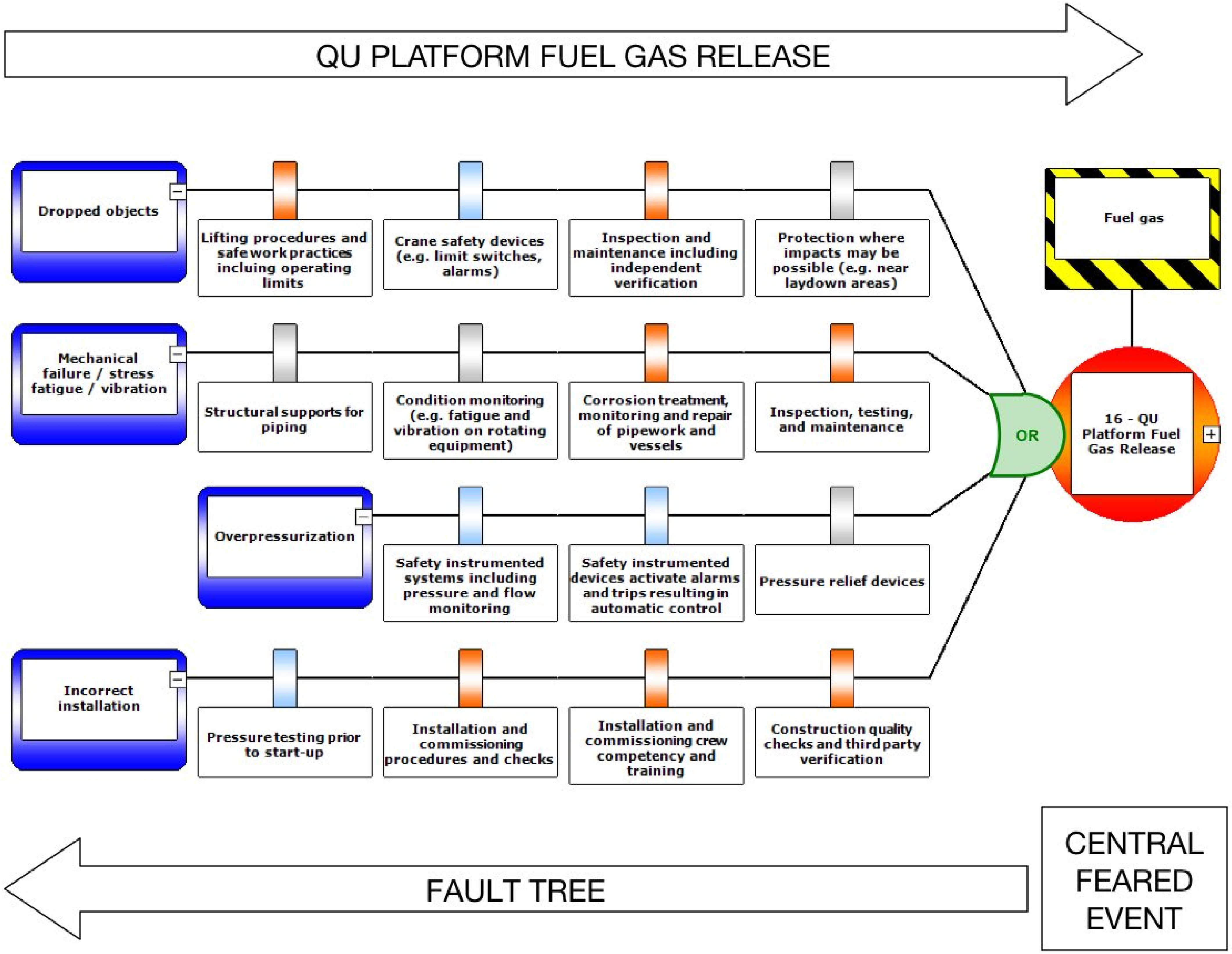
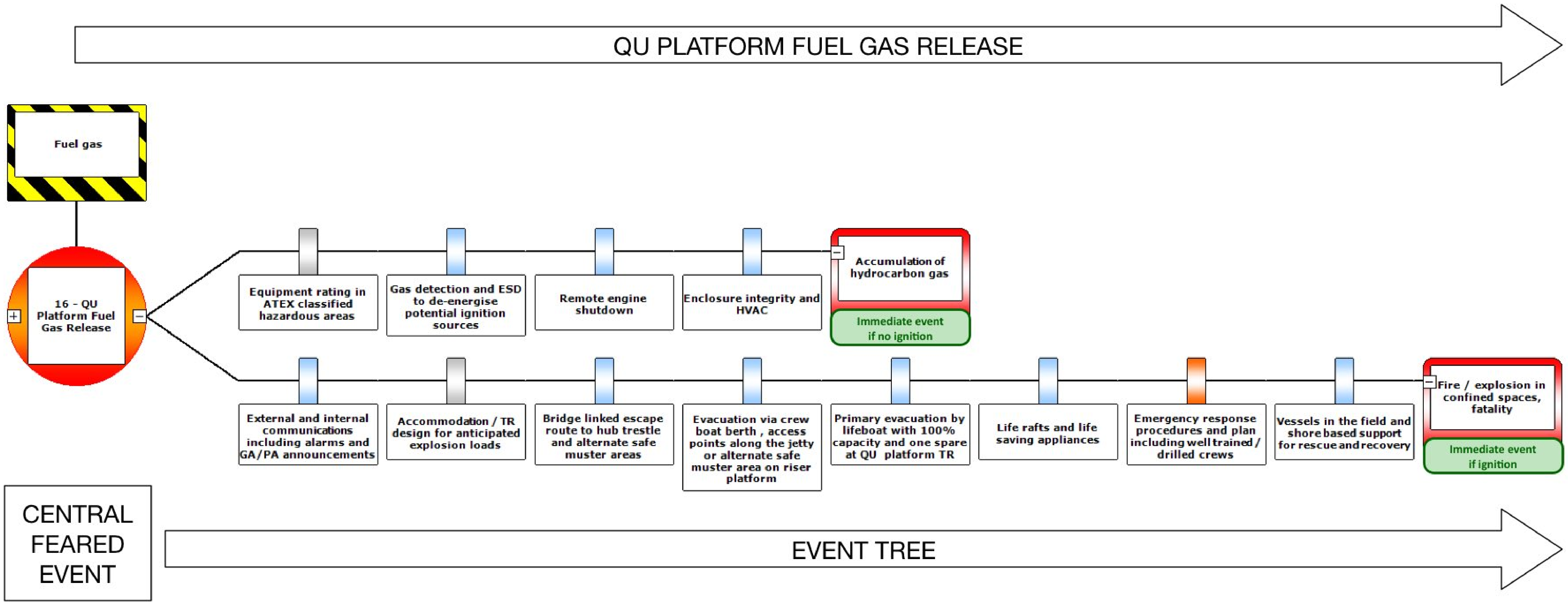


Figure AO-3.16: Bowtie 16 - QU Platform Fuel Gas Release (Right Hand Side)



APPENDIX O-4 : OCCUPATIONAL RISK ANALYSIS WORKSHEETS

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-03-01	Other flammables: Accommodation galley cooking oils	• Fire in the accommodation galley	• Overheating of oil • Oil spill on stove • Oil build up in extractor	• Risk of burns, smoke inhalation, serious injury and / or partial permanent disability	3	3	U	• Crew training and competence • Good housekeeping procedures to keep galley clean • Proper storage of cooking oil • Galley hood fire extinguishing system • Medical facilities for diagnosis / treatment	2	3	S
H-03-02	Other flammables: Miscellaneous accommodation materials including paper, fabrics, and plastics	• Fire in the accommodation	• Smoking and throwing lit cigarette, match • Lint build up in laundry dryers • Electrical fault	• Risk of burns, smoke inhalation, serious injury and / or partial permanent disability	3	3	U	• Crew training and awareness • Good housekeeping procedures to keep facilities clean • Non-smoking policy enforced • Fire extinguishing system • Medical facilities for diagnosis / treatment	2	2	S
H-03-03	Other flammables: Paints and miscellaneous flammable used and stored in small quantities	• Fire involving paint and miscellaneous flammables used and stored in small quantities	• Improper paint locker storage • Hot work	• Risk of burns, smoke inhalation, serious injury and / or partial permanent disability	2	3	S	• Crew training and competence • Proper storage of paint products • Hot work permit and restrictions near flammable materials with associated safe work practices/ procedures • Tool box talks / job safety analysis / risk assessments prior to hot work • Paint lockers protected by fire detection and extinguishing system • Medical facilities for diagnosis / treatment	1	3	A

<table>
<tr><th rowspan="2">ID</th><th rowspan="2">Hazard</th><th rowspan="2">Accident Event</th><th rowspan="2">Causes</th><th rowspan="2">Consequences</th><th colspan="3">Initial Risk</th><th rowspan="2">Prevention, Control and Mitigation</th><th colspan="3">Residual Risk</th></tr>
<tr><th>L</th><th>S</th><th>R</th><th>L</th><th>S</th><th>R</th></tr>
<tr><td>H-05-01</td><td>Pressure: Compressed gas cylinders under pressure (e.g. welding bottles)</td><td>• Uncontrolled emission from, or explosion of compressed gas cylinders</td><td>• Rupture of the valve on the cylinder nozzle
• Violent impact or fire
• Burning products near the gas storage area</td><td>• Rupture of the gas bottle
• Overpressure and possible projectiles
• Risk of very serious injury or fatality
• Possible damage to other equipment and / or facilities</td><td>2</td><td>4</td><td>S</td><td>• Crew training and competence
• Compliance with good practice and legally mandated design and inspection for pressurized gas cylinders
• Gas cylinders equipped with a protective cap for the valve
• Storage of the cylinders on stands specifically designed to avoid any risk of the cylinders' being dropped
• Compressed gas cylinders properly sealed and placed on a trolley
• No flammable materials handling near gas cylinders
• Medical facilities for diagnosis / treatment</td><td>1</td><td>3</td><td>A</td></tr>
<tr><td>H-05-02</td><td>Pressure: Instrument air systems and compressor tanks (for instrument control)</td><td>• Failure of instrument air systems and compressor tanks</td><td>• Violent impact or fire
• Corrosion of the tank
• Tank overpressure
• Burning products near the air storage area</td><td>• Tank rupture
• Overpressure and possible projectiles
• Risk of very serious injury or fatality
• Possible damage to other equipment and / or facilities</td><td>2</td><td>4</td><td>S</td><td>• Crew training and competence
• Compliance with good practice and legally mandated design and inspection for pressurized tanks
• Purging of condensed water to prevent tank internal corrosion
• No flammable materials handling near air compression systems
• Pressure relief valve on air system
• Medical facilities for diagnosis / treatment</td><td>1</td><td>3</td><td>A</td></tr>
</table>

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-05-03	Pressure: Nitrogen, purging or leak testing systems	• Failure of system under purging or leak testing	• Human error: over pressuring of system under leak testing • Hose failure	• Rupture of system under pressure test • Overpressure and possible projectiles • Asphyxiation • Risk of very serious injury or fatality • Possible damage to other equipment and / or facilities	2	4	**S**	• Crew training and competence • Permit to work required with associated safe work practices / procedures • All operations involving Nitrogen purging, and leak testing are governed strictly by procedures • Tool box talks / job safety analysis / risk assessments prior to work permit task • Pressure relief system on system under purging and leak testing • Medical facilities for diagnosis / treatment • Inspection and testing of hoses	1	4	**S**
H-05-04	Pressure: Pressure tests (during commissioning or maintenance)	• Failure of system under test pressure	• Human error: over pressuring of system under pressure test • Hose failure	• Rupture of system under pressure test • Overpressure and possible projectiles • Risk of very serious injury or fatality • Possible damage to other equipment and / or facilities	2	4	**S**	• Crew training and competence • Specific review and risk assessment prior to commencing the commissioning work to ensure required safeguards are implemented • Permit to work required with associated safe work practices / procedures • Tool box talks / job safety analysis / risk assessments prior to work permit task • Pressure relief system on system under pressure test • Medical facilities for diagnosis / treatment	1	4	**S**

<table>
<tr><th rowspan="2">ID</th><th rowspan="2">Hazard</th><th rowspan="2">Accident Event</th><th rowspan="2">Causes</th><th rowspan="2">Consequences</th><th colspan="3">Initial Risk</th><th rowspan="2">Prevention, Control and Mitigation</th><th colspan="3">Residual Risk</th></tr>
<tr><th>L</th><th>S</th><th>R</th><th>L</th><th>S</th><th>R</th></tr>
<tr><td>H-05-05</td><td>Pressure: Air compressors and tanks used during air diving operations</td><td>• Failure of air compressors and/or tanks used during air diving operations</td><td>• Violent impact or fire
• Corrosion of the tank
• Tank overpressure
• Burning products near the air storage area</td><td>• Tank rupture
• Overpressure and possible projectiles
• Risk of very serious injury or fatality
• Possible damage to other equipment and / or facilities</td><td>2</td><td>4</td><td>S</td><td>• Crew training and competence
• Compliance with good practice and legally mandated design and inspection for pressurized tanks
• Purging of condensed water to prevent tank internal corrosion
• No flammable materials handling near air compression systems
• Pressure relief valve on air system
• Medical facilities for diagnosis / treatment</td><td>1</td><td>3</td><td>A</td></tr>
<tr><td>H-05-06</td><td>Pressure: Pipeline pigging (during commissioning or maintenance)</td><td>• Accident release or failure during pipeline pigging operations</td><td>• High pressure behind pig with trap door opened
• Failure to follow safe work procedures (system depressured, interlocks etc.)</td><td>• High pressure ejects pig from trap
• Risk of very serious injury or fatality</td><td>2</td><td>4</td><td>S</td><td>• Crew training and competence
• Safe pigging practices and operating procedures
• Mechanical interlock prevent trap being opened if under pressure
• Medical facilities for diagnosis / treatment</td><td>1</td><td>4</td><td>S</td></tr>
<tr><td>H-06-01</td><td>Height difference: Working at height (from permanent or temporarily installed platforms including scaffolding)</td><td>• Fall from height onto deck
• Fall from height during ballast / cargo tank entry
• Fall from a temporarily installed platform including scaffolding</td><td>• Failure to follow safe work procedures
• Equipment failure</td><td>• Falling from a height of more than 2 meters
• Risk of very serious impact injury or fatality</td><td>2</td><td>4</td><td>S</td><td>• Crew training and competence
• Ballast / tank entry procedures
• Permit to work required with associated safe work practices / procedures
• Tool box talks / job safety analysis / risk assessments prior to working at heights or Over the side</td><td>1</td><td>4</td><td>S</td></tr>
</table>

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
								• Checking of access way / handrails or scaffolding prior to use • Appropriate personnel protective equipment (PPE) including safety harnesses and slip-resistant footwear • Medical facilities for diagnosis / treatment			
H-06-02	Height difference: Use of ladders (access during installation)	• Fall from a ladder	• Failure to follow safe work procedures • Equipment failure	• Falling from a height of more than 2 meters • Risk of very serious impact injury or fatality	2	4	**S**	• Crew training and competence • Permit to work required with associated safe work practices / procedures • Tool box talks / job safety analysis / risk assessments prior to working at heights • Checking of ladders prior to use • Appropriate personnel protective equipment (PPE) including safety harnesses and slip-resistant footwear • Medical facilities for diagnosis / treatment	1	4	**S**
H-06-03	Height difference: Working over water (during installation, inspection and maintenance)	• Fall from height into water	• Failure to follow safe work procedures • Equipment failure	• Falling from a height of more than 2 meters • Risk of very serious impact injury or fatality • Risk of drowning if falling into water	2	4	**S**	• Crew training and competence • Permit to work required with associated safe work practices / procedures • Tool box talks / job safety analysis / risk assessments prior to working over water • Appropriate personnel protective equipment (PPE) including safety	1	4	**S**

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
								harnesses and slip-resistant footwear • Medical facilities for diagnosis / treatment • Fast rescue craft and / or attendant vessels to rescue person from the water			
H-06-04	Height difference: Slippery or congested surface (e.g. walkways)	• Accidental slip or trip	• Congested / blocked pathways • Slippery surfaces	• Falling from a height of less than 2 meters • Risk of minor injury	3	1	A	• Crew training and competency • Pathways and access ways are kept clean and clear of obstructions • Slip-resistant footwear worn • Good housekeeping ensures floors are cleaned if a slippery product is spilled • Non-slip coatings on access and egress routes • Medical facilities for diagnosis / treatment	2	1	A
H-06-05	Height difference: Air diving with installation activities ongoing above	• Object falls onto diver from installation operations overhead	• Mechanical failure • Human error	• Risk of very serious impact / crushing injury or fatality	2	4	S	• Air diving operational restrictions • Review of simultaneous operations • Medical facilities for diagnosis / treatment • Fast rescue craft and / or attendant vessels to rescue person from the water	1	4	S
H-07-01	Induced stress: Maintenance on devices such as spring-loaded relief valves and actuators,	• Failure of spring loaded device • Failure of hydraulically operated devices	• Mechanical failure • Human error	• Release of a projectile that can impact personnel with a high velocity	2	4	S	• Crew training and competency • Maintenance procedures • Safety risk assessments • Medical facilities for diagnosis / treatment	1	4	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
	hydraulically operated devices			• Risk of very serious injury or fatality							
H-07-02	Induced stress: Vessel tie-offs / moorings	• Rupture of a mooring line or tie-off parts	• Unexpected weather • Error / misjudgment by vessel captain • Mechanical failure	• Lashing at high velocity of the mooring line or tie-off part to personnel • Risk of very serious injury or fatality	2	4	S	• Crew training and competency • Safe mooring procedures • Inspection and testing of mooring lines • Multiple lines used to tie up crew boats and vessels • Sheltered boat dock areas • Medical facilities for diagnosis / treatment	1	4	S
H-08-01	Dynamic situations: Driving / parking at the shore base	• Vehicle accident with another vehicle or with a pedestrian, on a road or in a parking of the shore base	• Excessive speed • Driver error • Poor visibility	• Risk of very serious injury or fatality due to the collision	3	4	U	• Road and highway training and awareness for facility workers • Speed limits for onshore facilities roads or parking areas and clear signage as to this limit • • Medical facilities for diagnosis / treatment	2	3	S
H-08-02	Dynamic situations: Forklift operations	• Impact of a forklift with personnel	• Forklift reversed unexpectedly • Failure to follow safe work procedures	• Risk of serious impact / crushing injury and / or partial permanent disability	2	3	S	• Training, competence and certification of forklift operators • Restricted access to areas where forklift operations are ongoing • Forklifts equipped with an audible warning system for operation in reverse • High visibility vest /coveralls in forklift area • Medical facilities for diagnosis / treatment	1	3	A

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-08-03	Dynamic situations: Maintenance involving moving or rotating equipment	• Personnel crushed or nipped by a moving or rotating part of the equipment	• Human error • Mechanical failure	• Risk of very serious injury or fatality • Potential projectile	2	4	S	• Crew training and competence • Equipment shutdowns prior to work with lock-out/ tagout • Personal protective equipment • Medical facilities for diagnosis / treatment	1	4	S
H-08-04	Dynamic situations: Use of hand tools	• Harmful contact between a hand tool (grinding, sawing) and a body part	• Slip or mistake • Poor visibility • Equipment failure	• Risk of moderate injury	4	2	S	• Crew training and competence • Hand guards on tool • Appropriate personnel protective equipment (PPE) worn (hand guards, gloves etc.) • Medical facilities for diagnosis / treatment	3	2	S
H-08-05	Dynamic situations: Use of knives in galley / kitchens	• Harmful contact between a knife (or machete or other sharp objects) and a body part	• Slip or mistake • Poor visibility • Equipment failure	• Risk of moderate injury	4	2	S	• Crew training and competence • Hand guards on tool • Appropriate personnel protective equipment (PPE) worn (hand guards, gloves etc.) • Medical facilities for diagnosis / treatment	3	2	S
H-08-06	Dynamic situations: Routine lifting (e.g., main cranes, supplies, containers etc.)	• Dropped object	• Equipment failure • Failure to follow safe work procedures	• Risk of very serious impact / crushing injury or fatality • Possible damage to other equipment and / or facilities	2	4	S	• Training, competence and certification of lifting equipment operators, and people involved in lifting operations • Regular inspections and preventive maintenance of lifting and materials / manual handling equipment • Use of certified lifting equipment and slings • Restricted access to areas where lifting and hoisting is being	1	4	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
								undertaken (safe lifting and hoisting areas) • Medical facilities for diagnosis / treatment			
H-08-07	Dynamic situations: Routine lifting or skidding of drilling equipment (e.g., in derrick, drill pipe, BOP, marine riser etc.)	• Dropped heavy object	• Equipment failure • Failure to follow safe work procedures • Collision of (hydraulic) equipment	• Risk of very serious impact / crushing injury or fatality • Possible damage to other equipment and / or facilities	2	4	S	• Training, competence and certification of lifting equipment operators, and people involved in lifting operations • Regular inspections and preventive maintenance of lifting and materials / manual handling equipment • Use of certified lifting equipment and slings • Derrick equipped with a collision avoidance system • Drilling pipe-handling systems controlled remotely from a mobile control panel • Restricted access to areas where lifting and hoisting is being undertaken (safe lifting and hoisting areas) • Medical facilities for diagnosis / treatment	1	4	S
H-08-08	Dynamic situations: Heavy construction lifts (piles, decking, subsea equipment, piping)	• Structural failure of crane • Dropped massive object	• Crane erected in proximity to other materials handling with potential for impacts	• Risk of very serious impact / crushing injury or fatality • Possible damage to other equipment and / or facilities	2	4	S	• Training, competence and certification of lifting equipment operators, and people involved in construction heavy lift operations • Specific safety analysis / risk assessments prior to starting a heavy construction lift	1	4	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
			• Overloading of crane • Structural failure (poor design, fatigue, corrosion)					• Safe lifting and materials / manual handling procedures • Use of appropriately designed and certified cranes, lifting equipment and slings • Crane ratings and safety lock-outs for excessive weight • Regular inspections and preventive maintenance of lifting and materials / manual handling equipment • Restricted access to areas where construction heavy lifting and hoisting is being undertaken • Medical facilities for diagnosis / treatment			
H-08-09	Dynamic situations: Use of lifts / elevators	• Failure of lifts / elevators	• Mechanical failure (brake, cable fatigue etc.) • Overloading • Failure to follow safe work procedures	• Drop or fall of the equipment with people on board • Risk of very serious impact / crushing injury or fatality	2	4	**S**	• Training, competence and certification of personnel in charge of maintenance of lifts and elevators • Lifts designed and undertaken in accordance with the ASME rules • Regular inspections and preventive maintenance of lifts and elevators • Safety locking system that immobilizes the lift if the maximum authorized weight is exceeded • Medical facilities for diagnosis / treatment	1	4	**S**

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-08-10	Dynamic situations: Use of man riding equipment	• Failure of man riding equipment	• Mechanical failure (brake, cable fatigue etc.) • Overloading • Failure to follow safe work procedures	• Drop or fall of the equipment with people on board • Risk of very serious impact / crushing injury or fatality	2	4	S	• Training, competence and certification of lifting equipment operators, and people involved in lifting operations • Man riding equipment designed and undertaken in accordance with the ASME rules • Regular inspections and preventive maintenance of lifting and materials / manual handling equipment • Use of certified lifting equipment and slings • Safety locking system that immobilizes the lift if the maximum authorized weight is exceeded • Medical facilities for diagnosis / treatment	1	4	S
H-08-11	Dynamic situations: Direct transfers from vessels, including crew boats (excludes baskets)	• Personnel slips or falls during transfer from shore boat dock to vessel, or from vessel to FPSO or near shore hub boat dock	• Sudden change in sea state • Crew boat movement • Failure to follow safe work procedures • Mechanical failure of access ramp	• Risk of very serious impact injury or fatality if crushed between dock and boat • Risk of drowning after falling into water	3	4	U	• Boat crews training, competence and certification • Safe operating procedures and practices for work boat transfers including environmental limits • Regular inspections and preventive maintenance of boat dock areas and transfer ramps • Near shore hub boat dock protected by the breakwater • Mandatory wearing of lifejackets during crew boat transfers	2	3	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
								• Fast rescue craft and / or attendant vessels to rescue person from the water • Medical facilities for diagnosis / treatment			
H-08-12	Dynamic situations: Use of baskets for personnel transfers	• Dropped personnel basket	• Mechanical failure (brake, cable fatigue etc.) • Overloading • Failure to follow safe work procedures • Sudden movement of vessel / basket (crane operator error, sudden wind)	• Drop or fall of the basket onto the vessel or into the sea • Risk of very serious impact injury or fatality • Risk of drowning after falling into water	2	4	S	• Training, competence and certification of lifting equipment operators, and people involved in lifting operations • Safe operating procedures and practices for basket transfers including environmental limits • Regular inspections and preventive maintenance of lifting and materials / manual handling equipment • Use of certified lifting equipment and slings • Mandatory wearing of lifejackets before use of the baskets • Fast rescue craft and / or attendant vessels to rescue person from the water • Medical facilities for diagnosis / treatment	1	4	S
H-09-01	Natural environment: Sea state / sea sickness	• Extreme weather event	• Location environment including excessive sea states	• Moderate injury from slips, trips, falls • Seasickness	3	2	S	• Crew training and awareness • Operations weather limitations • Weather forecasting and monitoring • Medical facilities for diagnosis / treatment	2	2	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-09-02	Natural environment: Excessive temperatures / heat	• Personnel heat stroke	• Local environment	• Personnel very serious injury or fatality	2	4	S	• Crew training and awareness • Weather forecasting and monitoring • Operations weather limitations • Medical facilities for diagnosis / treatment	2	3	S
H-09-03	Natural environment: Winds	• Slip / trip or fall from height • Flying objects (detached or unsecured)	• Local environment	• Personnel very serious injury or fatality	2	4	S	• Crew training and awareness • Weather forecasting and monitoring • Operations weather limitations • Medical facilities for diagnosis / treatment	2	3	S
H-09-04	Natural environment: Low visibility / night operations	• Slip / trip, choc/impact or fall from height • Personnel entering hazardous zone unwillingly and un-noticed	• Local environment	• Personnel serious injury and / or partial permanent disability	2	3	S	• Crew training and awareness • Facility lighting • Weather forecasting and monitoring • Operations weather limitations • Medical facilities for diagnosis / treatment	2	2	S
H-09-05	Natural environment: Lightning	• Personnel hit by lightning	• Local environment	• Personnel very serious injury or fatality	2	4	S	• Crew training and awareness • Weather forecasting and monitoring • Operations weather limitations • Medical facilities for diagnosis / treatment	2	3	S
H-10-01	Hot surfaces: Hot process piping and equipment	• Personnel contact with hot equipment parts	• Failure to follow safe work procedures • Missing / damage to	• Burns of body part • Risk of serious injury and / or partial permanent disability	3	3	U	• Maintenance personnel training and competence • Insulation / protection on hot equipment and piping • Regular inspections and preventive maintenance of	2	1	A

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
			lagging / heat shielding					lagging / equipment providing protection from hot surfaces • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment			
H-10-02	Hot surfaces: Exhausts (e.g., engines and turbines)	• Personnel contact with hot exhaust parts or exhaust fumes	• Failure to follow safe work procedures • Missing / damage to lagging / heat shielding	• Burns of body part • Risk of serious injury and / or partial permanent disability	3	3	U	• Maintenance personnel training and competence • Design of engine and turbine exhaust to disperse hot fumes at safe location • Insulation / protection on hot equipment and piping • Regular inspections and preventive maintenance of lagging / equipment providing protection from hot surfaces • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment	2	1	A
H-10-03	Hot surfaces: Steam piping including waste heat recovery units	• Personnel contact with hot steam piping surfaces	• Failure to follow safe work procedures • Missing / damage to lagging / heat shielding	• Burns of body part • Risk of serious injury and / or partial permanent disability	3	3	U	• Maintenance personnel training and competence • Insulation / protection on hot equipment and piping • Regular inspections and preventive maintenance of lagging / equipment providing protection from hot surfaces • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment	2	1	A

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-10-04	Hot surfaces: Galley cooking equipment	• Personnel contact with high temperature cooking equipment	• Failure to follow safe cooking procedure • Cooking equipment left on	• Risk of serious injury and / or partial permanent disability	3	3	U	• Crew training and competence • Safe galley cooking procedures • High temp cooking equipment and guards • Medical facilities for diagnosis / treatment	2	2	S
H-11-01	Hot fluids: Hot glycol (regeneration)	• Release of glycol regeneration fluid (temperatures greater than 150°C)	• Corrosion • Material defects • Fatigue • Flange leaks • Welding defect • Dropped object	• Risk of burns and very serious injury or fatality	2	4	S	• Crew training and competence • Regular inspections and preventive maintenance of process and utilities equipment • Appropriate design, including verification of pressure vessels / equipment and welds • Process emergency shutdowns • Medical facilities for diagnosis / treatment	2	3	S
H-11-02	Hot fluids: Galley cooking oils	• Spillage of hot cooking oil • Jet of hot steam	• Material defects • Fatigue • Flange leaks • Human error	• Risk of serious injury and / or partial permanent disability	3	3	U	• Crew training and competence • Safe galley cooking procedure • Regular inspections and preventive maintenance of process and utilities equipment • Medical facilities for diagnosis / treatment	2	3	S
H-12-01	Cold surfaces: Cryogenic pipework and equipment	• Personnel contact with cryogenic pipework or equipment (temperature less than -80°C)	• Failure to follow safe work procedures • Missing / damage to lagging / heat shielding	• Cryogenic burns • Personnel serious injury and / or partial permanent disability	3	3	U	• Crew training and competence • Insulation protection on cold equipment and piping • Regular inspections and preventive maintenance of lagging / equipment providing protection from cold surfaces • Appropriate personnel protective equipment (PPE) worn	2	2	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
								• Medical facilities for diagnosis / treatment			
H-12-02	Cold surfaces: Equipment associated with low temperature gas processing	• Personnel contact with low temperature gas processing equipment (temperature less than -10°C)	• Failure to follow safe work procedures • Missing / damage to lagging / heat shielding	• Cold burns • Personnel moderate injury	3	2	**S**	• Crew training and competence • Insulation protection on cold equipment and piping • Regular inspections and preventive maintenance of lagging / equipment providing protection from cold surfaces • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment	2	2	**S**
H-13-01	Cold fluids: Cryogenic liquids (LNG refrigerant) in liquefaction and storage process streams	• Cryogenic release of LNG process refrigerant	• Corrosion • Material defects • Fatigue • Flange leaks • Welding defect • Dropped object	• Frostbite • Cryogenic burns • Personnel very severe injury or fatality	2	4	**S**	• Crew training and competence • Appropriate design, including verification of pressure vessels / equipment and welds • Regular inspections and preventive maintenance of process and utilities equipment • Process emergency shutdowns • Medical facilities for diagnosis / treatment	1	4	**S**
H-13-02	Cold fluids: Cold gases (methane) in fractionation process streams	• Release of cold methane in vapour phase	• Corrosion • Material defects • Fatigue • Flange leaks • Welding defect	• Cold burns • Personnel serious injury and / or partial permanent disability	2	3	**S**	• Crew training and competence • Appropriate design, including verification of pressure vessels / equipment and welds	1	3	**A**

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
			• Dropped object					• Regular inspections and preventive maintenance of process and utilities equipment • Process emergency shutdowns • Medical facilities for diagnosis / treatment			
H-14-01	Open flame: Hot work, cutting and welding	• Personnel contact with flames or sparks	• Failure to follow safe work procedures	• Personnel moderate injury	3	2	**S**	• Training and competence of maintenance personnel • Hot work permit required with associated safe work practices / procedures • Tool box talks / job safety analysis / risk assessments prior to hot work (cutting/ welding) • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment	2	1	**A**
H-15-01	Electricity: Commissioning and maintenance of electrical equipment (high and low voltage equipment, power distribution and switchgear)	• Electrical shock from un-isolated power cables / equipment	• Faulty wiring • Failure to follow safe work procedures	• Risk of very serious injury or fatality	2	4	**S**	• Crew training and competence • Permit to work required with associated safe work practices / procedures including electrical isolation • Tool box talks / job safety analysis / risk assessments prior to work on electrical equipment • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment	1	4	**S**

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-16-01	Electromagnetic radiation: Thermal radiation from flare	• Harmful temperatures during flaring	• Flare exceeds maximum rating • Flare height too short • Incorrect flare angle selection • Failure to follow safe work procedures	• Risk of serious injury and / or partial permanent disability • Inability to egress due to heat	2	3	S	• Flare vendor completion of flare sizing requirements • Thermal radiation calculations in design to ensure radiation levels acceptable • Medical facilities for diagnosis / treatment	1	2	A
H-16-02	Electromagnetic radiation: Thermal radiation well test burners	• Harmful temperature from well test burners	• Mechanical failure • Failure to follow safe work procedures	• Risk of serious injury and / or partial permanent disability • Inability to egress due to heat	2	3	S	• Crew training and competence • Water curtain to limit thermal radiation at the drillship • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment	1	3	A
H-16-03	Electromagnetic radiation: Welding (heat and light)	• Personnel exposure to welding radiations	• Failure to follow safe work procedures	• Eye and skin damage (serious injury and / or partial permanent disability)	2	3	S	• Crew training and competence • Permit to work required with associated safe work practices / procedures • Tool box talks / job safety analysis / risk assessments prior to work permit task • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment	1	2	A
H-17-01	Ionizing radiation open source: Inspection and maintenance of process vessels with build-up of	• Personnel direct exposure to, or in contact with naturally occurring radioactive	• Failure to follow safe work procedures • Failure to follow safe handling procedures	• Risk of contamination or irradiation • Personnel moderate injury	2	2	S	• NORM not anticipated • Crew training and competence • Rigorous safe procedures and requirements for transport,	1	2	A

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
	naturally occurring radioactive materials (NORM)	materials (NORM)						handling and storage of radioactive materials • Workplace health checks			
H-18-01	Ionizing radiation closed source: Use of radioactive sources used during well logging	• Personnel excessive radiation exposure	• Failure to follow safe work procedures • Failure to follow safe handling procedures	• Long term exposure to personnel leading to potential cancer (very serious injury or fatality)	2	4	**S**	• Crew training and competence • Sources of radioactivity are transported and stored in custom-manufactured containers • Sources of radioactivity are handled by trained and competent third-party service provider (e.g., Schlumberger, or another service provider with similar HSE standards) • Rigorous safe procedures and requirements for transport, handling and storage of radioactive materials • Limitations on personnel exposure • Workplace health checks	1	3	**A**
H-19-01	Asphyxiates: Entry into confined spaces such as tanks and vessels	• Asphyxiation during confined space entry	• Shortage of oxygen • Contaminated atmosphere • Failure to follow safe work procedures	• Risk of very serious injury or fatality, including emergency responders	2	4	**S**	• Crew training and competence • Permit to work required with associated safe work practices / procedures • Tool box talks / job safety analysis / risk assessments prior to confined space entry • Testing of atmosphere prior to entry	1	4	**S**

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
								• Formal authorization prior to access to any confined spaces • Appropriate personnel protective equipment (PPE) worn • Continual monitoring by another person stationed outside the confined space • Emergency response equipment and procedures for rescue / recovery of people in confined spaces, including breathing apparatus • Medical facilities for diagnosis / treatment			
H-19-02	Asphyxiates: Areas with gaseous fire extinguishing systems (e.g., CO_2) such as electrical switchgear room, engine rooms, machinery spaces	• Accidental release of oxygen suppressor gas (like CO_2) from gaseous fire extinguishing systems	• Failure to isolate oxygen suppressor systems during maintenance • Incorrect handling of gas cylinders	• Cold burns • Risk of asphyxiation (very serious injury or fatality)	2	4	S	• Crew training and competence • Permit to work required with associated safe work practices / maintenance procedures and lock-out arrangements • Tool box talks / job safety analysis / risk assessments prior to work permit task • Medical facilities for diagnosis / treatment	1	4	S
H-19-03	Asphyxiates: Nitrogen systems	• Accidental release of nitrogen	• Failure to isolate N_2 systems during maintenance • Failure to purge systems containing N_2	• Risk of asphyxiation (very serious injury or fatality)	2	4	S	• Crew training and competence • System purging procedures • Permit to work required with associated safe work practices / maintenance procedures and lock-out arrangements	1	4	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
			before starting maintenance • Incorrect handling of Nitrogen gas cylinders					• Tool box talks / job safety analysis / risk assessments prior to work permit task • Medical facilities for diagnosis / treatment			
H-19-04	Asphyxiates: Lack of oxygen during air diving operations	• Lack of oxygen during diving operations	• Mechanical failure of compressor or hose • Human error	• Risk of very serious injury or fatality	2	4	**S**	• Training and competence of diving personnel • Regular inspections and preventive maintenance of diving equipment • Back-up oxygen tanks • Communication systems with topsides • Diver or support vessels to rescue person from the water • Medical facilities for diagnosis / treatment	1	4	**S**
H-19-05	Asphyxiates: Gas from cryogenic liquid spills (LNG and its refrigerant)	• Inadvertent release of cryogenic liquid fluid with large vapourisation	• Failure to purge systems containing cryogenic liquid before starting maintenance	• Cryogenic burns • Risk of asphyxiation (very serious injury or fatality)	2	4	**S**	• Crew training and competence • Permit to work required with associated safe work practices / maintenance procedures and lock-out arrangements • Tool box talks / job safety analysis / risk assessments prior to work permit task • Medical facilities for diagnosis / treatment	1	4	**S**

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-20-01	Toxic gas: Welding (exhaust fumes)	• Intoxication of personnel during welding	• Accumulation of exhaust fumes in enclosed spaces	• Irritation to eyes, nose and throat • Headache, dizziness, and fatigue • Occupational asthma • Lung disease from long term exposure • Personnel serious injury and / or partial permanent disability	3	3	U	• Crew training and competence • Permit to work required with associated safe work practices / procedures • Tool box talks / job safety analysis / risk assessments prior to work permit task • Ventilation systems in enclosed spaces and when welding • Appropriate personnel protective equipment (PPE) worn if welding fumes are toxic • Medical facilities for diagnosis / treatment	2	2	S
H-20-02	Toxic gas: Turbines, engines, diesel driven pumps, generators (exhaust fumes)	• Intoxication of personnel when working near turbines, engines, diesel driven pumps, generators	• Malfunction of combustion in turbines, engines, pumps and generators • Accumulation of exhaust fumes in enclosed spaces	• Irritation to eyes, nose and throat • Headache, dizziness, and fatigue • Occupational asthma • Lung disease from long term exposure • Personnel serious injury and / or partial permanent disability	3	3	U	• Crew training and competence • Exhaust routed to safe area to minimize impact on personnel • Regular inspections and preventive maintenance of combustion engine driven equipment • Ventilation systems in enclosed spaces with combustion engine • Medical facilities for diagnosis / treatment	2	2	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-20-03	Toxic gas: Hydrogen sulphide (H_2S) due to bacterial activity in stagnant water and confined spaces	• Personnel exposure to H_2S during confined space entry	• Stagnant water • Sulphate reducing bacteria (SRB)	• Risk of very serious injury or fatality, including emergency responders	2	4	S	• Crew training and competence • Design avoids potential for areas where stagnant water may collect, wherever possible • Permit to work required with associated safe work practices / procedures • Tool box talks / job safety analysis / risk assessments prior to confined space entry • Testing of atmosphere prior to entry • Formal authorization prior to access to any confined spaces • Appropriate personnel protective equipment (PPE) worn • Continual monitoring by another person stationed outside the confined space • Emergency response equipment and procedures for rescue / recovery of people in confined spaces, including breathing apparatus • Medical facilities for diagnosis / treatment	1	4	S
H-21-01 H-22-01	Toxic liquid: Toxic fluid hazards Toxic solid: Toxic solid hazards	• Direct exposure to, or in contact with, irritating, corrosive, or toxic products	• Spillage • Failure to follow safe work (handling) procedures	• Risk of burns (due to contact) or poisoning (due to inhalation or ingestion) • Respiratory issues from inhalation	3	2	S	• Crew training and competence • Procedure for safe handling of chemical products • MSDS available for all toxic substances	1	2	A

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
				• Personnel moderate injury				• Tool box talks / job safety analysis / risk assessments prior to handling toxic products • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment			
H-23-01	Corrosives	• Direct exposure to, or in contact with, irritating, corrosive, or toxic products	• Spillage • Failure to follow safe work (handling) procedures	• Risk of burns (due to contact) or poisoning (due to inhalation or ingestion) • Personnel moderate injury	3	2	S	• Crew training and competence • Safe handling of chemical products procedures • MSDS available for all corrosive substances • Tool box talks / job safety analysis / risk assessments prior to handling corrosive products • Appropriate personnel protective equipment (PPE) worn • Medical facilities for diagnosis / treatment	1	2	L
H-24-01	Biological: Communicable diseases such as Diphtheria, Hepatitis A, Tetanus, Typhoid, Malaria, and Yellow Fever	• Outbreak of disease	• Mosquitoes (malaria and yellow fever), ticks (lime disease) fleas (plague)	• Risk of very serious injury or fatality	3	4	U	• Training and awareness programs for crew • Vaccinations • Prophylaxis availability • Medical facilities for diagnosis / treatment	2	3	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-24-01	Biological: Contaminated food	• Food poisoning with Food-borne bacteria (e.g. e. coli)	• Failure to follow food safe handling and storage procedures • Outside contamination	• Risk of sickness (food poisoning, diarrhea) • Personnel moderate injury or illness	2	2	S	• Training and competence of cook and catering crew • Safe work procedures and practices for handling and preparation of food • Quality checks of food products when delivered • Regular checks of food preparation areas and cold-storage room • Medical facilities for diagnosis / treatment	1	2	A
H-24-02	Biological: Contaminated water	• Outbreak of contagious disease	• Contaminated water with water-borne bacteria (e.g. legionella)	• Risk of very serious injury or fatality	2	4	S	• Crew training and competence • Reverse osmosis water makers onboard • Regular testing of water quality • Medical facilities for diagnosis / treatment	1	3	A
H-25-01	Human factors: Manual materials handling	• Manual material handling injury	• Lifting • Carrying tools, hoses, bulk chemicals	• Muscle strain • Back injuries • Personnel moderate injury	4	2	S	• Crew training and competence • Safe work procedures for lifting / carrying • Lifting aids • Design of facilities with mechanical handling / rails to help with move heavy / awkward loads • Medical facilities for diagnosis / treatment	3	2	S
H-25-02	Human factors: Vibration	• Fatigue, muscular difficulties	• Repetitive use of vibrating hand tools • Failure to follow safe work	• Risk of minor injury	2	1	A	• Crew training and competence • Safe work procedures for handling tools • Selection and maintenance of tools to minimise vibration	2	1	A

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
			(handling) procedures					• Medical facilities for diagnosis / treatment			
H-25-03	Human factors: Poor lighting	• Extended exposure to low-light working areas	• Inadequate lighting of facilities	• Eye strain • Fatigue • Personnel minor injury	2	1	A	• Crew training and awareness • Workplace ergonomic assessments • Medical facilities for diagnosis / treatment	2	1	A
H-25-04	Human factors: Poorly positioned / laid out controls	• Inefficient control layout for actions	• Poor ergonomic design • Human error	• Potential delay in execution of control measures leading to event escalation • Personnel serious injury and / or partial permanent disability	2	3	S	• Crew training and awareness • Workplace ergonomic assessments • Equipment testing • Medical facilities for diagnosis / treatment	2	2	S
H-25-05	Human factors: Awkward location of workplaces, workstation and machinery areas	• Back pain, musculoskeletal disorders	• Prolonged adoption of an awkward posture	• Risk of chronic minor injury	3	1	A	• Crew training and awareness • Design of facilities includes human factors and ergonomic assessments to minimise potential hazards and risks associated with awkward posture during operation / maintenance • Workplace ergonomic assessments • Medical facilities for diagnosis / treatment	2	1	A
H-25-06	Human factors: Poor organization and job design	• Poor job design leading to an accident or operational inefficiency	• Human error • Lack of pre-job planning	• Inability to complete job safely and efficiently	2	3	S	• Crew training and competence • Tool box talks / job safety analysis / risk assessments prior to starting a job	2	2	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
				• Personnel serious injury and / or partial permanent disability				• Medical facilities for diagnosis / treatment			
H-25-07	Human factors: Heat stress	• Extended exposure to high temperatures	• High ambient temperatures in the region • Residual heat from process equipment	• Dehydration • Heat stroke • Risk of very serious injury or fatality	3	4	U	• Crew training and awareness • Air conditioning in high heat / humidity areas • Regular work breaks • Availability of water to rehydrate • Medical facilities for diagnosis / treatment	3	2	S
H-26-01	Psychological: Stress (causes, living on the job / away from family, working and living on a hazardous plant, post-traumatic stress following serious incidents, injuries to self)	• Personnel under high stress	• Family tragedy / away from home • Working and living on a hazardous plant • Post-traumatic stress following serious incident / accident, injuries to self	• Increased risk of accident with moderate injury	3	2	S	• Crew training and awareness • Leave of absence • Counseling • Medical physicals for personnel	2	2	S
H-26-02	Psychological: Fatigue from shift work	• Accumulation of fatigue from shift work	• Lack of rest	• Increased risk of accident with moderate injury	3	2	S	• Crews training and awareness • Work and shift limitations • Leave of absence • Medical physicals for personnel	2	2	S
H-29-01	Medical: Medical unfitness	• Personnel not medically fit to carry out job	• General health • Lack of rest	• Increased risk of accident	3	2	S	• Crew training and awareness • Leave of absence • Medical physicals for personnel	2	2	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
				• Personnel moderate injury							
H-29-02	Medical: Sea sickness	• Excessive sea motions and sickness on vessels	• Weather • General sea state	• Increased risk of accident with moderate injury	3	2	S	• Crew training and awareness • Weather / sea state restrictions for marine operations • Sea sickness medication • Medical facilities for diagnosis / treatment	2	2	S
H-30-01	Noise: High noise levels in machinery and process workplaces	• Excessive working noise	• High noise from plant and equipment (generators, compressors, flare, pumps, engines, etc.) • Damaged or removed noise insulation	• Noise induced hearing loss • Increase fatigue of personnel • Personnel serious injury and / or partial permanent disability	3	3	U	• Crew training and competence • Noise assessment and maps undertaken as part of design process to identify high noise areas and feed into appropriate design and operational hazard mitigation • High noise equipment located remote from accommodations • Protection for high noise equipment including enclosures, silencers, surface material application for sound insulation • Appropriate personnel protective equipment (PPE) worn (ear plugs, ear muffs) • Medical facilities for diagnosis / treatment	2	2	S

ID	Hazard	Accident Event	Causes	Consequences	Initial Risk			Prevention, Control and Mitigation	Residual Risk		
					L	S	R		L	S	R
H-30-02	Noise: Intrusive noise in sleeping areas, offices and recreational areas	• Personnel exposed to repeated excessive noise in accommodation	• Intrusive noise in sleeping areas, offices and recreational areas	• Noise induced hearing loss • Increase fatigue of personnel • Personnel serious injury and / or partial permanent disability	3	3	U	• Crew training and awareness • Noise assessment and maps undertaken as part of design process to identify high noise areas and feed into appropriate design and operational hazard mitigation • High noise equipment located remote from accommodations • Protection for high noise equipment including enclosures, silencers, surface material application for sound insulation • Accommodations insulation • Medical facilities for diagnosis / treatment	2	2	S

APPENDIX O-5 : FAULT/EVENT TREE BOWTIE APPROACH EXAMPLE (D-01 BLOWOUT OR WELL RELEASE)

Figure AO-5.1: Bowtie D-01 Blowout or Well Release (Fault/Event Tree Approach) (Left Hand Side)

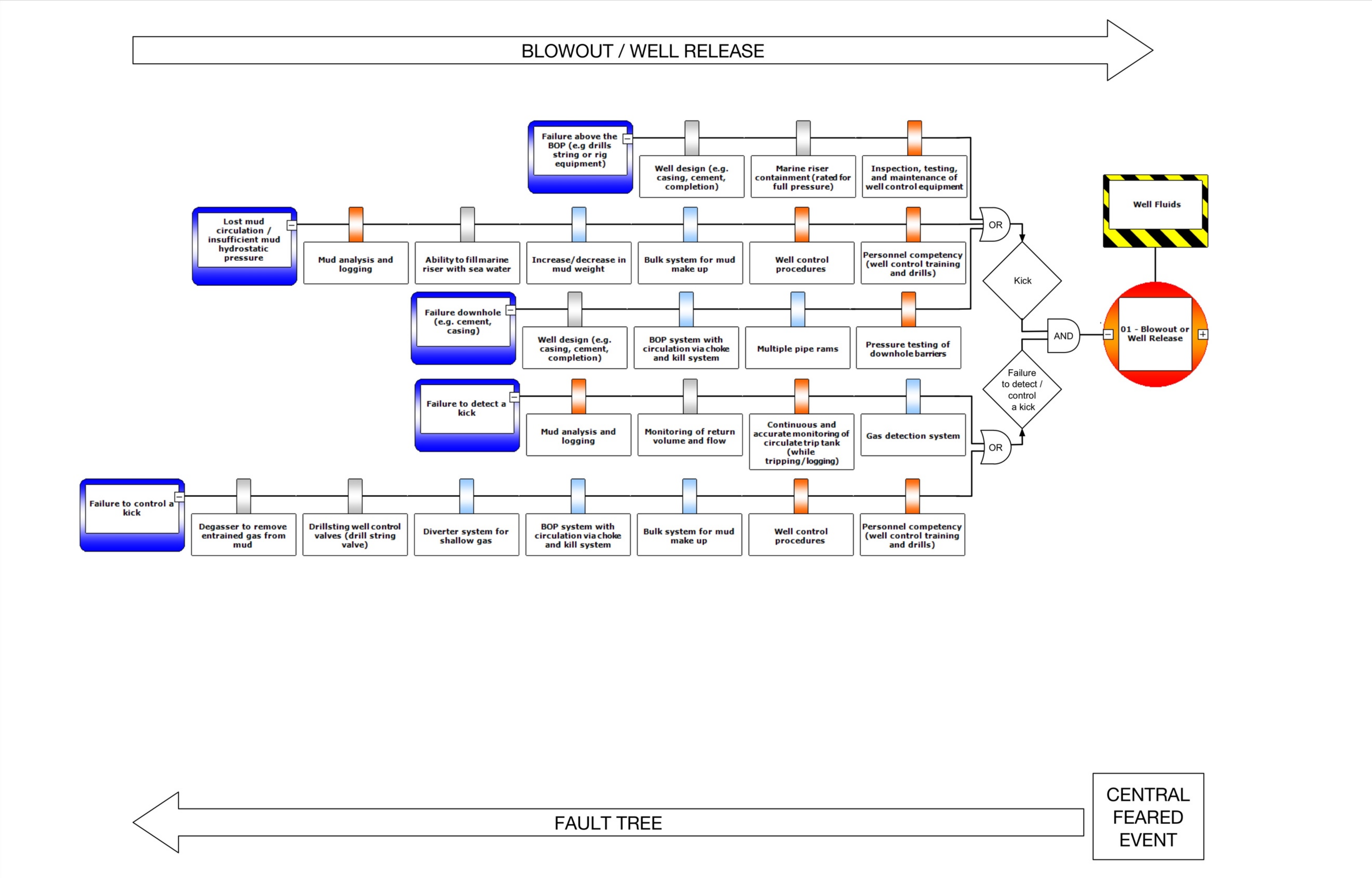
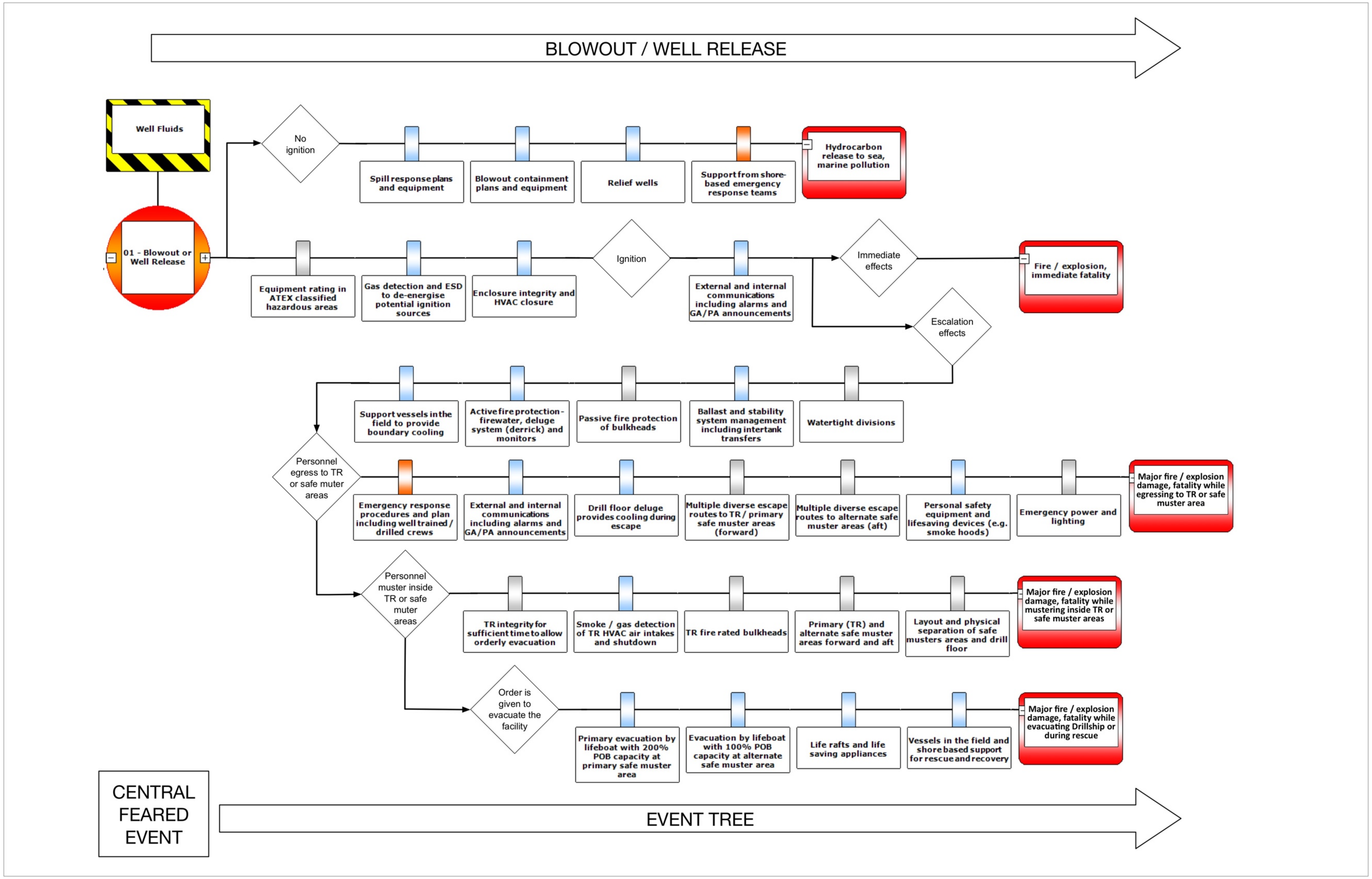


Figure AO-5.2: Bowtie D-01 Blowout or Well Release (Fault/Event Tree Approach) (Right Hand Side)



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