Preliminary Hazard Analysis

Kogarah Golf Club Redevelopment - Concept & Early Works SSDA (SSD-84467726)

For Stockland Development Pty Limited

20 March 2026

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Summary

This Preliminary Hazard Analysis (PHA) has been prepared for the Stockland Development Pty limited to accompany a State Significant Development Application (SSDA) (SSD-84467726) for a Concept Masterplan and Early Works associated with the Kogarah Golf Club Redevelopment located on land identified as 13-19A Marsh Street, Arncliffe (the site).

The site of the Kogarah Golf Club is in the vicinity of the APA Moomba-Sydney Ethane Pipeline (MSEP) which originally transported ethane from Moomba in South Australia to Botany, NSW. This pipeline is undergoing conversion to transport natural gas to the east coast gas network. This report has been prepared in accordance with Hazardous Industry Planning Advisory paper (HIPAP) No.6 [1] developed by the New South Wales Department of Planning, Housing and Infrastructure (DPHI).

Based on a comprehensive review of pipeline safety literature, a set of failure scenarios were selected for the pipeline, varying from a small hole of 10-25mm in diameter to a full-bore rupture (FBR). Immediate ignition of release gas would result in a jet fire that will continue until the section of pipeline is isolated, and the isolated inventory depleted. A delayed ignition may result in a flash fire or vapour cloud explosion depending on congestion and may be followed by a jet fire.

Based on generic failure rates for natural gas and liquefied flammable gas pipelines in the literature, the most appropriate data was used for the risk assessment. The latest SAFETI software package (version 9.11) was used for all consequence modelling and the generation of the risk contours and societal risk curves. The resulting risk values were compared with the risk criteria in HIPAP No.10 [2].

The following findings were made from the risk analysis and assessment:

- The Location Specific Individual Risk (LSIR) of fatality risk is below the relevant NSW DPHI risk criteria.
- There is no impediment to sensitive, residential, commercial, active open space, or industrial development on the basis of LSIR. Such developments, however, are still subject to the limitation of population to ensure societal risk (SR) criteria is satisfied.
- The injury, property damage and accident propagation risks are below the relevant NSW DPHI risk criteria.
- The current maximum societal risk is within the Negligible zone of the DHPI societal risk criteria presented in HIPAP 6 and HIPAP 10.
- Recommendations have been made to reduce risk to occupants of buildings and ensure occupiers of buildings do not engage in business activities that are inconsistent with the risk presented by the pipeline.

This PHA addresses the relevant Planning Secretary’s Environmental Assessment Requirements

(SEARs) for SSD-84467726, as outlined in Table 1 below.

Table 1 PHA SEARS Compliance Table

Relevant Requirements	Response
SEARS Item 24 Hazards and Risks	Compliant
State Environmental Planning Policy (SEPP) 33	Compliant
HIPAP 4,6 & 10	Compliant

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Notation

Abbreviation	Description
Arriscar	Arriscar Pty Ltd
ARUP	ARUP Australia Pty Ltd
AS	Australian Standard
BoM	Bureau of Meteorology
CIA	Chemical Industry Association (UK)
DoT	Department of Transport (USA)
DP	Deposited Plan
DPHI	NSW Department of Planning, Industry and Environment
EGIG	European Gas Pipeline Incident Data Group
FBR	Full Bore Rupture
F-N	Cumulative Frequency vs. Number of fatalities
GFA	Gross Floor Area
HAZID	Hazard Identification
HDD	Horizontal Directional Drilling
HDPE	High Density Polyethylene
HIPAP	Hazardous Industry Planning Advisory Paper
HP	High Pressure
HVL	Highly Volatile Liquids
kg/s	kilograms/ second
km	kilometres
KP	Kilometre Point (pipeline distance measurement)
kPa	kilo Pascals
kW/m^2	kilo Watts per square metre
LFL	Lower Flammability Limit
LPG	Liquefied Petroleum Gas
LSIR	Location-Specific Individual Risk
m	metres
m/s	metres per second
MAE	Major Accident Event
MAHP	Major Accident Hazard Pipeline
MAOP	Maximum Allowable Operating Pressure

Abbreviation	Description
MIE	Minimum Ignition Energy
mg/m^3	milligrams per cubic metres
mJ	milli Joules
mm	millimetres
MSEP	Moomba-Sydney Ethane pipeline
NG	Natural Gas
NSW	New South Wales
OGP	Offshore Oil & Gas producers Association
OSHA	Occupational safety and Health Agency (USA)
p.a.	per annum
PHA	Preliminary Hazard Analysis
PHMSA	Pipeline and Hazardous Materials Safety Administration (USA)
QRA	Quantitative Risk Assessment
SSD	State Significant Development
TNT	Tri-nitro Toluene
TPA	Third Party Activity
UFL	Upper Flammability Limit
UK HSE	United Kingdom Health & Safety Executive
UKOPA	United Kingdom Onshore Pipeline Operators' Association
v/v	volume/volume
VCE	Vapour Cloud Explosion

1 PROJECT OVERVIEW

1.1 Introduction

This Preliminary Hazard Assessment (PHA) has been prepared for the Stockland Development Pty Limited to accompany a State Significant Development Application (SSDA) (SSD-84467726) for a Concept Masterplan and Early Works associated with the Kogarah Golf Club Redevelopment located on land identified as 13-19A Marsh Street, Arncliffe (the site).

The vision for the Kogarah Golf Club Redevelopment is to create a world-class precinct that leverages the site's strategic location adjacent to Sydney Airport and strong transport connections by delivering multi-level logistics development, trade-related enterprise and supporting uses with publicly accessible open space. It seeks to deliver state-of-the-art facilities that will redefine the logistics landscape in Australia, setting new benchmarks for scale, efficiency, sustainability and innovation.

The Concept & Early Works SSDA seeks consent for an overarching Concept Masterplan that establishes maximum building envelopes, Gross Floor Area (GFA), land uses, and other parameters through Urban Design Guidelines and technical reporting. It also seeks consent for the carrying out of Early Works to facilitate the initial site preparation and infrastructure works required to support future development and publicly accessible open space.

1.2 Background

A Planning Proposal (PP-2022-1748) was previously submitted by John Boyd Properties for the site to amend and integrate planning controls into the Bayside Local Environmental Plan 2021 (Bayside LEP 2021). It sought to deliver refreshed planning controls that prioritise land uses which support the adjacent Sydney Airport, as one of Australia's most important trade gateways.

The Planning Proposal was granted Gateway Determination on 5 August 2022 and publicly exhibited between 24 April 2023 and 6 June 2023. It was determined to proceed to finalisation in March 2024, with the amendments to the Bayside LEP 2021 gazetted on 9 May 2025.

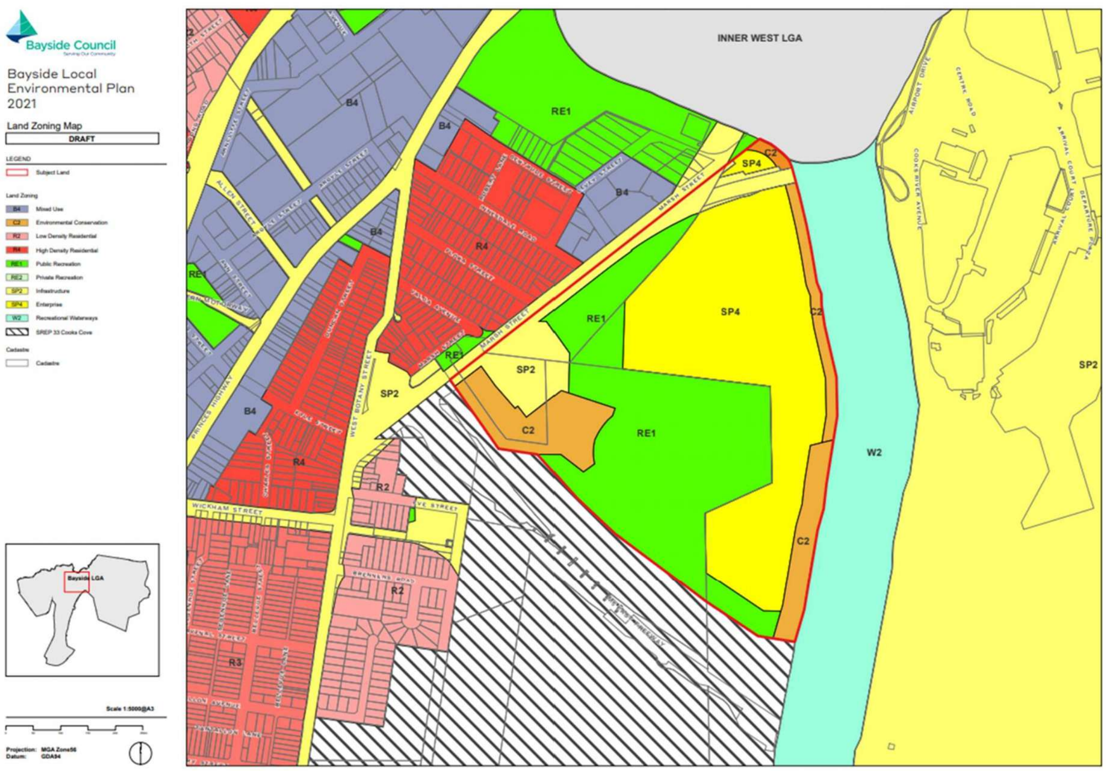
The amendments to the Bayside LEP 2021 are described as follows:

- Application of land uses, including:
    - SP4 Enterprise zone to form a development zone;
    - RE1 Public Recreation zone to facilitate the future Pemulwuy Park and overland flow areas.
    - C2 Environmental Conservation zone to enable the protection and conservation of land, including a foreshore zone; and
    - SP2 Infrastructure zone for land associated with the Marsh Street roadway and permanent M6/M8 Motorway Operation Facilities.
- An overall maximum building height of RL 51m (Lot 100 DP 1231954) graduating down to RL 40m in response to aviation controls in the south, and a maximum building height of 24m (Lot 31 DP 1231486).
- A total GFA of 343,250m², applied through:
    - Lot 31 DP 1231486 – A maximum FSR of 1.25:1 (3,250m²);

   - Lot 100 DP 1231954 – A total floorspace that does not exceed 340,000m² of GFA, inclusive of:
      - A maximum 20,000m² GFA for ‘office premises.
      - A maximum 20,000m² GFA for ‘hotel or motel accommodation’ and ‘serviced apartments’; and
      - A maximum 10,000m² GFA for ‘shops’ and ‘food and drink premises.
- Application of additional permitted uses including ‘Trade-related enterprises’ (Lot 100 DP 1231954) and ‘Advertising structures’ (Lot 31 DP 1231486).

The Land Zoning Map associated with the Planning Proposal is presented in Figure 1 below:

Figure 1 Land Zoning Map – Planning Proposal (PP-2022-1748)



1.3 Scope

This PHA addresses the relevant Planning Secretary’s Environmental Assessment Requirements (SEARs) for SSD-84467726 [3]. The relevant requirement is listed below:

Hazards and Risk – including:

- *a preliminary risk screening completed in accordance with State Environmental Planning Policy (Resilience and Hazards) 2021 and Applying SEPP 33 (DoP, 2011), that includes a clear indication of class, storage and handling quantities and location of all dangerous goods and hazardous materials associated with the development*
- *a Preliminary Hazard Analysis (PHA) prepared in accordance with Hazardous Industry Planning Advisory Paper No. 6 – Guidelines for Hazard Analysis (DoP, Page 5 of 11 2011) and*

Multi-Level Risk Assessment (DoP, 2011), should the preliminary risk screening indicate that the project is "potentially hazardous".

- *a hazard analysis that reports on the consultation outcomes with the adjoining pipeline corridor and verifies that the scope of the proposal is consistent with the land uses, population limits, and remains compliant with the findings of the recent planning proposal's pipeline risk analysis*

The scope of the PHA did not include preparation of a Safety Management Study (SMS), which may be required under AS 2885-2008 [4]. This is normally undertaken before the commencement of construction once detailed construction program and drawings are developed. A brief discussion on AS-2885-2003 [4] is included in this report.

1.4 Objectives

This PHA aims to confirm the new proposed land uses for the site to satisfy the NSW Department of Planning Housing and Infrastructure (DPHI) criteria for development in the vicinity of hazardous installations, as documented in Hazardous Industry Planning Advisory Paper No. 4 *Risk Criteria for Land Use Safety Planning* (HIPAP 4) [5].This document comprises the hazard analysis conducted in accordance with the requirements of HIPAP 6 *Hazard Analysis* [1]. This includes:

- Identification of gas release hazards from the MSEP in the vicinity of the development.
- Development of appropriate and relevant representative gas release scenarios that may impact on the site.
- Quantification of the consequences of harmful effects for each representative scenario (fires, explosions, exposure to unignited gas), including the potential for impact on the proposed development.
- Quantification of the likelihood of occurrence of each representative scenario;
- Development and justification of assumptions for the risk assessment that are appropriate, with a focus on minimising uncertainty and obtaining a 'cautious best estimate' of risk to the proposed development; and
- Generation of Location-Specific Individual Risk (LSIR) contours for comparison with the DPHI's risk criteria for land use safety planning, viz. as per HIPAP No.4 [5] and HIPAP No.10 [2].
- Estimation of Societal Risk for comparison with the DPHI's risk criteria for land use safety planning (HIPAP No.4 [5] and HIPAP No.10 [2]).

2 SITE LOCATION AND SURROUNDS

2.1 Site Location and surrounding land use

The site is identified as 13-19A Marsh Street, Arncliffe within the Bayside Local Government Area (LGA). It is situated to the immediate west of the Cooks River and Sydney Airport, located approximately 6 km west of Port Botany and 10 km south of the Sydney Central Business District (CBD). It includes frontages to Marsh Street, providing direct access to the M5 Motorway, Sydney Airport and St Peter's Interchange (via the Sydney Gateway).

The site comprises land associated with nine (9) allotments and a total area of approximately 32 hectares. The existing uses include the previous Kogarah Golf Club (vacated in March 2025) accessed via Levey Street and the temporary M6 Stage 1 construction compound accessed directly from Marsh Street.

he development area represents Lot 31 DP1231486 and Lot 100 DP1231954, excluding land subject to future dedication to Bayside Council. It comprises an area of approximately 16.7 hectares and is zoned SP4 Enterprise and C2 Environmental Conservation under the Bayside LEP 2021.

The site is described in Table 2, with the extent of the site and development area depicted in Figure 2 following:

Table 2 Site Description

Lot & DP	Address	Ownership
Lot 31 DP 1231486	19 Marsh Street, Arncliffe	Cook Cove Nominees No 1 Pty Ltd as trustee of Cook Cove Property Trust 1
Lot 100 DP 1231954	19A Marsh Street, Arncliffe	Cook Cove Nominees No 2 Pty Ltd as trustee of Cook Cove Property Trust 2
Lot 60 DP 1301057	13 Marsh Street, Arncliffe	Bayside Council
Lot 61 DP 1301057	19 Marsh Street, Arncliffe	Bayside Council
Lot 62 DP 1301057	Marsh Street, Arncliffe	Transport for NSW
Lot 63 DP 1301057	Marsh Street, Arncliffe	Transport for NSW
Lot 12 DP 570900	Marsh Street, Arncliffe	Transport for NSW
Lot 102 DP 1231954	Marsh Street, Arncliffe	Transport for NSW
Lot 103 DP 1231954	Marsh Street, Arncliffe	Transport for NSW

Figure 2 Site Aerial Map

2.2 Project Description

The Concept & Early Works SSDA seeks consent for the following:

1. Concept Masterplan to support the staged delivery of the Kogarah Golf Club Redevelopment, including:
   - Maximum building envelopes, including maximum building heights and minimum setbacks.
   - Maximum Gross Floor Area (GFA) up to 343,250 m², comprising;
     - 3,250 m² of GFA (FSR of 1.25:1) on Lot 31 DP 1231486; and
     - 340,000 m² of GFA on Lot 100 DP1231954.
   - Land uses, including the following primary uses:
     - Block 1 – Mixed use and advertising structures;
     - Block 2 – Logistics and mixed use;
     - Block 3A – Logistics;

    - Block 3B – Logistics; and
    - Block 3C – Logistics and data centres.
- Urban Design Guidelines to guide future development of the built form and public domain.
- Strategies and mitigation measures to manage potential environmental impacts.

2. Early Works to support future delivery of built form and publicly accessible open space, including:

- Site preparation works, comprising:
    - Demolition of existing structures.
    - Clearing of existing vegetation;
    - Remediation works; and
    - Bulk earthworks, including ground improvement and flood mitigation works
- Site servicing and infrastructure works, including:
    - Construction of the Flora Street East extension consistent with Item 3 of the executed Voluntary Planning Agreement with Bayside Council;
    - Construction of stormwater infrastructure; and
    - Construction and augmentation of service and utility infrastructure as necessary.

For a detailed description, refer to the Environmental Impact Statement prepared by Colliers Urban Planning.

The Concept Masterplan is supported by Indicative Reference Schemes that present as 'proof of concepts' within the proposed framework. The schemes demonstrate suitable primary land use, built form and public domain outcomes that align with the vision for a world-class precinct that leverages the site's strategic location adjacent to Sydney Airport and strong transport connections.

The Indicative Reference Schemes consider different potential development outcomes enabled by the Concept Masterplan to support the delivery of the highest and best use at the time of redevelopment. This includes a Logistics scheme and Alternative Uses scheme, which facilitate the potential for four (4) different primary land use outcomes across the Site. The alternative land use outcomes enabled by the Concept Masterplan include an alternative mixed-use outcome on Block 2 and alternative data centre outcome on Block 3C.

The Indicative Reference Schemes are established in Figure 3, with the Logistics scheme and Alternative Uses scheme prepared by Grimshaw depicted in Figure 4 and Figure 5.

It is noted that the Indicative Reference Schemes are indicative only and the development of future built form and publicly accessible open space will be subject to future Development Applications. The Indicative Reference Schemes demonstrate the ability to support different potential outcomes, consistent with the proposed framework under the Concept Masterplan including Urban Design Guidelines.

Figure 3 Indictive Reference Schemes

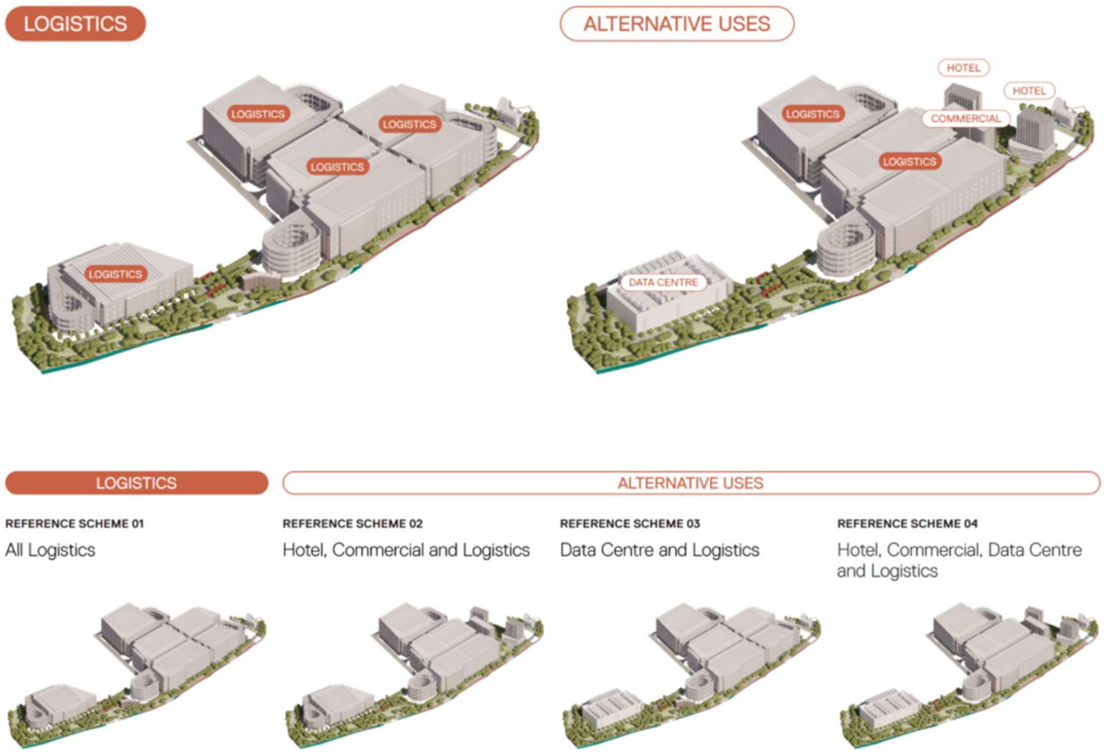


Figure 4 Indictive Reference Scheme – Logistics Scheme

Figure 5 Indicative Reference Scheme – Alternative Uses Scheme

The development yield associated with each land use outcome under the Indicative Reference Schemes is presented in Table 3 below.

Table 3 Land Use Matrix – Indicative Reference Schemes

Primary Land Use	Reference Scheme 1 Logistics	Reference Scheme 2 Logistics + Mixed-use	Reference Scheme 3 Logistics + Data Centre	Reference Scheme 4 Logistics + Mixed-use + Data Centre
Lot 31 DP1231486 (Block 1)				
Hotel	1,670m² (64 keys)			
Commercial	1,260m²			
F&B / Shops / Artisan F&B	320m²			
TOTAL	3,250m²			
Lot 100 DP1231954 (Block 2, 3A, 3B, 3C)				
Warehouse	336,200m²	293,000m²	276,200m²	231,600m²
F&B / Shops	1,950m²	10,000m²	1,850m²	10,000m²
Hotel	-	20,000m² (300 keys)	-	20,000m² (300 keys)
Commercial	1,850m²	17,000m²	1,850m²	17,000m²
Data Centre	-	-	25,400m² (80MW)	25,400m² (80 MW)
TOTAL	340,000m²	340,000m²	305,300m²	304,000m²

2.2.1 Meteorological Data

Sydney airport observations have been processed to develop two sets of weather conditions for day (one hour after sunrise, and one hour before sunset) and night. The weather categories are identified by their Stability Class (A – F), and windspeed. Weather conditions used for the analysis are presented in Table 4 and Table 5.

Table 4 Night-time Meteorology

Weather Category		8.3D	4.2D	1.0D	3.3E	1.0F	**Total**
Stability Class		D	D	D	E	F	
Wind speed [m/s]		8.3	4.2	1	3.3	1	
Temperature [°C]		17.57	16.74	16.8	15.27	15.89	
Relative Humidity		0.72	0.76	0.83	0.76	0.81	
Solar Radiation [kW/m²]		0.01	0.01	0.02	0	0	
Direction	**N**	0.011	0.006	0.037	0.023	0.026	**0.103**
	NNE	0.030	0.003	0.028	0.012	0.013	**0.086**
	NE	0.012	0.002	0.019	0.008	0.010	**0.051**
	ENE	0.003	0.002	0.009	0.003	0.006	**0.023**
	E	0.005	0.002	0.016	0.004	0.006	**0.033**
	ESE	0.007	0.001	0.013	0.003	0.005	**0.029**
	SE	0.014	0.002	0.016	0.003	0.004	**0.039**
	SSE	0.025	0.001	0.014	0.003	0.004	**0.047**
	S	0.061	0.002	0.025	0.005	0.006	**0.099**
	SSW	0.027	0.001	0.015	0.004	0.004	**0.051**
	SW	0.012	0.002	0.015	0.006	0.006	**0.041**
	WSW	0.017	0.002	0.021	0.010	0.010	**0.060**
	W	0.025	0.004	0.031	0.016	0.018	**0.094**
	WNW	0.008	0.004	0.022	0.017	0.017	**0.068**
	NW	0.006	0.006	0.033	0.024	0.024	**0.093**
	NNW	0.004	0.004	0.029	0.025	0.019	**0.081**
	TOTAL	**0.268**	**0.044**	**0.344**	**0.166**	**0.178**	**1.000**

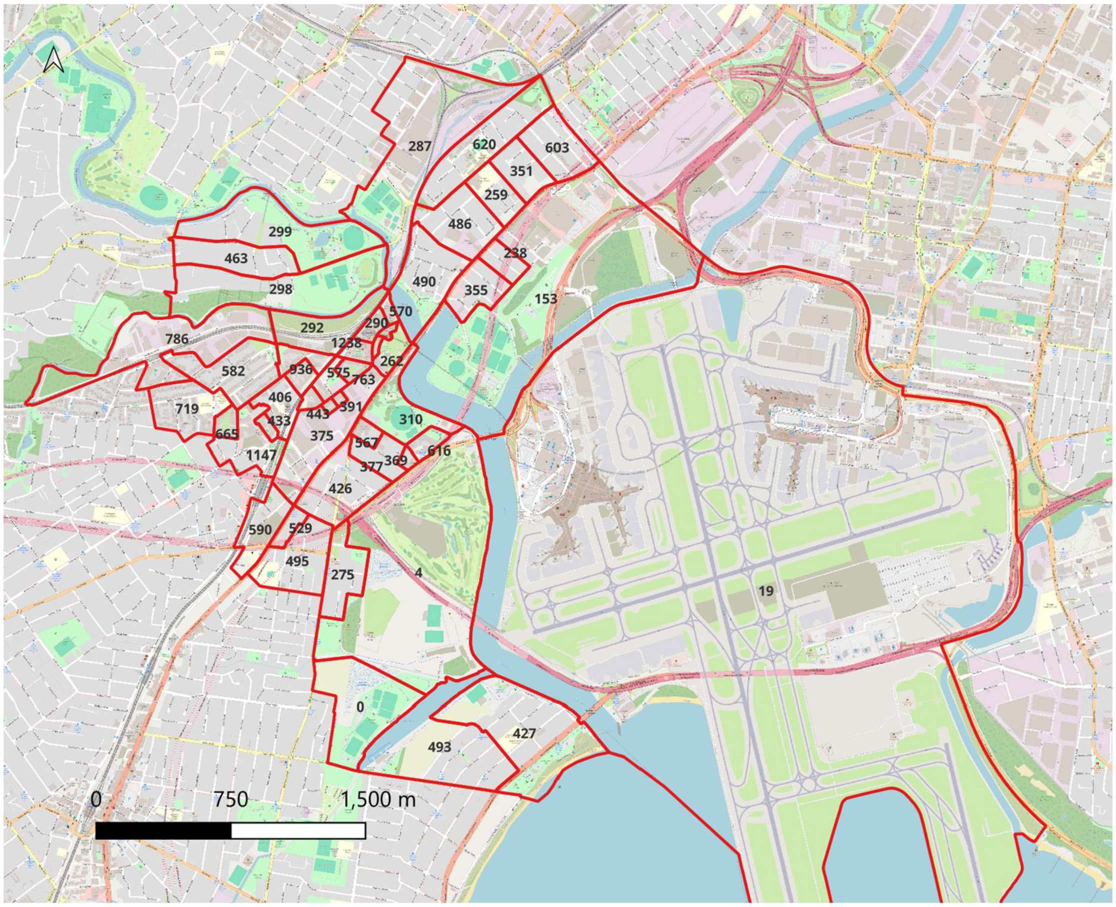
Table 5 Day-time Meteorology

Weather Category		2.2B	8.5D	4.2D	1.6D	
Stability Class		B	D	D	D	
Wind speed [m/s]		2.2	8.5	4.2	1.6	
Temperature [°C]		21.9	21.0	19.5	18.4	
Relative Humidity		0.6	0.6	0.6	0.7	
Solar Radiation [kW/m^2]		0.6	0.5	0.4	0.3	**Total**
Direction	N	0.010	0.012	0.003	0.025	**0.050**
	NNE	0.007	0.038	0.002	0.016	**0.063**
	NE	0.006	0.060	0.001	0.017	**0.085**
	ENE	0.004	0.029	0.001	0.014	**0.049**
	E	0.009	0.019	0.002	0.027	**0.058**
	ESE	0.005	0.013	0.001	0.020	**0.039**
	SE	0.006	0.026	0.002	0.027	**0.060**
	SSE	0.010	0.034	0.002	0.023	**0.070**
	S	0.006	0.114	0.002	0.036	**0.158**
	SSW	0.003	0.032	0.002	0.013	**0.049**
	SW	0.003	0.007	0.002	0.010	**0.022**
	WSW	0.004	0.017	0.003	0.013	**0.037**
	W	0.008	0.034	0.005	0.028	**0.076**
	WNW	0.009	0.017	0.005	0.036	**0.067**
	NW	0.012	0.011	0.005	0.048	**0.076**
	NNW	0.008	0.008	0.003	0.021	**0.040**
	TOTAL	**0.010**	**0.287**	**0.219**	**0.484**	**1.000**

2.2.2 Surrounding Population

The surrounding residential population has been based on the 2021 Census. Figure 6 shows Statistical Area 1(SA1) boundaries and the population of those areas.

Figure 6 Surrounding Residential Population (Usual Residents 2021 Census)



2.3 APA Moomba-Sydney Ethane Pipeline (MSEP)

Information obtained from APA for the Moomba–Sydney Ethane Pipeline (MSEP) at the site location is presented in Table 6. APA has recently undertaken a major infrastructure transition to repurpose the MSEP, originally constructed in the 1970s to transport ethane to industrial customers in Botany into a natural gas transmission pipeline. This conversion forms part of APA's East Coast Grid Expansion Program and enables an additional 25 TJ/day of southbound gas capacity to Sydney. Following the conversion, the MSEP continues to be operated and maintained in accordance with the requirements of AS 2885, consistent with APA's transmission pipeline safety and integrity management framework.

Pipeline Owner	**APA Group**
Pipeline Name	Moomba–Sydney Ethane Pipeline (MSEP) – Repurposed for Natural Gas
Material/s Transferred	Natural Gas (Methane)
Licence	Licensed transmission pipeline under the Pipelines Act 1967 (NSW)

Original Year of Construction	1974–1976 (originally constructed for ethane service; conversion to methane completed 2025)
MAOP	10,000 KPa
Normal Operating Pressure	8200KPa TBC
Operating Temperature	Typical approx. 20°C
Flowrate	25 TJ/day
Pipeline Material	High-strength carbon steel (API 5L ERW X52)
Pipeline Diameter	DN200
Wall Thickness	8.1mm TBC
Depth of Cover	1200mm (Minimum)
Cathodic Protection	The pipeline is fully protected according to AS2832
External / Internal Coating/s	HDPE (Yellowjacket) , (internal coating not specified publicly)
Leak Detection	TBC
Locations of Nearest Isolation Valves	Mainline Valve (MLV) at KP 1344 – Moorebank and MLV at KP 1368 – Marsh St (bounding the Kogarah Golf Club site section KP 1365–136
Inspections and Maintenance	APA pipelines are maintained in accordance with Australian Standard AS2885 [4]
Control Measures for Third Party Activity (TPA)	TBC
Pigging	Intelligent pigging used for wall-thickness monitoring and corrosion inspection; defect verification via targeted digs or direct examination.

Table 6 APA Moomba-Sydney Pipeline Details

The following assessments of equipment with the potential to cause external damage to the MSE has been made for locations near the development:

Max equipment sizes without risk of a leak (B Factor 1.3):

- Excavator with General Purpose Teeth, will not cause leak
- Excavator with Tiger Teeth (Single Point Penetration) 25T
- Excavator with Twin Tiger Teeth (Both Points Penetrate), will not cause leak

Max equipment sizes without causing risk of Rupture (B Factor 1.3):

- Excavator with General Purpose Teeth, will not rupture
- Excavator with Twin Tiger Teeth (Single Point Penetration) 55T
- Excavator with Twin Tiger Teeth (Both Points Penetrate) 55T

3 Risk Assessment Methodology

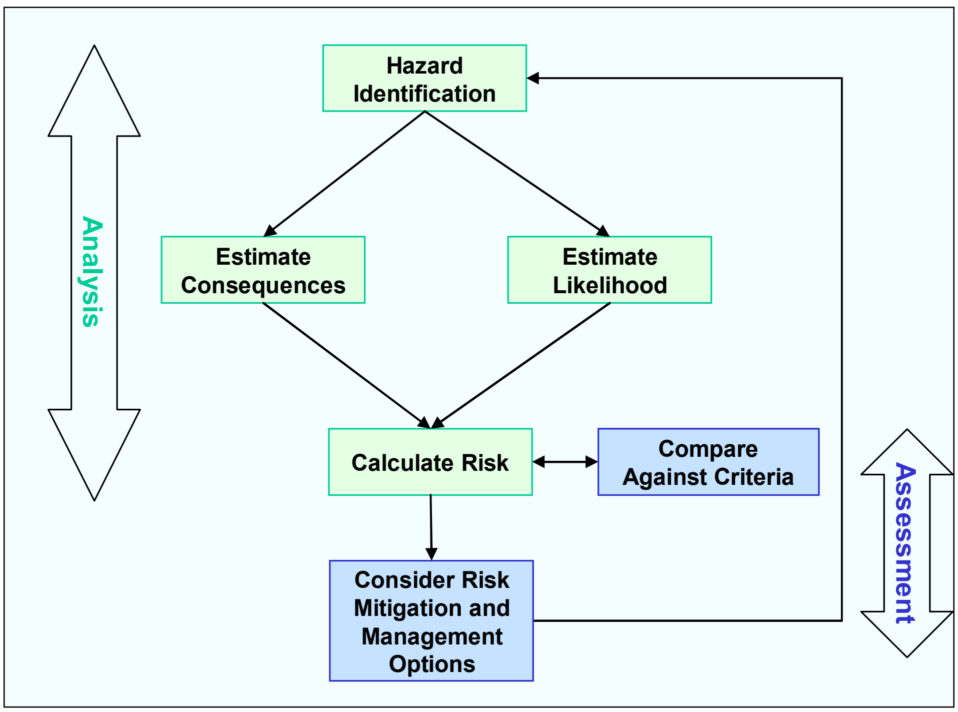
3.1 Introduction

This analysis involves the quantitative estimation of the consequences and likelihood of accidents (viz. a Quantitative Risk Assessment or QRA). For consequences to people, the most common risk measure is 'individual fatality risk' (viz. The likelihood of fatality per year).

In developing the estimates for use in a QRA, it is important to ensure that any estimates fall on the side of conservatism, particularly where there is uncertainty in the underlying data and assumptions. This precautionary approach uses 'cautious best estimate' values, which, whilst conservative, are still realistic. This approach is consistent with the DPHI's guidelines for undertaking this type of assessment [1].

Diagrammatically, the QRA process is as follows [1]:

Figure 7 Overview of QRA Process



3.2 Methodology Overview

3.2.1 Hazard Identification and Register of Major Accident Events

A hazard is something with the potential to cause harm (e.g. thermal radiation from a fire, physical impact from a moving vehicle or dropped object, exposure to stored energy, etc.). As well as identifying the hazards that exist, it is also important to identify how these hazards could be realised.

For example, the Hazard identification (or HAZID) step for a QRA of a potentially hazardous pipeline would identify representative events that could result in a release of the material from the pipeline with the potential to cause harm (e.g. due to a subsequent ignition and fire/explosion). The representative potentially hazardous events are commonly described as 'Major Accident Events' (or MAEs). In the context of the QRA, an MAE is an event with the potential to cause: off-site fatality or injury; off-site property damage; or, long-term damage to the biophysical environment (i.e. any outcome for which DPHI has defined an acceptable risk criterion – Refer to Section 3.4).

There is no single definitive method for hazard identification (HAZID); however, it should be comprehensive and systematic to ensure critical hazards are not excluded from further analysis.

When identifying hazards for modelling in a QRA, it is necessary to capture the following information, either during the hazard identification process, or as part of the preparation for hazard consequence modelling:

- Hazardous materials and material properties;
- Inventory of hazardous materials that could contribute to the accident;
- How the material is released (e.g. hole in a pipeline);
- The condition of the material prior to release (e.g. compressed gas at a specific temperature and pressure);
- The area/s into which the material is released (e.g. inside an enclosed area, etc.);
- Ambient conditions in the area where the material is released (e.g. air temperature, wind speed and direction, atmospheric stability);
- Locations of ignition sources around the release point; and
- Duration of release before it is isolated.

The above information was used to develop a detailed list of MAEs for the risk assessment. This QRA includes an estimate of the consequences and likelihood of each of these scenarios and aggregates the results to estimate the total risk.

3.2.2 Hazard Consequence Analysis

The physical consequences of a release of potentially hazardous material (e.g. flammable gas, flammable liquid, etc.) are generally dependent on:

- the quantity released;
- the rate of release; and,
- when ignition occurs for fire and explosion events.

The quantity of release depends on the inventory, size of release (viz. assumed equivalent hole diameter) and duration of release (how soon can the release be detected and isolated).

Meteorological conditions, such as wind speed, wind direction and weather stability class have an impact on the extent of the downwind and crosswind dispersion. Location-specific meteorological data is therefore required to undertake a QRA study. The representative wind directions, wind speeds and wind stability classes are normally determined from annual average of weather data available from the Bureau of Meteorology, for the local weather station.

In addition to wind speed, the Pasquill stability class has a significant impact on the vertical and crosswind dispersion of a released gas. Six wind stability classes (A to F) are normally used. Class A refers to more turbulent unstable conditions and Class F refers to more stable (inversion) conditions. Although the probability distribution of Pasquill stability classes is site-specific, it is generally observed that Class F conditions are more likely to occur during the night-time while Class D (neutral) conditions occur during the daytime (sunny conditions).

The wind direction, wind speed and stability class distribution used for the QRA is presented in Appendix A (Assumption No. 3).

The latest SAFETI software package (version 9.11) was used for all consequence modelling and the generation of the risk contours and societal risk curves.

3.2.3 Impairment Criteria

Impairment criteria have been developed for the effects of explosions and fires as outlined below. The impairment criteria adopted for the QRA are included in Appendix A (Section A.6).

Explosion

During a flash fire, acceleration of the flame front can occur due to the turbulence generated by obstacles within the combusting vapour cloud. When this occurs, an overpressure ('shock') wave is generated which has the potential to damage equipment and/or injure personnel.

The impact of explosion overpressure on humans takes two forms:

- For a person in the open, there could be organ damage (e.g. ear drum rupture or lung rupture), that may be considered to constitute serious harm.
- The person could be hit by a flying missile, caused by the explosion, and this can lead to serious injury or even fatality.

The effects of exposure to explosion overpressure are summarised in Table 7

Table 7 Effects of Explosion Overpressure

Overpressure [kPa]	Effect/s
0.3	Loud noise.
1.0	Threshold for breakage of glass.
4.0	Minimal effect in the open. Minor injury from window breakage in building.
7.0	Glass fragments fly with enough force to cause injury. Probability of injury is 10%. No fatality. Damage to internal partitions and joinery of conventional buildings but can be repaired.
14.0	1% chance of ear drum rupture. House uninhabitable and badly cracked.
21.0	10% chance of ear drum rupture. 20% chance of fatality for a person within a conventional building. Reinforced structures distort. Storage tanks fail.
35.0	50% chance of fatality for a person within a conventional building and 15% chance of fatality for a person in the open. House uninhabitable. Heavy machinery damaged. Significant damage to plant.
70.0	100% chance of fatality for a person within a building or in the open. 100% loss of plant.

Fire

The potential for injury or property damage from a fire is determined by the intensity of the heat radiation emitted by the fire and the duration of exposure to this heat radiation.

The effects of exposure to thermal radiation are summarised in Table 8 [1]. The vulnerability criteria used in the risk analysis are included in Appendix A.6.

Table 8 Effects of Thermal Radiation

Heat Radiation [kW/m^2]	Effect/s
1.2	Received from sun in summer at noon.
1.6	Minimum necessary to be felt as pain.
4.7	Pain in 15 to 20 seconds, 1st degree burns in 30 seconds. Injury (second degree burns) to person who cannot escape or seek shelter after 30s exposure.
12.6	High chance of injury. 30% chance of fatality for extended exposure. Melting of plastics (cable insulation). Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure. Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure.
23.0	Fatality on continuous exposure. 10% chance of fatality on instantaneous exposure. Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress temperatures, which can cause failure. Pressure vessel needs to be relieved or failure would occur.
35.0	25% chance of fatality on instantaneous exposure.
60.0	Fatality on instantaneous exposure.

The dominant effect in a flash fire is direct engulfment by flame within the burning cloud. To estimate the magnitude of the flammable gas cloud, the furthest distance from the release location with a concentration equal or above the lower flammability limit (LFL) is estimated using a dispersion model.

3.2.4 Frequency and Likelihood Analysis

Once the consequences of the various accident scenarios have been estimated, it is necessary to estimate the likelihood of each scenario. In a QRA, the likelihood must be estimated in quantitative terms (i.e. occurrences per year). Exponential notation (e.g. 5.0 x 10^{-6} per year or 5E-06 per year) is normally used because the likelihood of a MAE is usually a low number (i.e. less than 1 chance in 1000 to 10000 per year).

The likelihood of each scenario is normally estimated from historical incident and failure data. This is only possible because data on such incidents and failures has been collected by various organisations over a number of years. Various databases and reference documents are now available that provide this data.

When using historical data to forecast the likelihood of a future event, it is important to ensure any specific conditions that existed at the time of the historical event are taken into account. For very low frequency events (i.e. where historical occurrences are very rare), it might not be possible to estimate the likelihood values directly from the historical data and other techniques such as fault tree analysis may be required.

The frequency analysis data and results are summarised in Section 6 and Appendix C.

3.2.5 Risk Analysis and Assessment

Risk analysis and assessment are separate tasks although they are often undertaken together. Risk analysis involves combining the consequence and likelihood estimates for each scenario and then summing the results across all the accident scenarios to generate a complete picture of the risk. The risk assessment step involves comparing the risk results against risk criteria.

Location-specific individual risk (LSIR) contours are usually used to represent off-site risk for a land-use safety QRA study. These iso-risk contours are superimposed on a plan view drawing of the site. Example risk levels that are typically shown as iso-risk contours include: 1×10^{-6} per year, 10×10^{-6} per year and 50×10^{-6} per year.

The iso-risk contours show the estimated frequency of an event causing a specified level of harm at a specified location, regardless of whether or not anyone is present at that location to suffer that harm. Thus, individual iso-risk contour maps are generated by calculating individual risk at every geographic location, assuming a person will be present and unprotected at the given location 100% of the time (i.e. peak individual risk with no allowance for escape or occupancy).

The assessment of risk results involves comparing the results against risk criteria. In some cases, this assessment may be a simple listing of each criterion together with a statement that the criterion is met. In other, more complex cases, the risk criteria may not be met, and additional risk mitigation controls may be required to reduce the risk.

The latest SAFETI 9.11 software package was used to generate the iso-risk contours / transects and societal risk results (Refer to Section 6).

3.3 Study Assumptions

It is necessary to make technical assumptions during a risk analysis. These assumptions typically relate to specific data inputs (e.g. material properties, equipment failure rates, etc.) and modelling assumptions (e.g. release orientations, impairment criteria, etc.).

To comply with the general principles outlined in Section 2.2 of HIPAP No. 6 [1], all steps taken in the risk analysis should be: "*traceable and the information gathered as part of the analysis should be well documented to permit an adequate technical review of the work to ensure reproducibility, understanding of the assumptions made and valid interpretation of the results*". Therefore, details of the key assumptions adopted for the risk analysis are provided in Appendix A.

3.4 Quantitative Risk Criteria

3.4.1 Individual Fatality Risk

The individual fatality risk imposed by a proposed (or existing) industrial activity should be low relative to the background risk. This forms the basis for the following individual fatality risk criteria in Table 9 adopted by the NSW DPHI [2] and [5].

Table 9 Individual Fatality Risk Criteria – Other Land Uses

Land Use	Risk Criterion [per million per year]
Hospitals, schools, childcare facilities and old age housing developments	0.5
Residential developments and places of continuous occupancy, such as hotels and tourist resorts	1
Commercial developments, including offices, retail centres, warehouses with showrooms, restaurants, and entertainment centres	5
Sporting complexes and active open space areas	10
Industrial sites	50 *

* HIPAP 4 allows flexibility in the interpretation of this criterion. For example, 'where an industrial site involves only the occasional presence of people, such as in the case of a tank farm, a higher level of risk may be acceptable'.

The DPHI has adopted a fatality risk criterion of 1×10^{-6} per year (or 1 chance of fatality per million per year) for residential area exposure because this risk is very low in relation to typical background risks for individuals in NSW. For sensitive land uses such as schools, the criterion is one-half that for a residential area, viz. 0.5×10^{-6} pe year.

3.4.2 Injury Risk

The DPHI has adopted risk criteria for levels of effects that may cause injury to people but will not necessarily cause fatality. Criteria are included in HIPAP No. 4 [5] for potential injury caused by exposure to heat radiation, explosion overpressure and toxic gas/ smoke/dust.

The DPHI's suggested injury risk criterion for heat radiation is as follows:

- *Incident heat flux radiation at residential and sensitive use areas should not exceed 4.7 kW/m² at a frequency of more than 50 chances in a million per year.*

The DPHI's suggested injury/damage risk criterion for explosion overpressure is as follows:

- *Incident explosion overpressure at residential and sensitive use areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year.*

The DPHI's suggested injury risk criteria for toxic gas/ smoke/dust exposure are as follows:

- *Toxic concentrations in residential and sensitive use areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure at a maximum frequency of 10 in a million per year.*

- *Toxic concentrations in residential and sensitive use areas should not cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community over a maximum frequency of 50 in a million per year.*

3.4.3 Risk of Property Damage and Accident Propagation

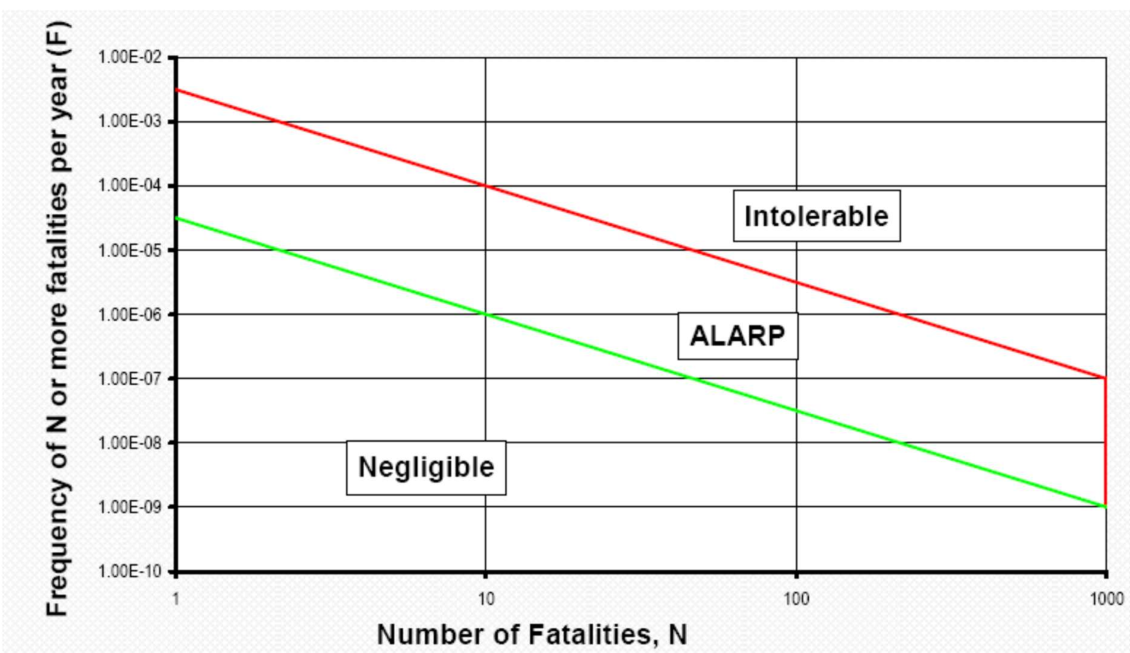
Heat radiation exceeding 23 kW/m^2 may cause unprotected steel to suffer thermal stress that may cause structural damage and an explosion overpressure of 14 kPa can cause damage to piping and low-pressure equipment. The DPHI's criteria for risk of damage to property and accident propagation are as follows [5]:

- *Incident heat flux radiation at neighbouring potentially hazardous installations or at land zoned to accommodate such installations should not exceed a risk of 50 in a million per year for the 23 kW/m^2 heat flux level.*
- *Incident explosion overpressure at neighbouring potentially hazardous installations, at land zoned to accommodate such installations or at nearest public buildings should not exceed a risk of 50 in a million per year for the 14 kPa explosion overpressure level.*

3.4.4 Societal Risk

The DPHI's suggested societal risk criteria (Refer to Figure 8), recognise that society is particularly intolerant of accidents, which though infrequent, have a potential to create multiple fatalities. Below the negligible line, provided other individual criteria are met, societal risk is not considered significant. Above the intolerable level, an activity is considered undesirable, even if individual risk criteria are met. Within the 'As Low As Reasonably Practicable' (ALARP) region, the emphasis is on reducing risks as far as possible towards the negligible line. Provided other quantitative and qualitative criteria of HIPAP 4 [5] are met, the risks from the activity would be considered tolerable in the ALARP region.

Figure 8 Indicative Societal Risk Criteria



The F-N criterion in NSW imposes an absolute upper limit of N=1000 (i.e. an incident that could cause more than 1000 fatalities is not tolerable), regardless of how low the frequency is.

HIPAP No.4 [5] also states that the criteria in Table 9 is an indicative criteria & provisional only and does not represent a firm requirement in NSW.

3.5 Qualitative Risk Criteria

Irrespective of the numerical value of any risk criteria for risk assessment purposes, it is essential that certain qualitative principles be adopted concerning the land use safety acceptability of a proposed development or existing activity. The qualitative risk criteria outlined in HIPAP No. 4 [5] encompass the following general principles:

- Avoidance of all 'avoidable' risks;
- Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low;
- Containment, wherever possible, within the site boundary of the effects (consequences) of the more likely hazardous events; and,
- Recognition that if the risk from an existing installation is already high, further development should not be permitted if it significantly increases that existing risk.

4 Hazard Identification and Preliminary Screening

4.1 Introduction

The hazard identification was based on a review of the: information on the MSEP pipeline; properties of Methane; and, potential failure modes and consequences if a leak were to occur from a pipeline. These findings are presented as follows:

Section 4.2 - Properties of Methane.

Section 4.3 - Pipeline Failure Modes.

Section 4.4 - Consequences.

Section 4.5 - Control Measures.

The representative MAEs carried forward to the consequence analysis are listed in Section 4.6.

A discussion on preliminary screening in accordance with *State Environmental Planning Policy (Resilience and Hazards) 2021* and *Applying SEPP 33* is included in

4.2 Properties of Methane

Natural Gas typically contains 95 to 97% methane (CH_4) and is modelled as methane in this PHA. It is primarily used as a fuel for heating, electricity generation, and as a feedstock in the production of chemicals such as hydrogen, methanol, and ammonia. It is also the main component of natural gas, widely utilised in residential, commercial, and industrial energy applications. It is modelled as 100% Methane in the QRA.

Physical properties are listed in Table 10

Table 10 Physical Properties of Methane

Boiling Point	-162 °C
Autoignition Temperature	540 °C
Relative Density (Air =1)	0.55
Lower Flammability Limit in air (vol. %)	5.0%
Upper Flammability Limit in air (vol. %)	15.0%

Methane is:

- A gas at ambient conditions;
- Highly Flammable.
- Much lighter than air at ambient temperatures (relative density ~0.55);
- Colourless and non-toxic.

Methane is transported by pipeline as a compressed gas under high pressure

4.3 Pipeline Failure Modes

Pipelines may leak due to various causes. The four principal failure modes that may result in a leak from an underground pipeline include [6]:

- **Mechanical failures**, including material defects or design and construction faults;
- **Corrosion**, including both internal and external corrosion;
- **Ground movement and other failure modes**, including ground movement due to earthquakes, heavy rains/floods or operator error, and other natural hazards such as lightning, etc.; and
- **Third Party Activity (TPA)**, including damage from heavy plant and machinery, damage from drills/boring machines and hot tapping, etc.

The relative likelihood of each failure mode is shown in Appendix C for underground pipelines.

4.3.1 Mechanical Failure

Leaks due to mechanical failures are usually caused by a construction fault, a material fault / defect or design of the pipeline.

This failure mode is credible for the MSE; however, historical incident data for other pipelines (Refer to Appendix C) indicates this is generally a low likelihood failure mode, particularly for more recently manufactured pipelines (i.e. post 1980).

4.3.2 Corrosion

Leaks due to internal corrosion are generally a function of the material being transported, the wall thickness of the pipeline and the materials of construction.

Leaks due to external corrosion do not depend on the material being transported and are generally dependent on the soil type / conditions, pipeline coating and materials of construction, and the age of the pipeline.

This failure mode is credible for the MSE; however, historical incident data for other pipelines (Refer to Appendix C) indicates this is a low likelihood failure mode, particularly for pipelines with a higher wall thickness (i.e. > 10 mm) and more recently manufactured pipelines (i.e. post 1980).

4.3.3 Ground Movement and Other Failure Modes

Pipeline leaks may occur due to ground movement (e.g. following a landslide or earthquake). The potential also exists for ground movement in the vicinity of water crossings (water erosion) or as a result of construction activities (new road infrastructure and buildings).

Other external events, such as lightning strikes, operational errors and erosion may also lead to a leak.

This failure mode is credible for the MSE.

4.3.4 Third Party Activity

Most leaks due to Third Party Activity (TPA) are caused by construction vehicles and equipment (drills, etc.) or by farm machinery in rural areas. The leak typically occurs immediately upon contact; however, it may be delayed (i.e. if the TPA only weakens the pipeline such that it fails at a later time).

Leaks due to TPA include those caused by horizontal directional drilling (HDD), which is commonly used to install utilities and services (communication cables, etc.).

Leaks due to TPA are particularly relevant when considering development in the vicinity of existing pipelines due to the potential for significant construction activities (e.g. new road infrastructure and buildings).

This failure mode is credible for the MSE.

4.4 Consequences of Gas Release

4.4.1 Asphyxiation

Although non-toxic, Methane has the potential to cause asphyxiation at higher concentrations due to oxygen depletion, particularly if exposure occurs in a confined space.

Methane is classified as a simple asphyxiant with low toxicity to humans. If a release does not ignite, then the potential exists for the gas concentration to be high enough to present an asphyxiation hazard to individuals nearby.

An atmosphere with marginally less than 21% oxygen can be breathed without noticeable effects. However, at 19.5% (which is OSHA's lower limit for confined space entry in 29 CFR 1915.12 [7]) there is a rapid onset of impairment of mental activity.

An oxygen concentration of about 15% will result in impaired coordination, perception and judgment. This may prevent a person from performing self-rescue from a confined space.

The potential for unconsciousness and fatality is only significant at less than 10% oxygen. However, to reduce the oxygen concentration to 10% requires a relatively high concentration (viz. approximately 52% v/v, which equates to 342,000 mg/ m^3 for Methane).

Oxygen deficiency from exposure to Methane should not be a major issue because the fire hazards are usually the dominant effects in most locations (the LFL for Methane is approximately one-twentieth, or 5%, of the fatal asphyxiant concentration). Therefore, the potential for fatality from asphyxiation was not carried forward to the consequence, likelihood and risk estimation steps of the QRA.

4.4.2 Jet Fire

Release of Methane from high pressure through a hole in a pipeline may create a jet plume. The gas plume extends several metres in the direction of discharge due to its momentum jet effect, entraining air. Ignition would result in a jet fire.

The potential for fatality due to exposure to heat radiation from a jet fire (including direct exposure to the jet) was included in the QRA.

4.4.3 Flash Fire

Ignition of an unconfined gas or vapour cloud will usually progress at low flame front velocities and will not generate a significant explosion overpressure. Unobstructed combustion of the gas cloud is referred to as a flash fire, which has the potential to cause injuries or fatalities for individuals within the ignited cloud.

A flash fire was included in the QRA as a potential outcome for all the gas releases. The potential for fatality due to direct exposure to a flash fire was included in the QRA.

4.4.4 Vapour Cloud Explosion

A high degree of confinement and congestion is required to produce high flame speeds (i.e. > 100 m/s) in a flammable gas or vapour cloud, due to promotion of turbulence and accelerated combustion. This may occur inside buildings and around obstacles (e.g. buildings, vehicles, trees etc.). The potential for fatality due to direct exposure to a vapour cloud explosion was included in the QRA.

4.4.5 Gas Ingress into Buildings

There is potential for flammable gas to be drawn into buildings through ventilation air intake, and through open doors or windows. If the gas concentration within the cloud is in the flammable region, an ignition within the building would result in a confined explosion with serious harm to occupants and structural damage. There is potential for fatalities, which has been included in the QRA. Refer to Assumption No. 22 in Appendix A.

4.4.6 Toxic Smoke

Large quantities of smoke can be produced from hydrocarbon fires; however, this is rarely injurious for persons at ground level due to the buoyancy of the hot plume and its subsequent dispersion at heights well above ground level. Methane is a very clean burning fuel, and potential for injury due to smoke exposure was not carried forward to the consequence, likelihood and risk estimation steps of the QRA.

4.5 Control Measures

Under the NSW Pipelines Act (1967) and Pipeline Regulations (2013), a pipeline operator must ensure the design, construction, operation, and maintenance of a licensed pipeline is in accordance with the relevant provisions of Australian Standard AS 2885 [8] for gas and liquid petroleum pipelines.

A licensee must implement a pipeline management system that relates to the pipeline operated under the licence and is in accordance with the relevant provisions of AS 2885.

4.5.1 Prevention of Mechanical Failure

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to develop and implement systems and processes to ensure the pipeline structural integrity for the design life of the pipeline in accordance with Section 6 of AS 2885.3:2012 [9] as part of the pipeline management system.

Continual monitoring is required while the pipeline is in operation to ensure that pipeline structural integrity is maintained. They shall not be operated above the maximum allowable operating pressure (MAOP). Anomalies should be assessed, and defects repaired.

4.5.2 Corrosion Prevention

Systems and processes to ensure the pipeline structural integrity for the design life of a pipeline such as the Moomba to Sydney Pipeline are included in Section 6 of AS/NZS 2885.3:2012 [10]. These should include corrosion protection systems.

Two key control measures are typically implemented by pipeline operators to minimise the likelihood of failure due to corrosion: cathodic protection systems and external pipe coatings.

The MSEP Pipeline is inspected using 'intelligent pigging' and has a significant wall thickness (11.9 mm). It is equipped with a cathodic protection system and a double layered HDPE coating.

4.5.3 Prevention of Damage due to Ground Movement and Other Failures

Normal loads (e.g. due to the internal and external pressure, weight of soil, traffic loads, etc.) and occasional loads (e.g. due to flood, earthquake, transient pressures in liquid lines and land movement due to other causes) are considered during design of a pipeline (as per AS/NZS 2885.1:2018 and AS/NZS 4645:2018). Additional depth of cover may also be required where the minimum depth of cover cannot be attained because of the action of nature (e.g. soil erosion, scour)

4.5.4 Prevention of Damage due to Third Party Activity

Section 11 of AS 2885.3:2012 [10] requires a Safety Management Study to be undertaken to assess the risks associated with threats to the pipeline and to instigate appropriate measures to manage the identified threats.

Two key control measures are typically implemented by pipeline operators to minimise the likelihood of impact from TPA: the 'Before You Dig Australia' (BYDA) process and periodic patrols.

The probability of leak on impact depends on the pipeline wall thickness. The depth of cover may also reduce the likelihood of impact.

4.5.5 Mitigation Control Measures

Section 11 of AS 2885.3:2012 [10] requires the development and implementation of an Emergency Response Plan as part of the pipeline management system.

An Emergency Response Plan should typically detail the response and recovery strategies and procedures to address all pipeline related emergency events, including loss of containment; full-bore pipeline rupture; fires; and natural events.

Leaks may be detected during visual inspections, incident notifications and/or by instrumented monitoring systems. If a leak is detected, then the pipelines can be isolated by closing automated and/or manual valves.

4.6 Pipeline Release Scenarios for Risk Analysis

The list of Gas release events included in the risk analysis is provided in Table 11

Table 11 List of Release Events

MAE	Potential Consequences
Release of High-Pressure Methane from APA Moomba-Sydney Pipeline	Jet Fire, Flash Fire or Explosion

4.7 Preliminary Screening of Development Materials

Currently, there is no proposal to store hazardous materials listed in Table 1 of *Applying SEPP 33* [11]. Hence, there is no basis for conducting a PHA for the development itself.

It is anticipated that any data centres occupying the development may need back-up power supply, and that may require diesel to fuel emergency generators. Diesel alone will not trigger a risk assessment as it is a class C1 combustible liquid, and "If combustible liquids of class C1 are present on site and are stored in a separate bund or within a storage area where there are no flammable materials stored they are not considered to be potentially hazardous." [11].

Should occupiers need to store dangerous goods in the development, additional development applications would be required and subject to preliminary screening and, if necessary, hazard analyses.

5 CONSEQUENCE ANALYSIS

5.1 Release of Flammable Liquid / Gas

5.1.1 Representative Hole Diameter

Representative hole diameters were selected for the consequence modelling. These were selected to align with the leak frequency data (Refer to Appendix C), which includes four hole size categories: Pinhole (≤ 25 mm); Small Hole (> 25 mm to ≤ 75 mm), Large Hole (> 75 mm to ≤ 110 mm); and, Rupture (> 110 mm). The representative hole diameter/s in each hole size category were selected based on a review of the available historical data (Refer to Appendix B.1):

- Leaks from underground pipelines in the Pinhole size category tend to be larger for TPA incidents (i.e. typically c. 20 mm to 25 mm - Refer to Appendix D) than for the other failure modes (i.e. typically less than c. 10 mm). Therefore, two representative hole diameters were selected in this category: 25 mm for TPA and 10 mm for all other failure modes.

Table 12 Representative Hole Diameters Selected for Consequence Analysis

Pipeline/s	Internal Diameter (mm)	Representative Hole Diameter (mm)			
		Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)
MSEP	202.9	10 or 25*	75	110	Full bore

* 10 mm for all failure modes except TPA. 25 mm for TPA only.

5.1.2 Discharge Model

Release events were modelled using SAFETI. The estimated release rates are tabulated below for each representative hole size.

Table 13 Representative Hole Diameters Selected for Consequence Analysis

MAE	Hole Diameter (mm)	Peak Release Rate [kg/s]
Release of High-Pressure Methane from MSEP	10	0.9
	25	5.62
	75	81.1
	110	174.39
	FBR	593.32
Release of High-Pressure Methane from Marsh Street MLV	25	5.52
	75	79.75
	110	171.56
	FBR	540.79

5.1.3 Height and Orientation of Release

The direction of release from the MSEP pipeline is dependent on the location. 2 Locations of failure were considered:

1. **Underground** – Releases from an underground pipeline were modelled for two puncture locations.
    a. Top of the pipe (unobstructed vertical release); or
    b. Middle of the pipe (on the side – obstructed horizontal release)
2. **Aboveground** – Above ground releases from the Marsh Street MLV station have been modelled as releases oriented 45° above the horizontal. This is to account for the large embankment at Marsh Street. Justification is provided in Assumption No. 13.

5.1.4 Duration of Release

Methane is flammable and any adverse impact of flammable hazards will occur quickly (fire or explosion); therefore, the duration of exposure is not as critical as it would be if there were a toxic material in the pipelines (i.e. where the adverse impact can significantly increase for longer exposure durations).

The isolation time and duration of release is not specified in the QRA as these will be significantly longer than the period of exposure required for an adverse effect to people (Refer to Section A.6) and the time required for each representative release case to reach steady state.

Duration of release becomes significant only from a fire escalation point and not required for risk assessment based on short duration exposure to fire.

5.2 Fire Modelling

The DNV software package SAFETI (Version 9.11) was used to model all the representative fire events included in the risk analysis.

The key data and assumptions used to model the representative fire events are included in Appendix A.4.

5.2.1 Jet Fire

Example distances to heat radiation levels of 4.7, 12.5, 23 and 35 kW/m^2 are tabulated in Appendix D for representative jet fire events included in the risk analysis.

5.2.2 Flash Fire

Example distances to the lower flammability limit (LFL) concentration are tabulated in Appendix D for representative flash fire events included in the risk analysis.

5.3 Vapour Cloud Explosion

When a flammable vapour cloud ignites, the flame front advances as the cloud burns. If there are obstacles in the path of the flame front, the level of turbulence increases causing accelerated burning and thus the flame front accelerates, reaching speeds of 100-200 m/s. The whole combustion process occurs over a period of less than a second, but this short burst of high speed flame front results in a blast wave, resulting in a pressure above the atmospheric pressure on the target surface (referred to as blast overpressure).

The blast wave can cause damage to the structure and injury/ fatality to exposed individuals and is commonly called vapor cloud explosion (VCE).

6 RISK ANALYSIS

6.1 Individual Risk of Fatality

There are no risk contours for individual fatality risk at 1.0 and 0.5 x 10^{-6} per annum (p.a.). This complies with the DHPI risk criteria in section 3.4.1.

6.2 Risk of Acute Toxic Injury or Irritation

No events with the potential to cause acute toxic injury or irritation were identified for inclusion in the risk analysis (Also refer to Section 4.4.6); therefore the proposed rezoning complies with the relevant DPHI risk criteria (Refer to Section 3.4.2).

6.3 Risk of Property Damage and Accident Propagation (Exceeding 14 kPa or 23 kW/m^2)

Neither the cumulative risk of overpressure exceeding 14 kPa nor the cumulative risk of heat radiation exceeding 23 kW/m^2 reach 50 x 10^{-6} per annum. The property damage and accident propagation criteria are satisfied (Refer to Section 3.4.3).

6.4 Injury/Damage Risk Criterion for Explosion Overpressure

The DPHI criteria for injury risk applies to the hotel development. The cumulative risk of injury (Overpressure exceeding 7 kPa) does not reach 50 x 10^{-6} per annum; therefore the proposed rezoning complies with the DPHI injury/damage risk criterion for explosion overpressure (Refer to Section 3.4.2) within residential and sensitive use areas.

6.5 Injury Risk Criterion for Heat Radiation

The cumulative risk of injury (Heat radiation exceeding 4.7 kW/m^2) does not reach 50 x 10^{-6} per annum; therefore the proposed rezoning complies with the DPHI injury risk criterion for heat radiation (Refer to Section 3.4.2) within residential and sensitive use areas.

6.6 Qualitative Risk Criteria

Irrespective of the numerical value of any risk criteria level for risk assessment purposes, it is essential that certain qualitative principles be adopted concerning the land use safety acceptability of a proposed development or existing activity. The proposed development is considered to comply with the qualitative risk criteria outlined in HIPAP No. 4, as follows:

- **Avoidance of all 'avoidable' risks** – The pipeline is an existing facility and cannot be relocated to avoid risk exposure. While redevelopment of current recreational space could theoretically be avoided, there are significant societal benefits from the redevelopment proposed such as generation of economic activity, generation of ongoing employment activity, locating logistics centres near Sydney Airport to reduce transport related issues.
- **Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low**. This would require a review of the proposed development details to determine if refinements can be made to focus residential intensification in the Study Area further from the MSE.
- **Containment, wherever possible, within the site boundary of the effects (consequences) of the more likely hazardous events.** There are no further reasonably practicable means of containing the effects of hazardous release from the MSE.

- **Recognition that if the risk from an existing installation is already high, further development should not be permitted if it significantly increases that existing risk**. The risk levels within the development area from the MSE are below the criteria for commercial development, sporting complexes and active open space, and industrial development. Hence, the office, retail and logistics components of the development are unrestricted by the HIPAP 4 criteria. Components of the development subject to criteria for residential or sensitive use have been located in areas where the criteria are satisfied.

6.7 Societal Risk

An F-N curve depicting the societal risk from the MSE in the Study Area before the redevelopment is shown in Figure 9 while the societal risk after redevelopment is shown in Figure 10. There is a noticeable increase in societal risk at all points along the F-N curve, but when the Study Area is fully developed, the risk is still within the ALARP region.

Figure 9 Societal Risk F-N Curve Before Development

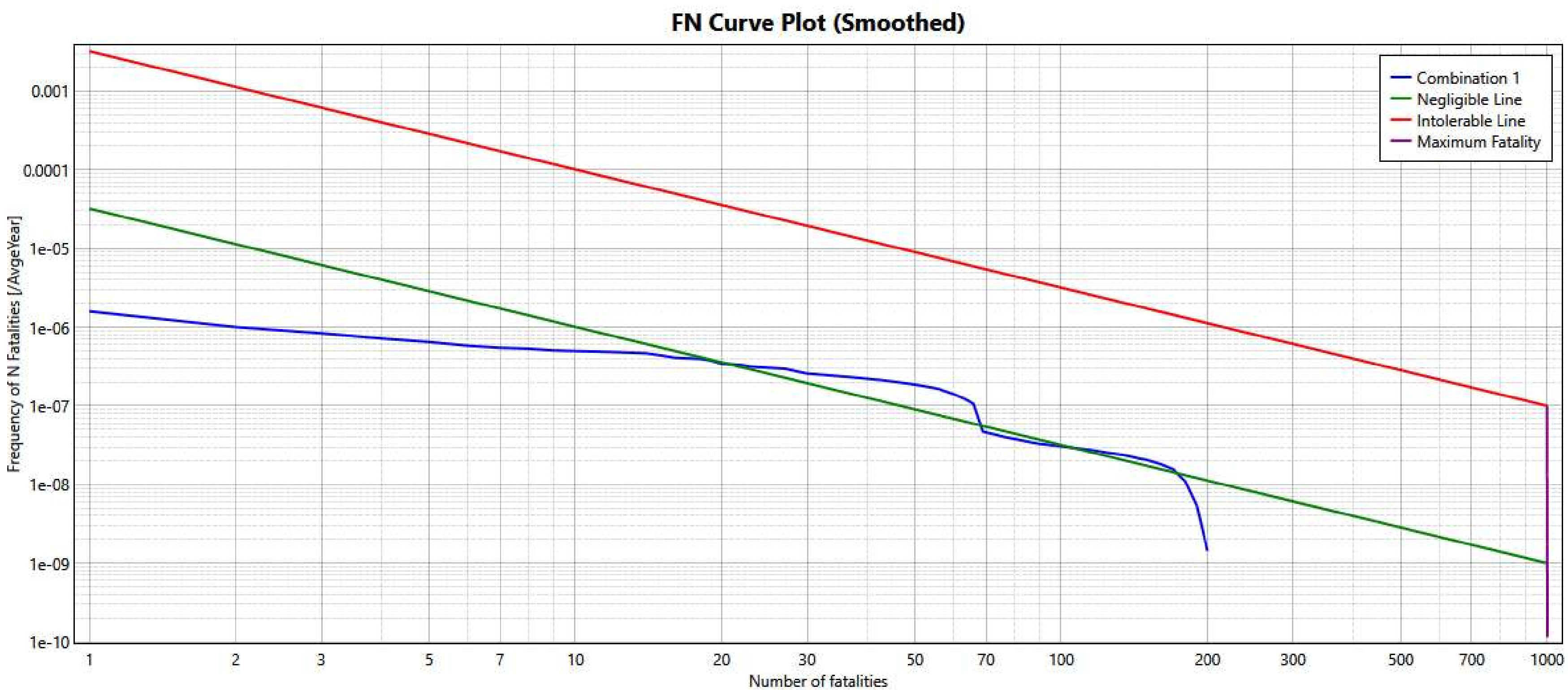
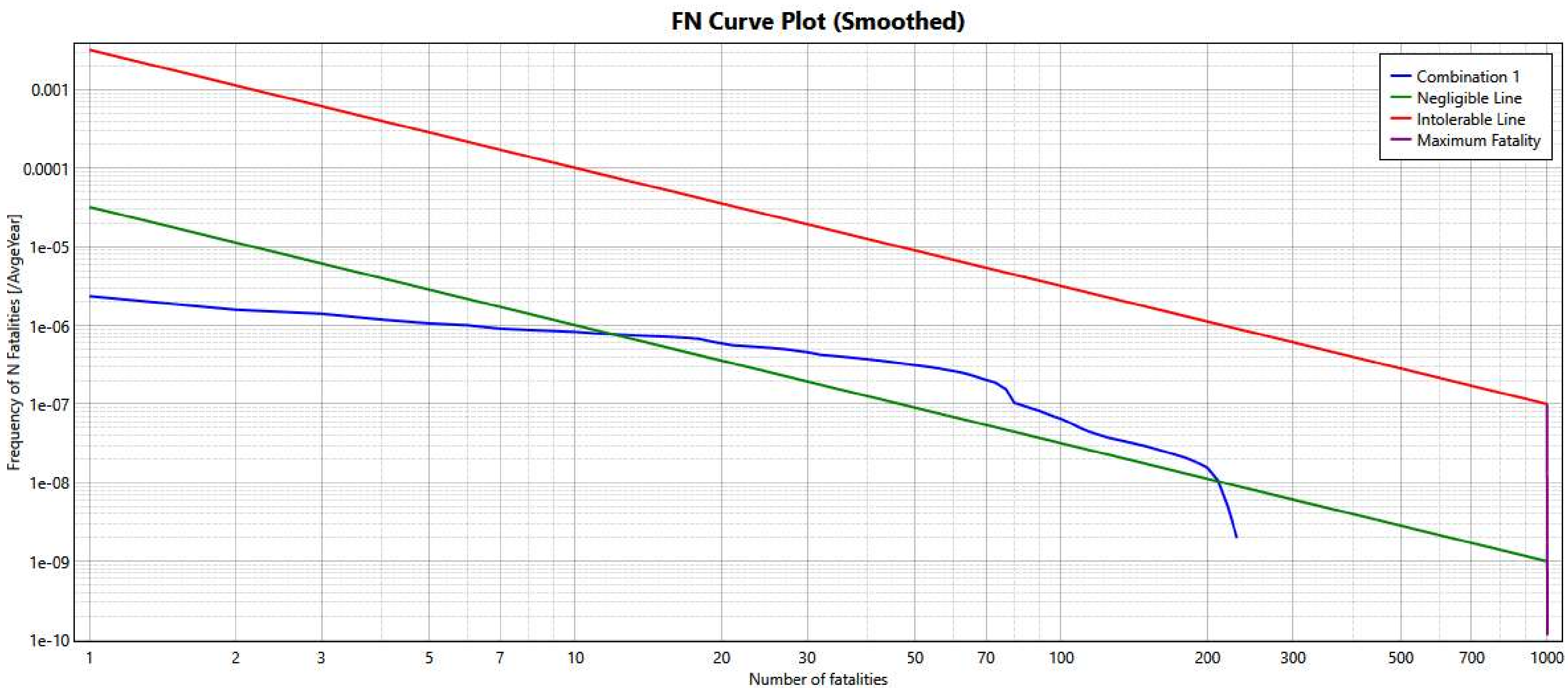


Figure 10 Societal Risk F-N Curve After Redevelopment.



7 FINDINGS AND RECOMMENDATIONS

7.1 Findings

The Risk assessment demonstrates that the proposed development complies with the individual fatality risk criteria outlined in Table 14 - Individual Fatality Risk Criteria. The following findings were made:

- No sensitive land uses such as hospitals, schools, childcare facilities, or aged housing are proposed within high-risk zones, and any future inclusion would be required to comply with the 0.5×10^{-6} p.a. criterion.
- The level of risk at the proposed hotel location is less than 1.0×10^{-6}p.a. The proposal for a hotel at the location satisfies the DPHI criteria for residential use.
- The individual risk of fatality never exceeds 5.0×10^{-6} p.a. and therefore intensification of other land uses (business use) as proposed is consistent with DPHI criteria.
- The societal risk, represented as an F-N curve, is within the ALARP region and below the upper limit of the risk tolerability band. This level of societal risk does not preclude the changes envisaged.

Table 14 - Individual Fatality Risk Criteria

Land Use	Risk Criterion [per million per year]	Comment
Hospitals, schools, childcare facilities and old age housing developments	0.5	Complies
Residential developments and places of continuous occupancy, such as hotels and tourist resorts	1	Complies
Commercial developments, including offices, retail centres, warehouses with showrooms, restaurants, and entertainment centres	5	Complies
Sporting complexes and active open space areas	10	Complies
Industrial sites	50 *	Complies

The proposed development complies with HIPAP No. 4 qualitative risk principles by avoiding all avoidable risks where practicable and ensuring that further development does not significantly increase existing risk.

The risk levels within the development area from the MSEP are below the criteria for commercial development, sporting complexes and active open space, and industrial development. Hence, the office, retail and logistics components of the development are unrestricted by the HIPAP 4 criteria. Components of the development subject to criteria for residential or sensitive use are located in areas where the criteria are satisfied.

7.2 Recommendations

While the land uses proposed satisfy the DPHI criteria for land use safety planning, the following recommendations are made to reduce risk so far as is reasonably practicable:

1. The construction of buildings should consider the hazards arising from the MSE and ensure in the event of a release and ignition of ethane from the MSE, there is adequate means of

egress from the building to a place of safety, or alternatively, there is a suitable place of refuge within the building that remains tenable until the release is isolated.

2. In conjunction with recommendation 1, emergency response plans for the buildings should consider the potential hazards arising from the MSEP
3. Include a high-pressure gas transmission pipeline as a credible scenario, assessing potential consequences, existing safeguards and ensuring emergency response plans and separation distances are within the ALARP limits.

8 REFERENCES

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[2] NSW Department of Planning, "Hazardous Industry Planning Advisory Paper No.10 - Land Use Safety Planning," Sydney, 2011.

[3] NSW Department of Planning, Housing and Infrastructure, *Planning Secretary's Environmental Assessment Requirements for SSD-84348959,* Sydney, 9 July 2025.

[4] Standards Australia, "AS/NZS 2885.0:2018 - Pipelines - Gas and Liquid Petroleum - General Requirements," 2018.

[5] NSW Department of Planning, "Hazardous Industry Planning Advisory Paper No.4 - Risk Criteria for Land Use Safety Planning," Sydney, 2011.

[6] Health and safety Laboratory, "Research Report RR 1035 - Update of pipeline failure rates for land use planning assessments," HSE Books, London, 2015.

[7] Occupational Safety and Health Administration, "Precautions and the order of testing before entering confined and enclosed spaces and other dangerous atmospheres.," US Department of Labour, Washington, D.C., 1995.

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[9] Standards Australia, "Pipelines - Gas and Liquid Petroleum Operations and Maintenance," 2012.

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Appendices

Appendix A Assumptions

It is necessary to make technical assumptions during a risk analysis. These assumptions typically relate to specific data inputs (e.g. material properties, equipment failure rates, etc.) and modelling assumptions (e.g. release orientations, impairment criteria, etc.).

To comply with the general principles outlined in Section 2.2 of HIPAP No. 6, all steps taken in the risk analysis should be: "*traceable and the information gathered as part of the analysis should be well documented to permit an adequate technical review of the work to ensure reproducibility, understanding of the assumptions made and valid interpretation of the results*". Therefore, details of the key assumptions adopted for the risk analysis are provided in this Appendix.

Each assumption is numbered and detailed separately. The basis for each assumption is explained together with its potential impact on the risk results and the MAEs potentially affected. Key references are also listed for each assumption, where relevant.

It is important that the assumptions be supported by:

- experimental data in the literature, where available;
- actual operating experience, where available;
- similar assumptions made by experts in the field and a general consensus among risk analysts; and
- engineering judgement of the analyst.

The main objectives are to minimise uncertainty in the risk estimate as far as is possible, and to ensure that the assumptions result in a 'conservative best estimate' of the risk. Such an approach is consistent with the following extract from Section 5 of HIPAP No. 6: "*In the consequence analysis and throughout the hazard analysis, the analyst must be conscious of the uncertainties associated with the assumptions made. Assumptions should usually be made on a 'conservative best estimate' basis. That is, wherever possible the assumptions should closely reflect reality. However, where there is a substantial degree of uncertainty, assumptions should be made which err on the side of conservatism.*"

List of Assumptions

A.1 Operational Data

Assumption No. 1 Pipeline Operating Conditions
Subject: Operational Data
Assumption/s: • All pipeline operating conditions (pressure, temperature, etc.) are as reported in Section 2.3
Justification and Impact/s of Assumption/s: • All operational data for the pipelines was provided by the pipeline owner (APA Group). • Operating conditions (particularly operating pressure) are required to undertake the release and dispersion modelling.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group.

Assumption No. 2 Pipeline Utilisation
Subject: Operational Data
Assumption/s: • The pipeline is utilised 100% of the time.
Justification and Impact/s of Assumption/s: • Utilisation data is required to undertake the release and dispersion modelling and to estimate the release frequency.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group.

A.2 Locational Data

Assumption No. 3	Representative Wind Speeds, Wind Directions and Stability Classes

Subject: Locational Data

Assumption/s:

- Representative weather data is based upon 25 years of observations at Sydney Airport, BoM Station ID 066037.
- The probabilistic distribution of wind speed and wind direction for the representative stability classes is provided in Section 2.
- The data was split into daytime and night-time conditions.
- Night-time is considered the period from 1 hour before sunset, to one hour after sunrise. This approximates to 10 hours daytime and 14 hours night-time.

Justification and Impact/s of Assumption/s:

- Sydney Airport is the closest meteorological station to the study area and is located directly across Cook's River from the study area.
- Raw data from Sydney airport observations have been rationalised into a set of wind speed/weather stability classes for dispersion calculations.
- Wind will cause flames to tilt downwind. The higher the wind speed, the greater the tilt. The net effect of the tilt is to increase the heat radiation in the downwind direction. This is much more pronounced for pool fires than jet fires because jet fires have much greater momentum. An allowance for flame tilt is included in the SAFETI models for pool fires and vertical jet fires. The SAFETI model assumes horizontal jet fires are directed in the same direction as the wind.
- The downwind gas concentrations, and hence the hazard ranges for dispersion of flammable gas or vapour, vary with wind speed and weather stability class. Therefore, multiple representative wind speed and stability class categories are included in accordance with standard practice for undertaking a quantitative risk assessment (QRA).
- The day/night split of the weather data is required to allow for the fact that residential, commercial and industrial occupancies change over a 24-hour period.

MAE/s Affected:

- All.

Reference/s:

- BoM meteorological data for Sydney Airport AWS.

Assumption No. 4 Surface Roughness Length

Subject: Locational Data

Assumption/s:

- A conservative roughness length of 0.5 m is applicable for Cook's Cove.

Justification and Impact/s of Assumption/s:

- The roughness length for different surface types, as listed in the SAFETI user manual, is shown below in Table 15. The Cook's Cove development is located adjacent Botany Bay and Sydney airport to the East and South. These could be described as "open flat terrain". In all other directions (from SSW through to ENE), there is significant suburban development.

Table 15 Surface Roughness Length

Description	Roughness Length (m)
Open water, at least 5 km	0.0002
Mud flats, snow, no vegetation, no obstacles	0.005
Open flat terrain, grass, few isolated objects	0.03
Low crops; occasional large obstacles, x/h > 20	0.1
High crops, scattered large obstacles, 15<x/h<20	0.25
Parkland, bushes, numerous obstacles, x/h<15	0.5
Regular large obstacle coverage (suburb, forest)	1
City centre with high- and low-rise buildings	3

- The surface roughness affects the dispersion analysis. As the surface roughness increases, a release of gas or vapour will disperse more quickly with increasing distance from the source. Therefore, it is necessary in SAFETI to select a surface roughness length that is representative of the types of terrain and obstacles near the source of release.
- It is not possible to define different surface roughness lengths for different locations within a single SAFETI model. Only a single representative value can be defined for the entire area.

MAE/s Affected:

- Dispersion modelling for all relevant MAEs.

Reference/s:

- SAFETI software documentation.

Assumption No. 5 Location of High Pressure Gas Pipelines
Subject: Locational Data
Assumption/s: • The location of the pipelines is sourced from the Australian Pipeline and Gas Association's (APGA) Australian Pipeline Database (APD).

Justification and Impact/s of Assumption/s:
• The Australian Pipeline Database (APD) is made available to users to raise awareness of the location of high-pressure hydrocarbon pipelines and facilitate discussions between pipeline operators and stakeholders regarding the potential for planning and development decisions to trigger requirements in the Australian Standard, AS 2885, for pipeline Safety Management Studies.
• Use of the APD is conditional on several factors that are consistent with the objectives of this study, including:
  • The APD is to be used solely for the purpose of facilitating discussion regarding planning activity and decisions in the vicinity of pipelines. **This is consistent with the objectives of this study**.
  • The APD is not to be used for proving and construction activities. Dial Before You Dig enquiries must be made for these activities and any condition complied with. **It is not the intent of this study to provide detailed construction information**.
• When overlayed onto aerial photos, the APGA Pipeline database accuracy appears no less accurate than the accuracy expected of the consequence models and frequency estimates.

MAE/s Affected: • All.
Reference/s: • APGA Australian Pipeline Database

Assumption No. 6	Residential Population (Day and Night)
Subject:	Locational Data

Assumption/s:

- The current residential population of areas outside the development is based upon the Census of Population and Housing, 2021, obtained from the Australian Bureau of Statistics TableBuilder service. The population is based upon Statistical Area Level 1.

Justification and Impact/s of Assumption/s:

- The 2021 Census data is the latest available data.

MAE/s Affected:

- All societal risk calculations. Population density, along with the area of consequence distances, determines the F-N points of societal risk.
- Locational specific risk is not impacted by these assumptions.

Reference/s:

- Census of Population and Housing, 2021, TableBuilder.

Assumption No. 7	Development Population (Day and Night)

Subject: Locational Data

Assumption/s:

- Adopted workspace ratio's obtained from the NSW common planning assumptions 2023 and Colliers research:

Table 16 NSW Workspace Ratio

Type	Workspace Ratio
Retail	20
Retail/office	35
Hotel	100
Logistics	200

- Hotels Guest occupancy is modelled as present during both day and night. It is assumed 80% of employees are present during the night, 20 % during the day.
- Other Locations (e.g., offices, retail, warehouses): These are modelled as having daytime-only activity, with 0 occupants at night.

Justification and Impact/s of Assumption/s:

- The population is calculated by obtaining the Gross Floor Area (GFA) and dividing it by the workspace ratio.

Table 17 Gross Floor Area and Population

Building	Type	GFA	Population	Day	Night
3A	Warehouse & Logistics	25300	127	0	0
3B-1	Hotel, Retail & offices	50050	501	100	400
3B-2	Warehouse & Logistics	212714	1064	1064	0
3C	Warehouse & Logistics	21986	110	110	0
R1	Retail Block	1610	80	80	0
R2	Retail Block	3250	93	93	0

8

MAE/s Affected:

- All societal risk calculations. Population density, along with the area of consequence distances, determines the F-N points of societal risk.
- Locational specific risk is not impacted by these assumptions.

Reference/s:

NSW Common Planning Assumptions 2023

Assumption No. 8	Indoor / Outdoor distribution of people

Subject: Locational Data

Assumption/s:

- 99% of the night-time population will be located indoors.
- 90% of the daytime population will be located indoors.
- All population is located at ground level.

Justification and Impact/s of Assumption/s:

- The default values recommended by the TNO [‘Purple Book’] for residential and industrial areas are tabulated below.

Table 18 Proportion of Population Indoor and Outdoor During Day and Night [TNO]

Location	Day Time	Night Time
Indoor	93%	99%
Outdoor	7%	1%

- The % of the total population located indoors and outdoors was estimated from similar risk analyses (Including some data provided by DPHI). It is reported in these analyses that the % of people indoors and outdoors is 90% indoors and 10% outdoors during the day, which differs slightly from the TNO data, but is typically justified as being more applicable for Australian environmental conditions. Similarly, it is reported in these analyses that the % of people indoors and outdoors is 95 to 99% indoors and 1 to 5% outdoors during the night.

MAE/s Affected:

- All societal risk calculations

Reference/s:

- TNO, VROM, Guidelines for Quantitative Risk Assessment, 'Purple Book', CPR18E, 3rd Edition.

A.3 Risk Analysis Methodology

Assumption No. 9 Location and Segmentation of Pipelines
Subject: Risk Analysis Methodology
Assumption/s: • Representative release events are modelled using the 'Long Pipeline' model in SAFETI, which distributes these events along the pipeline at set intervals.
Justification and Impact/s of Assumption/s: • The 'Long Pipeline' model in SAFETI is used to estimate the time-dependent release from a long pipeline. The 'Long Pipeline' model includes inputs for use in the risk calculations, such as pipeline burial depth, leak frequency, etc. • The interval at which representative incidents are distributed along the pipeline is selected automatically by the 'Long Pipeline' model based on the incident consequence.
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation.

A.4 Consequence Analysis

Assumption No. 10 Representative Materials
Subject: Consequence Analysis
Assumption/s: • Methane is modelled as 100% Methane
Justification and Impact/s of Assumption/s: • The composition and materials used affect the magnitude of the consequences. Materials containing multiple components are simplified for modelling purposes by choosing a representative component to best approximate the variable composition. Modelling a representative material rather than a multi-component material reduces complexity, limits the potential for inconsistencies and ultimately has a minimal effect on the results. • The pipeline carries Methane
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group.

Assumption No. 11 Pressure and Flow for Release Modelling

Subject: Consequence Analysis

Assumption/s:

- A release of Methane from the Moomba to Sydney Ethane Pipeline is modelled at 8.2 MPag (Operating pressure), compared to an MAOP of 10 MPag.
- The flowrate of Methane through the pipeline is 25 TJ/day
- Release events are modelled using the 'Long Pipeline' model in SAFETI. Ten different release rates over the first 5 minutes of release are used for hole sizes 75 mm and above. The release rates are selected by Safeti so that the same mass is released in each segment.
- The release rates used for consequence modelling are dependent upon the type of consequence modelled:
    - The release rate for jet fires is the average rate over the first 30 seconds of the release – being equal to the assumed exposure to a jet fire (and hence worst case assuming immediate ignition).
    - Dispersion calculations are based on 10 different observer rates, equivalent to the 10 release rates and intervals as discussed above.
- For hole sizes less than 75 mm, the pipeline maintains a constant pressure at the release point. This also implies a constant release rate at the point of release.

Justification and Impact/s of Assumption/s:

- The release rate is dependent on the pressure and the MAOP is the maximum pressure permitted under an existing licence.
- The pressure used to model the release rates was based on the pipeline pressure near the proposed development, as advised by the pipeline owner.
- The long pipeline model assumes the input pressure is reduced by frictional losses along the pipeline length until the breach point. This results in a lower pressure at the release point that the operating pressure and hence also a lower release rate.
- Providing a flow will slow the rate of pressure reduction calculated by the long pipeline model.
- HIPAP 6 does not include guidance on the use of time dependent or multiple release rates. The Netherlands *Reference Manual Bevi Risk Assessments* states: "*In exceptional cases, it is possible to deviate from the approach set out above. In particular, this includes situations in which the duration of outflow is greater than 50 s and the outflow rate reduces significantly in the period from 0 to 1800 s. In such a situation it is possible to assume a time-dependent outflow, in which case at least five segments are defined".* The pressure in the pipeline drops rapidly for large hole sizes and the analysis uses 10 release rates, double the minimum recommended in the Bevi Manual.

MAE/s Affected:

- All.

Reference/s:

- Data provided by APA Group.

Assumption No. 12	Representative Hole Diameters for Release Modelling
Subject:	Consequence Analysis

Assumption/s:

- Consequence modelling is based on the following representative hole diameters:

Table 19 Representative Hole Diameters Selected for Consequence Analysis

Pipeline/s	Material	Internal Pipeline Diameter (mm)	Representative Hole Diameter (mm)			
			Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)
APA Ethane Pipeline	Methane	202.9	10 or 25*	75	110	Full bore

* 10 mm for all failure modes except Third Party Activity (TPA). 25 mm for TPA only.

Justification and Impact/s of Assumption/s:

- The representative hole diameters were selected to align with the leak frequency data (Refer to C.1.1), which includes four hole size categories: Pinhole (≤ 25 mm); Small Hole (> 25 mm to ≤ 75 mm), Large Hole (> 75 mm to ≤ 110 mm); and, Rupture (> 110 mm). The representative hole diameter/s in each hole size category were selected based on a review of the available historical data (Refer to Appendix B.1):
  - Leaks from underground pipelines in the Pinhole size category tend to be larger for TPA incidents (i.e. typically c. 20 mm to 25 mm – Refer to Appendix C) than for the other failure modes (i.e. typically less than c. 10 mm). Therefore, two representative hole diameters were selected in this category: 25 mm for TPA and 10 mm for all other failure modes.
  - There is insufficient historical incident data for Methane to determine the representative hole diameter/s in each hole size category. Therefore, the representative hole diameters were assumed to be the same as proposed by the UK HSE for LPG (Refer to C.1.1). Methane is transported as a compressed gas.

MAE/s Affected:

- All.

Reference/s:

- Refer to Appendix B.1.

Assumption No. 13 Location of Release for Transmission Pipelines
Subject: Consequence Analysis

Assumption/s:

- High pressure gas releases would create a crater on the ground. The direction of release for underground pipeline failures from the crater is always vertical.
- The location of failure on the pipe can be taken as:
  - Top of the pipe (unobstructed releases); or
  - Middle of the pipe (on the side – obstructed releases).
- The release frequency is distributed between the two locations (37% from middle of pipe and 63% from top of pipe for all release cases except non-TPA events with a hole size less than or equal to 25mm, which are modelled as 100% from middle of pipe).
- Above ground releases at the Marsh Street valve station have been modelled angled 45° from the horizontal originating at a height of 1m.

Justification and Impact/s of Assumption/s:

- The crater size depends on the location of the hole on the pipe and hence all three locations (top, middle and bottom) may be modelled (DNVGL, 2020). Top releases are taken as non-obstructed releases and middle/ bottom releases are taken as obstructed releases.
- Impingement reduces the momentum of the release, and the dispersion modelling is dominated by the representative wind conditions.
- The UK HSE [RR 1034] reports that some data from UKOPA includes the 'hole circumferential position' for releases from underground pipelines. Based on the 71 recorded incidents (All pipelines and materials) and average crater dimensions, an unobstructed release (c. ±71° from vertical) was estimated to occur for 63% of the releases and an obstructed release was estimated to occur for the balance (37% of releases). The distribution is not reported for different failure modes.
- Horizontal releases at 1m are typical assumptions for QRA and the layout of the valve stations does not give rise to any compelling reason to deviate from this practice.
- The Marsh Street valve station is located close to a road embankment, which separates the valve station from most of the development. Horizontal releases directed towards the hotel and office components of the development would impinge the embankment. Making all releases from 45° from the horizontal better reflects the impact on the development. Parts of the development to the north of the valve station will still be within the 35 kW/m^2 radiation zone of substantial releases when modelled at 45°. Further distant on the north side is open space, so the reduction in length to hazardous radiation is unlikely to impact societal risk calculations. The buried pipeline is still the major contributor to individual risk.
- Diagrams below highlight the arrangement of the valve station, its location in relation to the embankment, and the width of the embankment (carrying six lanes of traffic).


NOVOTEL

Assumption No. 13	Location of Release for Transmission Pipelines
MAE/s Affected: • All.	
Reference/s: • SAFETI software documentation. • UK HSE, 2015, *Review of the Event Tree Structure and Ignition Probabilities used in HSE's Pipeline Risk Assessment Code MISHAP*, Research Report (RR) 1034.	

Assumption No. 14 Maximum Extent of Flash Fire
Subject: Consequence Analysis

Assumption/s:

- The maximum extent of a flash fire is defined by the downwind and crosswind distances from the release location to a concentration equal to 100% of the lower flammability limit (LFL) concentration calculated using an 18.75s averaging time.

Justification and Impact/s of Assumption/s:

- Justification is provided in (Benintendi, 20171031, p. 341):

  For passive dispersion models, the shorter the averaging time, the higher the centreline concentration, and there is concern that flammable concentrations may exist beyond the 100% LFL contour determined for a specific averaging time.

  To take into account the different averaging times, the following empirical formula is recommended for converting concentrations from 10 minute averaging time to another (Hanna et al., 1993):

  $$\frac{C_t}{C_{600}} = \left(\frac{600}{t}\right)^{0.2} \quad ...(1)$$

  where time is in seconds. C_t denotes time averaged concentration at the new averaging time of t seconds

  Hanna claims that experimentally:

  $$C_{max} = 2 \times C_{600} \quad ...(2)$$

  where C_{max} is the maximum peak concentration in the plume.

  Substituting C_{max} from (2) with $C_{600}\left(\frac{600}{t}\right)^{0.2}$ from (1) and solving for t, it is yields

  t = 18.75 s.

  This time should be adopted to carry out worst case predictions for the extent of 100% LFL. It is the core averaging time for flammable dispersion in Safeti.

MAE/s Affected:

- All MAEs with a flash fire as a potential outcome.

Reference/s:

- SAFETI software documentation.
- Benintendi, R. (20171031). Process Safety Calculations. [[VitalSource Bookshelf version]]. Retrieved from vbk://9780081012291.
- Hanna, S.R., Strimaitus, D.G., Chang, J., 1993. Hazard Response Modeling Uncertainty (A Quantitative Method) Vol 11 - Evaluation of Commonly Used Hazardous Gas Dispersion Models, Environics Division Air Force Engineering & Services Center, Engineering & Services Laboratory.

Assumption No. 15 Isolation Time and Duration of Release
Subject: Consequence Analysis
Assumption/s: • Isolation time and duration of release is not specified as these will be significantly longer than the period of exposure required for an adverse effect to people (Refer to Section A.6) and time required for each representative release case to reach steady state.
Justification and Impact/s of Assumption/s: • Ethane is flammable and any adverse impact will occur quickly (fire or explosion); therefore, the duration of exposure is not as critical as it would be if there were toxic materials in the pipeline (i.e. where the adverse impact can significantly increase for longer exposure durations). • The assumption is justified from the consequence calculations of the Long Pipeline Model, using a 30 sec. exposure time (user specified), compared to isolation valve closure times which typically vary from minutes (full bore rupture case) to hours (small to medium leaks).
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation.

Assumption No. 16 Shielding by Intervening Structures
Subject: Consequence Analysis
Assumption/s: • The presence of intervening structures (e.g. buildings) does not shield other receptors from the heat radiation from a jet fire. • Only releases from the above ground section in relation to raised sections of Marsh Street have been modified to account for topography (refer Assumption No. 13)
Justification and Impact/s of Assumption/s: • In the SAFETI software, it is not possible to take account of the potential protection provided by intervening structures. • This analysis is taking place during the concept stage of development of a large growth area. There is insufficient information available to determine the location of large structures that could offer protection against radiant heat. • People located indoors are typically less vulnerable to fire, which is a relevant consideration for the societal risk assessment (Refer to Assumption No. 21). • The Marsh Street embankment will have a significant impact on the behaviour of above ground releases.
MAE/s Affected: • All MAEs with a pool fire or jet fire as a potential outcome, with the exception of releases from the above ground sections of pipeline.
Reference/s: • SAFETI software documentation.

Assumption No. 17 3D Explosion Model Parameters
Subject: Consequence Analysis
Assumption/s: • The maximum explosive mass in a flammable gas or vapour cloud is the maximum mass between the LFL and UFL concentration for that section of the cloud that overlaps a congested area. • The peak side-on overpressure resulting from an explosion is estimated using the Extended Explosion Modelling option in the SAFETI software. • The severity of the blast is based on an unconfined blast strength of 4, with no specified obstruction region. • The blast strength is estimated based on the obstructed volume (%) and potential obstructions in each congested area. The following congested areas are included in the QRA: • **Buildings** - A medium obstructed volume (60% for a residential building) and level of congestion is assumed to simulate entry of the gas or vapour into the building and the subsequent confined explosion. This equates to TNO Model curve number 4. • Only overpressure effects are included. Projectiles and whole-body displacement are not included.
Justification and Impact/s of Assumption/s: • The explosive mass and blast strength are key parameters for modelling the overpressure from a VCE. • There are no significantly congested locations in the study area; however, a confined explosion could occur if gas or vapour enters a building. • The open space between the buildings in the study area is not strictly a congested area; however, the presence of vehicles, trees etc. at ground level may contribute to flame acceleration and the formation of an overpressure if ignition occurs. Therefore, TNO Model curve number 4 was assumed to apply. • The 3D Obstructed Region Explosion Modelling option considers the interactions between the flammable cloud and obstructed regions that have been defined for the study area. This is more valid than simple models (e.g. TNT equivalence) which do not consider these interactions.
MAE/s Affected: • All MAEs with a VCE as a potential outcome.
Reference/s: • Centre for Chemical Process Safety, Estimating the flammable mass of vapour clouds", American Institute of Chemical Engineers, 1999. • TNO, VROM, 'Yellow Book'. • SAFETI software documentation.

A.5 Likelihood Analysis

Assumption No. 18 Likelihood of Release (Loss of Containment)
Subject: Likelihood Analysis
Assumption/s: • The likelihood of each representative release is provided in Appendix C.1.4. • The UK HSE pipeline failure rate data is the primary data used for the risk assessment.
Justification and Impact/s of Assumption/s: • The estimated likelihood of release (or loss of containment) is a critical and significant input for the risk analysis. The risk results are directly proportional to this input. • Generic failure rate data for cross-country pipelines from the UK, USA and Europe were reviewed. The UK data incorporates the European data. There are two sources of data from the UK: (a) HSE recommended data for land use safety planning (RR 1035); and (b) British Standards Institute PD 8010-3:2009+A1:2013. The HSE data is primarily used in this study, which is consistent with the NSW performance data. • The HSE data identifies four contributors to pipeline failure: (a) mechanical failure; (b) corrosion; (c) ground movement/other; and (d) Third Party Activity (TPA). Of these, mechanical, corrosion and TPA are similar to conditions in Australia and hence no frequency adjustments due to local conditions are justified. • The justification for the data used in this risk analysis is provided in Appendix C.1.1.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.1.1.

Assumption No. 19 Ignition Probability
Subject: Likelihood Analysis
Assumption/s: • The probability of ignition for each representative release is provided in Appendix C.
Justification and Impact/s of Assumption/s: • The estimated probability of ignition is a critical and significant input for the risk analysis. The risk results are directly proportional to this input. • The justification for the data used in this risk analysis is provided in Appendix C
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.

Assumption No. 20 Probability of VCE or Flash Fire
Subject: Likelihood Analysis
Assumption/s: • Ignition of a free gas or vapour cloud is modelled as a flash fire in uncongested areas and as a vapour cloud explosion in congested areas. • Congested areas include buildings in the vicinity of the pipelines.
Justification and Impact/s of Assumption/s: • Ignition of a free gas cloud may demonstrate characteristics of a flash fire and/or an explosion. SAFETI uses the delayed ignition probability resulting in either of the events. • Obstructed areas in the dispersing vapour cloud are defined by the user in the layout map. As the model calculates gas dispersion, it automatically calculates the consequence as vapour cloud explosion in congested areas and flash fires in uncongested areas. • The current version of SAFETI, with the 3D obstructed area module, does not require a conditional probability of an explosion given ignition.
MAE/s Affected: • All MAEs with clouds in an obstructed region.
Reference/s: • SAFETI software documentation. • TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

A.6 Vulnerability Parameters

Assumption No. 21 Exposure to Heat Radiation from a Fire (Indoor or Outdoor)
Subject: Vulnerability Parameters
Assumption/s: • For individuals located outdoors, the probability of fatality is based on the following probit equation [TNO 'Purple Book']: $Y = -36.38 + 2.56 \ln\left(I^{1.333} t\right)$ Where Y is the probit value, *I* is the heat radiation intensity (W/m^2) and t is the exposure duration (seconds). • A maximum exposure duration of 30 seconds is applicable for individuals located outdoors in an urban setting. It is assumed after 30 seconds, the persons will have found shelter from heat radiation. • The probability of fatality for an individual located outdoors (30 seconds exposure), as calculated using the above probit equation, is as follows:

Assumption No. 21 Exposure to Heat Radiation from a Fire (Indoor or Outdoor)

Table 20 Probability of Fatality for Exposure to Heat Radiation (Outdoor)

Heat Radiation Intensity (kW/m^2)	Probit	Probability of Fatality
4.7	1.19	0
12.6	4.55	0.32
15.9	5.35	0.63
23.0	6.61	0.94
35.0 *	8.04	1.0

* - Safeti assumes fatal injuries are incurred at 35 kW/m^2 and above, regardless of the exposure duration.

- For the calculation of societal risk:
  - The probability of fatality for individuals located outdoors is factored by 0.14 (SAFETI default) to allow for the protection provided by clothing and the possibility of seeking shelter behind obstacles.
  - The probability of fatality for an individual located indoors is 0 at less than 35 kW/m^2 and 1.0 at 35 kW/m^2 or greater.

Assumption No. 21 Exposure to Heat Radiation from a Fire (Indoor or Outdoor)

Justification and Impact/s of Assumption/s:

- The probit equation adopted for the risk analysis is generally consistent with the following data from HIPAP No. 4.

Table 21 Effects of Thermal Radiation

Heat Radiation Intensity [kW/m^2]	Effect/s
1.2	Received from sun in summer at noon.
1.6	Minimum necessary to be felt as pain.
4.7	Pain in 15 to 20 seconds, 1st degree burns in 30 seconds. Injury (second degree burns) to person who cannot escape or seek shelter after 30s exposure.
12.6	High chance of injury. 30% chance of fatality for extended exposure. Melting of plastics (cable insulation). Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure. Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure.
23.0	Fatality on continuous exposure. 10% chance of fatality on instantaneous exposure. Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress temperatures, which can cause failure. Pressure vessel needs to be relieved or failure would occur.
35.0	25% chance of fatality on instantaneous exposure.
60.0	Fatality on instantaneous exposure.

- It is reported in the TNO 'Purple Book' that people indoors are assumed to be protected from heat radiation until the building catches fire. The threshold for the ignition of buildings in the TNO 'Purple Book' is set at 35 kW/m^2 and if the building is set on fire, all the people inside the building are assumed to die (i.e. The probability of fatality indoors is 1 if the heat radiation exceeds 35 kW/m^2 and it is 0 if the heat radiation is less than 35 kW/m^2).

MAE/s Affected:

- All MAEs with a pool fire or jet fire as a potential outcome.

Reference/s:

- TNO, VROM, *Methods for the determination of possible damage*, 'Green Book', CPR16E.
- TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

Assumption No. 22 Exposure to Flash Fire (Indoor or Outdoor)
Subject: Vulnerability Parameters
Assumption/s: • For calculation of location-specific individual risk, the probability for fatality = 1 for any individual located within the flammable cloud (Distance to LFL concentration). • For calculation of societal risk, the probability for fatality for any individual located within the flammable cloud (Distance to LFL concentration) is 1 (outdoor) or 0.1 (indoor).
Justification and Impact/s of Assumption/s: • The assumed probabilities differ from the guidance in the TNO 'Purple Book' and the default values in the SAFETI software. In both cases, the probability of fatality is set at 1 for all individuals (outdoor or indoor). This was considered too conservative. The probability of fatality indoors was set at 0.1 to take account of the possibility of open doors / windows and/or failure to evacuate.
MAE/s Affected: • All MAEs with a flash fire as a potential outcome.
Reference/s: • SAFETI software documentation. • TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

Assumption No. 23	Exposure to Explosion Overpressure (Indoor or Outdoor)

Subject: Vulnerability Parameters

Assumption/s:

- The probability of fatality from exposure to the peak side-on overpressure from an explosion is as shown in Table 22 (Person located outdoors) and Table 23 (Person located indoors).

Table 22 Probability of Fatality from Exposure to Peak Side on-Overpressure (Outdoor)

Overpressure (kPa)	Probability of Fatality	Source
35	0.15	NSW HIPAP 4
70	1.0	NSW HIPAP 4

Table 23 Probability of Fatality from Exposure to Peak Side on-Overpressure (Indoor)

Overpressure (kPa)	Probability of Fatality	Source
21	0.2	NSW HIPAP 4
35	0.5	NSW HIPAP 4
70	1.0	NSW HIPAP 4

For comparison, the description of explosion overpressure effects from HIPAP 4 are:

Table 24 Effects of Explosion Overpressure

Overpressure [kPa]	Effect/s
0.3	Loud noise.
1.0	Threshold for breakage of glass.
4.0	Minimal effect in the open. Minor injury from window breakage in building.
7.0	Glass fragments fly with enough force to cause injury. Probability of injury is 10%. No fatality. Damage to internal partitions and joinery of conventional buildings, but can be repaired.
14.0	1% chance of ear drum rupture. House uninhabitable and badly cracked.
21.0	10% chance of ear drum rupture. 20% chance of fatality for a person within a conventional building. Reinforced structures distort. Storage tanks fail.
35.0	50% chance of fatality for a person within a conventional building and 15% chance of fatality for a person in the open. House uninhabitable. Heavy machinery damaged. Significant damage to plant.

Assumption No. 23	Exposure to Explosion Overpressure (Indoor or Outdoor)
70.0	100% chance of fatality for a person within a building or in the open. 100% loss of plant.

Justification and Impact/s of Assumption/s:

- When calculating location-specific individual injury or fatality risk contours (peak individual risk), all individuals must be considered to be located outdoors for 100% of the time since this is the underlying basis for the NSW DPIE's individual risk criteria. Vulnerability parameters for individuals located indoors are only applicable for the calculation of societal risk.
- The probability of fatality is higher for an individual located in a conventional building than when outdoors due to the higher chance of harm from collapse of the structure.
- The NSW DPIE's injury/damage risk criterion for explosion overpressure is as follows: "Incident explosion overpressure at residential and sensitive use areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year".

Incidents Affected:

- All incidents with a VCE as a potential outcome.

Reference/s:

- NSW Department of Planning and Infrastructure, Jan 2011, Hazardous Industry Planning Advisory Paper (HIPAP) No. 4, *Risk Criteria for Land Use Safety Planning*.
- SAFETI software documentation.
- Oil & Gas Producers Association (OGP), Risk Assessment Data Directory, Report No. 434-14.1, *Vulnerability to Humans*, March 2010.
- Chemical Industries Association (CIA), 2003, *Guidance for the location and design of occupied buildings on chemical manufacturing sites*, 2nd. ed.

Appendix B Representative Hole Sizes

B.1 Representative Hole Diameters

Representative hole diameters were selected for the consequence modelling. These were selected to align with the leak frequency data, which includes four hole size categories: Pinhole (≤ 25 mm); Small Hole (> 25 mm to ≤ 75 mm), Large Hole (> 75 mm to ≤ 110 mm); and, Rupture (> 110 mm). The representative hole diameter/s in each hole size category were selected based on a review of the following available historical data.

B.1.1 Leak Data for Above Ground or Underground Cross-Country Pipelines – Various Materials

United Kingdom Onshore Pipeline Operators' Association (UKOPA), Major Accident Hazard Pipelines (1962-2014)

The definition of a Major Accident Hazard Pipeline (MAHP) from the Pipelines Safety Regulations 1996 (PSR 96) includes various materials (e.g. including natural gas at >8 bar, flammable liquids, etc.). The pipeline may be above or below ground.

The failure reports in the UKOPA database include the length and width of the failures. The failure area is also recorded for some events. The equivalent diameter of a circular opening with the same cross-sectional area was calculated.

The following table includes the recorded incidents where the hole size was reported [Cited by HSE in RR1035]. This data is almost exclusively for Natural Gas (NG) leaks, with only one leak from another material (Propylene).

Table 25 Dimensions of Leaks for Above Ground or Underground Cross-Country Natural Gas or Propylene Pipelines (UKOPA - Reported Values Only)

Fault ID	Discovery Date	Product	Wall Thickness (mm)	Diameter (in)	Diameter (mm)	Equivalent Hole Diameter (mm)	Cause
1950	1998	NG	4.4	3.9	100	1.1	Corrosion
1948	1997	NG	4.4	3.9	100	11.3	Corrosion
400	1998	NG	Not Recorded	4	102	2.8	Corrosion
3112	2010	NG	4.4	4.5	114	1.1	Corrosion
1424	1990	NG	4.5	4.5	114	3.6	Corrosion
1998	2001	NG	4.8	5.9	150	24.5	Corrosion
2569	2005	NG	4.7	6.4	163	1.1	Corrosion
2979	2009	NG	4.3	6.4	163	17.8	Corrosion
728	1990	NG	6	6.6	168	1.1	Corrosion
425	2000	NG	6.6	8.6	218	1.1	Corrosion
417	1998	NG	5.2	8.6	218	3.2	Corrosion
402	1999	NG	5.2	8.6	218	3.6	Corrosion
422	1999	NG	6.6	8.6	218	3.6	Corrosion
1934	1993	NG	6.4	14	356	1.1	Corrosion
730	1994	NG	6.4	18	457	1.1	Corrosion
1460	2001	NG	6.35	12.7	323	3.6	Ground movement/Other
1490	1989	NG	6.4	12.8	325	1.1	Ground movement/Other
1489	1989	NG	6.4	12.8	325	3.6	Ground movement/Other
1388	1998	NG	8	18	457	2.3	Ground movement/Other

Fault ID	Discovery Date	Product	Wall Thickness (mm)	Diameter (in)	Diameter (mm)	Equivalent Hole Diameter (mm)	Cause
2923	2008	NG	9.52	18	457	3.4	Ground movement/Other
2872	2000	NG	9.52	18	457	27.8	Ground movement/Other
1972	1990	NG	4.5	3.5	89	3.6	Mechanical
1949	1997	NG	4.4	3.9	100	3.6	Mechanical
1947	1990	NG	4.4	4	102	3.6	Mechanical
1909	1989	NG	4.4	4	102	11.3	Mechanical
1913	1990	NG	4.4	4	102	11.3	Mechanical
1914	1990	NG	4.4	4	102	11.3	Mechanical
1916	1990	NG	4.4	4	102	11.3	Mechanical
1917	1990	NG	4.4	4	102	11.3	Mechanical
1919	1990	NG	4.4	4	102	11.3	Mechanical
363	1997	NG	Not recorded	5.9	150	1.1	Mechanical
1928	1990	NG	4.5	5.9	150	11.3	Mechanical
1973	1990	NG	4.5	5.9	150	11.3	Mechanical
2028	1990	NG	4.8	5.9	150	11.3	Mechanical
2078	1989	NG	5.6	5.9	150	11.3	Mechanical
1996	1993	NG	4.8	6.6	168	1.1	Mechanical
1875	1989	NG	5.2	6.6	168	11.3	Mechanical
1886	1990	NG	4.4	6.6	168	11.3	Mechanical
1887	1990	NG	4.4	6.6	168	11.3	Mechanical
1925	1989	NG	4.4	6.6	168	11.3	Mechanical
1926	1989	NG	4.4	6.6	168	11.3	Mechanical
1940	1990	NG	4.4	6.6	168	11.3	Mechanical
2069	1990	NG	6.4	8.6	218	3.6	Mechanical
1876	1989	NG	6.4	8.6	218	11.3	Mechanical
2055	1989	NG	6.4	8.6	218	11.3	Mechanical
1710	1989	NG	7.9	14	356	3.6	Mechanical
1842	1992	NG	9.5	17.7	450	1.1	Mechanical
1361	1994	NG	9.5	24	610	1.1	Mechanical
1117	1993	NG	12.7	36	914	160.1	Mechanical
1918	1990	NG	4.4	4	102	22.6	TPA
1987	1990	NG	4.8	6.6	168	23.9	TPA
2980	2009	NG	5.56	6.6	168	25	TPA
1645	1992	NG	7.1	8.6	218	5.5	TPA
366	1991	NG	4.8	8.6	218	24	TPA
2783	2006	NG	4.5	8.6	219	25	TPA
1560	1989	NG	6.4	12.8	325	56.2	TPA
1185	1998	NG	10.4	15.7	400	20	TPA
1193	1990	NG	9.5	16	406	25	TPA
3109	2009	Propylene	7.1	6.6	168	6.8	TPA

B.1.2 Leak Data for Underground Cross-Country Pipelines – Natural Gas

US Department of Transportation (DoT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Reported Data for Underground Natural Gas Steel Pipelines (January 2010 to September 2017)

The dimensions of a leak are not always included in the US DoT database. The following tables include all recorded incidents where the hole size was reported.

The length and width of the hole is reported in the US DoT database; therefore, the equivalent diameter of a circular opening with the same cross-sectional area was calculated.

Table 26 Dimensions of Rupture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)

MAOP (psig)	MAOP (kPag)	Pipe Diameter (in)	Rupture Length (in)	Rupture Width (in)	Approx. Rupture Area (sq.in)	% of Cross-Section Area	Equiv. Hole Diameter (mm)	Cause
15	205	1.66	1.5	1.5	1.8	81.7	38.1	Natural Force - High Winds
95	756	20	16	1	12.6	4.0	101.6	Corrosion - External
15	205	1	3.3	1	2.6	330.0	46.1	Excavation Damage
60	515	1.25	2	0.1	0.2	12.8	11.4	Excavation Damage
60	515	2	7.5	0.5	2.9	93.8	49.2	Material Failure of Pipe or Weld - Butt Weld
60	515	2.375	6.5	2.1	10.7	242.0	93.8	Material Failure of Pipe or Weld - Butt Weld
60	515	2.375	2	2	3.1	70.9	50.8	Excavation Damage
433	3087	4	10	0.2	1.6	12.5	35.9	Excavation Damage
60	515	6.625	12.5	0.5	4.9	14.2	63.5	Material Failure of Pipe or Weld - Pipe
78	639	16	16	16	201.1	100.0	406.4	Other Cause - Unknown

Table 27 Dimensions of Puncture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)

MAOP (psig)	MAOP (kPag)	Pipe Diameter (in)	Puncture Axial Length (in)	Puncture Circumferential Length (in)	Approx. Puncture Area (sq.in)	% of Cross-Section Area	Equiv. Hole Diameter (mm)	Cause
60	515	0.75	0.5	0.5	0.2	44.4	12.7	Other Outside Force - Electrical arcing
260	1894	0.75	0.8	0.8	0.5	113.8	20.3	Excavation Damage
60	515	1.25	1.5	0.7	0.8	67.2	26.0	Excavation Damage
4	129	2	2	1	1.6	50.0	35.9	Excavation Damage
9.5	167	2	1	3	2.4	75.0	44.0	Excavation Damage
25	274	2	3.5	0.7	1.9	61.3	39.8	Incorrect Operation
52	460	2	0.5	0.5	0.2	6.3	12.7	Other Outside Force - Electrical arcing
60	515	2	1	0.5	0.4	12.5	18.0	Excavation Damage
60	515	2	0.5	0.5	0.2	6.3	12.7	Excavation Damage
60	515	2	1.5	0.7	0.8	26.3	26.0	Other Outside Force - Not Specified
35	343	2.375	1	1	0.8	17.7	25.4	Excavation Damage
440	3135	2.375	2.5	0.5	1.0	22.2	28.4	Excavation Damage
60	515	3	3	9.4	22.1	313.3	134.9	Excavation Damage
17	219	4	1.3	1.3	1.3	10.6	33.0	Excavation Damage
30	308	4	6	3	14.1	112.5	107.8	Excavation Damage
35	343	4	2	2	3.1	25.0	50.8	Excavation Damage
35	343	4	3	3	7.1	56.3	76.2	Excavation Damage
57	494	4	5	2	7.9	62.5	80.3	Excavation Damage

MAOP		Pipe Diameter (in)	Puncture Axial Length (in)	Puncture Circumferential Length (in)	Approx. Puncture Area (sq.in)	% of Cross-Section Area	Equiv. Hole Diameter (mm)	Cause
(psig)	(kPag)							
60	515	4	24	2	37.7	300.0	176.0	Excavation Damage
60	515	4	9	3	21.2	168.8	132.0	Excavation Damage
60	515	4	0.8	0.8	0.5	4.0	20.3	Excavation Damage
250	1825	4	5	3	11.8	93.8	98.4	Excavation Damage
285	2066	4	0.6	1.3	0.6	4.9	22.4	Excavation Damage
300	2170	4.5	1	12.6	9.9	62.2	90.2	Excavation Damage
10	170	6	6	6	28.3	100.0	152.4	Excavation Damage
35	343	6	3	3	7.1	25.0	76.2	Excavation Damage
60	515	6	6	6	28.3	100.0	152.4	Excavation Damage
60	515	6	6	6	28.3	100.0	152.4	Excavation Damage
60	515	6	6	6	28.3	100.0	152.4	Excavation Damage
60	515	6	0.5	0.5	0.2	0.7	12.7	Other Outside Force - Electrical arcing
150	1136	6	1.5	0.5	0.6	2.1	22.0	Excavation Damage
200	1480	6	1.2	1	0.9	3.3	27.8	Excavation Damage
200	1480	6	2	2	3.1	11.1	50.8	Excavation Damage
300	2170	6	0.5	0.5	0.2	0.7	12.7	Excavation Damage
400	2859	6	4	1	3.1	11.1	50.8	Excavation Damage
500	3549	6	1	0.5	0.4	1.4	18.0	Other Outside Force - Other Vehicle
60	515	6.58	1	1	0.8	2.3	25.4	Other Outside Force - Other Vehicle
300	2170	6.625	3	4	9.4	27.3	88.0	Excavation Damage
50	446	8	2.1	2.1	3.5	6.9	53.3	Excavation Damage
50	446	8	11	4	34.6	68.8	168.5	Excavation Damage
60	515	8	0.1	0.1	0.0	0.0	2.5	Excavation Damage
80	653	8	12	8	75.4	150.0	248.9	Excavation Damage
120	929	8	6.5	2.5	12.8	25.4	102.4	Excavation Damage
157	1184	8	3.9	3.2	9.8	19.5	89.7	Excavation Damage
300	2170	8	4	2	6.3	12.5	71.8	Excavation Damage
400	2859	8	2	6	9.4	18.8	88.0	Excavation Damage
870	6100	8	25.1	25.1	494.8	984.4	637.5	Excavation Damage
0.43	104	8.625	6	6	28.3	48.4	152.4	Excavation Damage
60	515	8.625	1	1	0.8	1.3	25.4	Other Outside Force - Not Specified
250	1825	8.625	1	5	3.9	6.7	56.8	Excavation Damage
15	205	10	5	5	19.6	25.0	127.0	Excavation Damage
50	446	10	1.5	0.5	0.6	0.8	22.0	Excavation Damage
60	515	10	0.3	13	3.1	3.9	50.2	Excavation Damage
60	515	10	1	3	2.4	3.0	44.0	Excavation Damage
150	1136	10	7.5	1.1	6.5	8.3	73.0	Excavation Damage
240	1756	10	2	2	3.1	4.0	50.8	Excavation Damage
82	667	10.75	3	2	4.7	5.2	62.2	Excavation Damage
33	329	12	11	4	34.6	30.6	168.5	Excavation Damage
60	515	12	3	3	7.1	6.3	76.2	Excavation Damage
100	791	12	2.3	2.5	4.5	4.0	60.9	Excavation Damage
100	791	12	3	3	7.1	6.3	76.2	Excavation Damage
225	1653	12	7	6.3	34.6	30.6	168.7	Excavation Damage

MAOP		Pipe Diameter (in)	Puncture Axial Length (in)	Puncture Circumferential Length (in)	Approx. Puncture Area (sq.in)	% of Cross-Section Area	Equiv. Hole Diameter (mm)	Cause
(psig)	(kPag)							
0.64	106	12.75	2.5	2.5	4.9	3.8	63.5	Other Outside Force - Not Specified
15	205	12.75	6	6	28.3	22.1	152.4	Excavation Damage
170	1273	14	6	3	14.1	9.2	107.8	Other Outside Force - Other Vehicle
58	501	16	2.5	5	9.8	4.9	89.8	Excavation Damage
188	1398	16	4	4	12.6	6.3	101.6	Excavation Damage
300	2170	16	1.1	3.5	3.0	1.5	49.8	Excavation Damage
150	1136	20	5	1	3.9	1.3	56.8	Excavation Damage
400	2859	26	0.2	0.2	0.0	0.0	5.1	Excavation Damage

Appendix C Likelihood Analysis - Data and Results

C.1.1 Likelihood of Release from Underground Pipelines

The likelihood of a release (i.e. leak) from each underground pipeline was estimated based on a review of relevant data sources. The primary data sources included:

- Department of Industry, Resources and Energy, New South Wales, *2017-18 Licensed Pipelines Performance Report*. This includes data for all licensed pipelines in NSW for the 5-year period: 2013/14 to 2017/18; and
- UK Health and Safety Executive (HSE), 2015, *Update of Pipeline Failure Rates for Land Use Planning Assessments*, Research Report (RR) 1035.
- British Standards Institute, 2013, *Pipeline Systems – Part 3: Steel Pipelines on Land – Guide to the Application of Pipeline Risk Assessment to Proposed Developments in the Vicinity of Major Accident Hazard Pipelines Containing Flammables – Supplement to PD 8010-1:2004*, PD 8010-3:2009+A1:2013.
- US Department of Transportation (DoT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Hazardous Liquid Pipeline Systems (January 2010 to September 2018).

The leak frequency data reported in RR1035 was adopted for the QRA as it is comparable to the NSW performance data and it includes the leak frequency for four hole size categories (pinhole, small hole, large hole and rupture), four failure mode categories (mechanical failure, corrosion, ground movement / other and third party activity), and in some cases for varying pipe diameters and / or wall thicknesses.

The leak frequency data derived from the British Standards Institute PD 8010-3:2009+A1:2013 was not used since the leak rates (other than ruptures) are not clearly defined for all failure modes and the UK HSE does not accept the use of zero frequencies. Also, the rupture frequencies are disproportionally higher than for other hole sizes (unless factored down to account for concrete slab protection), which is not consistent with other data sources.

The leak frequency data reported in RR1035 has been based on:

- An analysis of pipeline failure data from multiple organisations, including:
  - CONCAWE (CONservation of Clean Air and Water in Europe);
  - UKOPA (United Kingdom Onshore Pipeline Operators' Association); and
  - EGIG (European Gas pipeline Incident Group).
- A conservative, yet realistic, analysis of the available data. For example:
  - For failure mode categories where zero failures have occurred, assumptions have been made to estimate the chance of a failure, even if not seen historically (over the observation period).
  - Only the most recent 22 years of historical incident data was analysed to ensure a consistent pipeline population and to remove the older incident data, which may not be as representative of current practice.
  - Incident data for pipelines carrying products at elevated temperatures was excluded from the analysis.

- Although the location of failures (e.g. rural or urban) may be recorded in the various databases, it is recognised that there is insufficient data to estimate the leak frequency for different locations.
- The recommended failure rates for specific materials have been derived from the most appropriate dataset (e.g. for a specific substance the failure rates for corrosion may derived from the CONCAWE products dataset, whilst the mechanical failure rates may be derived from the UKOPA dataset).

NSW Performance Report

The average leak frequency from the 2018 NSW Performance Report for all licensed pipelines in NSW for the 5-year period 2013/14 to 2017/18 is 8.2E-05 per km per year.

UK HSE (RR1035)

The data for natural gas (methane), ethylene and LPG (propane and butane) was reviewed. The data for LPG was selected as it is slightly more conservative for the larger leak diameters and is more applicable for a liquefied gas.

The total leak frequency data reported in Section 7.6 of RR1035 for underground LPG pipelines is slightly more conservative (e.g. 2.1E-04 per km per year for a pipeline with wall thickness ≥ 5 mm to < 10 mm) and was adopted in the QRA for the underground HP Methane pipeline (Refer to **Error! Reference source not found.**).

Table 28 Leak Frequencies for Underground LPG Pipelines

Failure Mode	Pipeline Diameter (mm)	Wall Thickness (mm)	Leak Frequency (per km per yr)				
			Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	All	All	5.7E-05	1.3E-05	6.7E-06	8.3E-06	8.5E-05
Corrosion	All	< 5	1.6E-04	8.9E-07	4.5E-07	1.3E-06	1.6E-04
		5 to < 10	8.4E-05	2.4E-07	4.8E-07	7.3E-07	8.6E-05
		10 to < 15	4.5E-06	1.3E-08	2.6E-08	3.9E-08	4.6E-06
		≥ 15	4.3E-07	1.2E-09	2.5E-09	3.7E-09	4.4E-07
Ground Movement / Other	All	All	1.2E-05	2.5E-06	1.5E-07	2.5E-06	1.7E-05
TPA	All	All	2.2E-05	2.4E-06	1.0E-07	1.0E-07	2.5E-05
Total Leak Freq. =	All	5 to < 10	1.7E-04	1.8E-05	7.4E-06	1.2E-05	**2.1E-04**
% =			82.4	8.7	3.5	5.5	100

British Standards Institute (PD 8010-3:2009+A1:2013)

The data and approach included in Annex B of PD 8010-3:2009+A1:2013 was used to estimate the leak frequencies for the Moomba to Sydney Ethane Pipeline. The data applicable for a pipeline with a wall thickness of 8.1 mm, manufactured after 1980, was used.

Leak frequency data is not reported for internal corrosion; therefore, the total leak frequencies reported in Table 28 may be underestimated.

For leaks (other than ruptures) due to 'Ground Movement / Other', the estimated leak frequency was assumed to be distributed evenly across the other hole sizes (Note: There is no guidance in PD 8010-3:2009+A1:2013 on how to distribute the non-rupture events).

For leaks (other than ruptures) due to 'TPA', the estimated leak frequency was assumed to be distributed across the smaller hole sizes and weighted to the smaller hole size categories (Note: There is no guidance in PD 8010-3:2009+A1:2013 on how to distribute the non-rupture events).

The rupture frequency due to 'TPA' was derived from the generic pipeline failure frequency, which was modified in accordance with the relevant parameters for the Moomba to Sydney Ethane Pipeline (i.e. location, design factor, wall thickness and depth of cover). As this pipeline has concrete slab protection and marker tapes, the base rupture frequency was reduced by a factor of 0.125 (Table A.0, p.31).

Table 29 Approx. Leak Frequencies for Underground Methane Pipeline

Failure Mode	Approx. Leak Frequency (per km per yr)				
	Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	8.0E-06	3.2E-06	0.0E+00	0.0E+00	1.1E-05
Corrosion	3.2E-05	1.1E-05	3.0E-06	0.0E+00	4.6E-05
Ground Movement / Other	4.9E-07	4.9E-07	4.9E-07	6.6E-08	1.5E-06
TPA	6.1E-06	4.0E-06	2.0E-06	8.1E-06	2.0E-05
Total Leak Freq. =	4.7E-05	1.9E-05	5.5E-06	8.1E-06	**7.9E-05**
% =	59.0	23.7	7.0	10.3	100

US Department of Transportation (DoT)

The US Department of Transportation (DoT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Hazardous Liquid Pipeline Systems (January 2010 to September 2018) include incidents for Ethane pipelines; however, the total length of the Ethane pipelines is not available (i.e. it is not possible to determine the leak rate per km.year).

To enable a comparison with the UK data, the data for all Highly Volatile Liquids (Except Ammonia) was analysed and the leaks categorised using the same representative hole sizes as reported in the UK (i.e. RR1035 and PD8010). The results are reported in Table 30.

Period of Recorded Incident Data =	8.75	years	(Jan 2010 to Sept 2018)
Total Length of All HVL Pipelines =	102663	km	Note: Average for 2010 to 2017 for ALL HVLs

Table 30 Leak Frequencies for Underground HVL Pipelines (Excluding Ammonia)

Failure Mode	Approx. Leak Frequency (per km per yr)					Comments
	Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency	
Mechanical Failure	3.9E-05	0.0E+00	0.0E+00	0.0E+00	3.9E-05	Excludes pipelines manufactured prior to 1980.

Failure Mode	Approx. Leak Frequency (per km per yr) Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency	Comments
Corrosion	5.6E-06	0.0E+00	0.0E+00	1.1E-06	6.7E-06	Excludes external corrosion (other than SCC).
Ground Movement / Other	5.6E-06	2.2E-06	1.1E-06	5.6E-06	1.4E-05	
TPA	8.9E-06	6.7E-06	2.2E-06	8.9E-06	2.7E-05	
Total Leak Freq. =	5.9E-05	8.9E-06	3.3E-06	1.6E-05	**8.7E-05**	
% =	67.9	10.3	3.8	17.9	100	

Australia /New Zealand Pipeline Incident Database

A comparison with limited Australian data between 2000 and 2018 extracted from the report "Experience with the Australian/New Zealand Pipeline Incident Database" [12] has been undertaken. The report [12] does not provide explicit rates for loss of containment from pipelines but provides data from which some conclusions may be drawn. These are:

- Total km of pipelines within a given interval Table 31 and
- Total number of leaks and ruptures in the period 2000 to 2018. A total of 17 are reported in the database.

Table 31 Australian Pipeline Population by Half Decade [12]

Period		km of Pipeline				Pipeline Population (km.yr)
Start	End	Interval (yr)	Start of period	End of period	Average during period	
2000	2005	5	26000	29000	27500	137,500
2005	2010	5	29000	32000	30500	152,500
2010	2015	5	32000	36000	34000	170,000
2015	2018	3	36000	36000	36000	108,000
					Total	**568,000**

From **Error! Reference source not found.** and the total of 17 release incidents, the expected total release frequency is

$$f = \frac{N}{km.y} = \frac{17}{568{,}000} = 2.99 \times 10^{-5}\ \mathrm{km}^{-1}\mathrm{y}^{-1}$$

The value selected for the release of ethane from the MSE is $2.124 \times 10^{-4}\ \mathrm{km}^{-1}\mathrm{y}^{-1}$. This is conservative when compared to the Australia /New Zealand Pipeline Incident Database.

C.1.2 Likelihood of Release from Aboveground Pipelines

Above ground sections of pipeline considered in this study have been limited to the valve station at Marsh Street. The above ground equipment is contained within a secure compound. For this reason, the failure frequencies have been obtained from the UK HSE Document "Failure Rate and Event Data for use within Risk Assessments (06/11/17)", specifically item FR 3.1.2 "Above Ground Pipelines in a Gas Installation". These values are replicated in Table 32.

Table 32 Item Failure Rates (UK HSE)

Failure Category	Failure Rate (per m per year)
Rupture (>110mm diameter)	6.5×10^{-9}
Large Hole (>75 –≤110mm diameter)	3.3×10^{-8}
Small Hole (>25 mm – ≤75 mm diameter)	6.7×10^{-8}
Pin Hole (≤25 mm diameter)	1.6×10^{-7}

C.1.3 Ignition Probability

The ignition probabilities adopted in the risk analysis are listed below. This was based on a review of relevant ignition probability data and ignition probability correlations (Refer to Sections C.1.3.1 - C.1.3.3).

Ethane

1. The total ignition probability was based on OGP Scenario 3, which is release rate dependent (Refer to Section C.1.3.1).

   No historical ignition data was identified for ethane pipelines; however, it is typically grouped with other liquefied gases such as propane.

2. The total ignition probability was split 50:50 for immediate ignition: delayed ignition.

   The IOGP data assumes an immediate ignition probability of 0.001. A 50:50 split was assumed for the QRA.

Ignition data is usually reported by hole size rather than failure mode and inconsistent reporting of immediate ignition due to TPA (which is sometimes reported to be the highest immediate ignition probability and sometimes not) means it was not possible to estimate the immediate ignition probability based on failure mode.

C.1.3.1 Ignition Probability Data for Above Ground or Underground Cross-Country Pipelines – Various Materials

United Kingdom Onshore Pipeline Operators' Association (UKOPA), Major Accident Hazard Pipelines (1962-2014)

The definition of a Major Accident Hazard Pipeline (MAHP) from the Pipelines Safety Regulations 1996 (PSR 96) includes various materials (e.g. including natural gas at >8 bar, flammable liquids, etc.). The pipeline may be above or below ground.

There were 9 out of 192 (4.7%) product loss incidents that resulted in ignition.

Table 33 Ignition Probability - UKOPA

<table>
<tr><th>Hole Size Class #</th><th>Total Number of Incidents</th><th>Number of Incidents with Ignition</th><th>Total Ignition Probability</th><th>Total Ignition Probability</th></tr>
<tr><td>Full Bore and Above</td><td>7</td><td>1</td><td>0.14</td><td rowspan="2">0.09</td></tr>
<tr><td>110mm – Full Bore</td><td>4</td><td>0</td><td>0.0</td></tr>
<tr><td>40mm – 110mm</td><td>7</td><td>1</td><td>0.14</td><td rowspan="2">0.03</td></tr>
<tr><td>20mm – 40mm</td><td>23</td><td>0</td><td>0.0</td></tr>
<tr><td>6mm – 20mm</td><td>31</td><td>3</td><td>0.10</td><td rowspan="2">0.05</td></tr>
<tr><td>0 – 6mm</td><td>118</td><td>4</td><td>0.03</td></tr>
<tr><td>Unknown</td><td>2</td><td>0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>Total =</td><td>192</td><td>9</td><td>0.047</td><td>0.047</td></tr>
</table>

OGP, Ignition Probabilities for Pipe-Gas-LPG-Industrial (Scenario 3: Gas or LPG release from onshore pipeline in an industrial or urban area)

The following data applies for releases of flammable gases, vapours or liquids significantly above their normal (Normal Atmospheric Pressure (NAP)) boiling point from onshore cross-country pipelines running through industrial or urban areas.

The OGP Data applies for cross-country pipelines. Although not explicitly stated, it is assumed the pipeline may be above ground or underground.

These curves represent "total" ignition probability. The method assumes that the immediate ignition probability is 0.001 and is independent of the release rate.

Table 34 Ignition Probability – OGP Scenario 3

Release Rate (kg/s)	Total Ignition Probability
0.1	0.0010
0.2	0.0017
0.5	0.0033
1	0.0056
2	0.0095
5	0.0188
10	0.0316
20	0.0532

Release Rate (kg/s)	Total Ignition Probability
50	0.1057
100	0.1778
200	0.2991
500	0.5946
1000	1.0000

C.1.3.2 Ignition Probability Data for Underground Cross-Country Pipelines – Flammable or Combustible Liquids

US Department of Transportation (DoT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Hazardous Liquid Pipeline Systems (January 2010 to September 2018)

Reporting of data is required by 49 CFR Part 195. An accident report is required for each failure in a pipeline system subject to this part in which there is a release of the hazardous liquid or carbon dioxide transported resulting in any of the following:

(a) Explosion or fire not intentionally set by the operator.

(b) Release of 5 gallons (19 litres) or more of hazardous liquid or carbon dioxide, except that no report is required for a release of less than 5 barrels (0.8 cubic meters) resulting from a pipeline maintenance activity if the release is:

(1) Not otherwise reportable under this section;

(2) Not one described in §195.52(a)(4);

(3) Confined to company property or pipeline right-of-way; and

(4) Cleaned up promptly;

(c) Death of any person;

(d) Personal injury necessitating hospitalisation;

(e) Estimated property damage, including cost of clean-up and recovery, value of lost product, and damage to the property of the operator or others, or both, exceeding $50,000.

Table 35 Ignition Probability – US DoT

Liquid	Leak			Mechanical Puncture			Other			Rupture			Total		
	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition
HVLs *	0	46	0.0	0	7	0.0	4	2	0.7	5	5	0.5	9	60	0.13

* Highly Volatile Liquids (Includes Ethane).

C.1.3.3 Ignition Probability Data for Underground Cross-Country Pipelines – Gases Other Than Natural Gas

UK HSE (RR 1034) - Typical Event Tree Probabilities for Flammable Gas other than Natural Gas

The following data is proposed in RR 1034 for the HSE's computer program MISHAP to calculate the level of risk around Major Accident Hazard Pipelines (MAHPs), particularly in land use planning (LUP) assessments. A MAHP may be above or below ground; however, the MISHAP model appears to be primarily for underground pipelines. The probabilities are not reported for varying hole sizes and appear to be only applicable for larger release events.

For MISHAP, the risk associated with VCE events is negligible because the development of MISHAP (and its predecessors) was based on areas with low congestion and confinement (e.g. rural pipelines), which are not conducive for creating the large flammable clouds required by VCE. It is acknowledged in RR 1034 that this may require further review.

Table 36 Ignition Probability – UK HSE (RR 1034)

Outcome	Probability of Outcome		
	R12 Materials with a MIE < 0.2 mJ (1)	R12 Materials with a MIE ≥ 0.2 mJ (2)	R11 and Low Reactive Materials (3)
Immediate ignition, fireball and jet fire	0.350	0.300	0.250
Delayed ignition and jet fire	0.325	0.210	0.188
Delayed ignition, flash fire and jet fire	0.096	0.145	0.167
No ignition	0.229	0.345	0.396

(1) For example: ethylene

(2) For example: butane, ethane and propane

(3) For example: ammonia, carbon monoxide

C.1.3.4 Ignition Probability Data for Underground Cross-Country Pipelines – Natural Gas

An analysis of historical data for rupture incidents on natural gas transmission pipeline incidents [13] shows the ignition probability increases linearly with pd^2. The correlation derived for rupture releases takes the form:

$P_{ign} = 0.0555 + 0.0137\ pd^2;\ 0 \le pd^2 \le 69$

$P_{ign} = 1;\ pd^2 > 69$

P_{ign} = probability of ignition

p = pipeline operating pressure (bar)

d = pipeline diameter for ruptures (m)

Since the pd^2 for the Methane Pipe Rupture is less than 3.367 it falls within the range $0 \le pd^2 \le 69$ meaning the linear correlation derived from the historical data was used.

The probability of ignition P_{ign}, calculated as detailed above, is then generally apportioned as 0.5 for immediate ignition and 0.5 for delayed ignition, where delayed ignition occurs after 30 seconds.

This correlation is for ignition by all causes and is applicable to underground cross-country pipelines carrying high pressure natural gas. It does not take the location of the pipeline (e.g. rural or urban) or the cause of failure (e.g. external) into consideration. The following data was combined to derive the correlation:

- Transmission pipeline incident data recorded between 1970 and 2004; and
- US Office of Pipeline Safety Office (OPS) data between 2002 and 2007.

The authors state that the total ignition probability for releases caused by external interference, such as excavating machinery, is much lower than releases caused by other means (viz. 0.11 vs. 0.34 for pipeline ruptures from 1970 to 2004).

For puncture releases (all causes), the same ignition probability relationship may be applied, with d equal to the release hole diameter and with the pd^2 value halved, reflecting the difference between the two sources following a rupture and the single source contributing to a puncture release.

Table 37 Ignition Probability Based on NG Transmission Pipeline Incidents [13]

Pipeline Diameter (mm)	Operating Pressure (bar)	Equivalent Hole Diameter (mm)	pd^2	Probability of Immediate Ignition	Probability of Delayed Ignition	Total Ignition Probability
202.9	82	FBR	3.376	0.039	0.041	0.079
		110	0.992	0.031	0.032	0.062
		75	0.461	0.029	0.030	0.059
		25	0.051	0.028	0.029	0.056
		10	0.008	0.008	0.004	0.012

EGIG (9th Report, 2015), Natural Gas Transmission Pipelines (1971-2013)

Although the pipeline definition does not preclude above ground pipelines, the data is predominantly for underground natural gas transmission pipelines with a maximum operating pressure > 15 bar.

In the period 1970 - 2013, only 5% of the gas releases recorded as incidents in the EGIG database ignited.

Table 38 Ignition Probability – EGIG

Hole Size Class		Total Ignition Probability
Rupture (FB and Above)	All diameters	0.139
	<= 16 inches	0.103
	> 16 inches	0.32
Hole (>20 mm to FB)		0.023
Pinhole / Crack (Up to 20 mm)		0.044

UK HSE (RR 1034) - Typical Event Tree Probabilities for Natural Gas

The following data is proposed in RR 1034 for the UK HSE's computer program MISHAP. This program is used by the UK HSE to calculate the level of risk around Major Accident Hazard Pipelines (MAHPs), particularly in land use planning (LUP) assessments.

A MAHP may be above or below ground; however, the MISHAP model appears to be primarily for underground pipelines. The probabilities are not reported for varying hole sizes or operating pressures (i.e. are not release rate dependent) and appear to be only applicable for larger release events (i.e. ruptures).

For example, the literature cited in RR 1034 indicates an overall ignition probability between 0.2 and 0.5 for larger releases of natural gas, depending on the degree of confinement. On this basis, the total ignition probability proposed in CR 1034 for natural gas is 0.44.

It is reported in RR 1034 that the risk associated with VCE events is negligible because the development of MISHAP (and its predecessors) was based on areas with low congestion and confinement (e.g. rural pipelines), which are not conducive for creating the large flammable clouds required for a VCE. It is acknowledged in RR 1034 that this may require further review.

The proposed conditional probability value for delayed remote ignition is zero. It is reported in RR 1034 that this is "to take into account the reasoning that natural gas is unlikely to form a significant vapour cloud due to its buoyant nature".

Table 39 Ignition Probability – UK HSE (RR 1034)

Outcome	Probability of Outcome
Immediate ignition, fireball and jet fire	0.250
Delayed ignition and jet fire	0.188
Delayed ignition, flash fire and jet fire	0.000
No ignition	0.563

Note: Some of the sources cited in RR 1034 with an overall ignition probability between 0.2 and 0.5 are relatively old (c. mid 1980s - See below). This data would also appear to confirm that the total ignition probability proposed for natural gas in MISHAP is for a worst-case rupture event on a larger transmission pipeline.

Table 40 Ignition Probability – Data Cited by UK HSE (RR 1034)

Data source	Ignition probability	
World-wide, Townsend & Fearnehough (1986)	Leaks	0.1
	Ruptures	0.5
US Gas, Jones (1986)	Ruptures	0.26
	All sizes	0.16
European Gas, European Gas Pipeline Incident Data Group (1988)	Pinholes / cracks	0.02
	Holes	0.03
	Ruptures < 16”	0.05
	Ruptures ≥ 16”	0.35
	All sizes	0.03

C.1.4 Likelihood of Representative Release Scenarios and Ignition Probabilities

The estimated likelihood of each representative release scenario from sections of pipeline are listed in Table 41 and Table 41

Table 41 Release Frequency – Underground Sections of Pipeline (MSEP)

Leak Scenario	Release Frequency (per km per year)			Probability of scenario compared to total
	TPA	All Other Failure Modes	Total Release Frequency	
10mm MID		1.53E-04	1.53E-04	0.7200
10mm TOP		0.00E+00	0.00E+00	0.0000
25mm MID	2.20E-05		2.20E-05	0.1036
25mm TOP	0.00E+00		0.00E+00	0.0000
75mm MID	2.40E-06	5.94E-06	8.34E-06	0.0393
75mm TOP	0.00E+00	1.01E-05	1.01E-05	0.0476
110mm MID	1.00E-07	2.70E-06	2.80E-06	0.0132
110mm TOP	0.00E+00	4.60E-06	4.60E-06	0.0217
FBR	1.00E-07	1.15E-05	1.16E-05	0.0547
Total	2.46E-05	1.88E-04	**2.124E-04**	1.0000

Leak Scenario	Failure Rate (per m per year)
Full Bore Rupture (FBR) Horizontal	6.5×10^{-9}
110 mm Horizontal	3.3×10^{-8}
75 mm Horizontal	6.7×10^{-8}
25 mm Horizontal	1.6×10^{-7}

Appendix D Consequence Results

D.1 Discharge Results

Table 42 Discharge Consequence Results

Scenario	Material	Mass Flow (kg/s)	Final Velocity (m/s)
Marsh St 110mm	METHANE	171.558	731.249
Marsh St 25mm	METHANE	5.52758	672.491
Marsh St 75mm	METHANE	79.7532	723.404
Marsh St FBR	METHANE	540.792	742.193
Pipeline on Redevelopment_MSEP 10mm MID	METHANE	0.895469	45.3602
Pipeline on Redevelopment_MSEP 110mm MID	METHANE	173.762	149.292
Pipeline on Redevelopment_MSEP 110mm TOP	METHANE	173.762	409.794
Pipeline on Redevelopment_MSEP 25mm MID	METHANE	5.59668	45.3602
Pipeline on Redevelopment_MSEP 75mm MID	METHANE	80.7776	115.435
Pipeline on Redevelopment_MSEP 75mm TOP	METHANE	80.7776	361.723
Pipeline on Redevelopment_MSEP FBR	METHANE	591.197	50.1004
Pipeline Upstream of Cooks River_MSEP 10mm MID	METHANE	0.89885	45.3502
Pipeline Upstream of Cooks River_MSEP 110mm MID	METHANE	174.388	149.551
Pipeline Upstream of Cooks River_MSEP 110mm TOP	METHANE	174.388	409.901
Pipeline Upstream of Cooks River_MSEP 25mm MID	METHANE	5.61781	45.3502
Pipeline Upstream of Cooks River_MSEP 75mm MID	METHANE	81.0686	115.679
Pipeline Upstream of Cooks River_MSEP 75mm TOP	METHANE	81.0686	362.173
Pipeline Upstream of Cooks River_MSEP FBR	METHANE	593.327	50.1
Underwater Pipe Section_MSEP 10mm MID	METHANE	0.896401	45.3574
Underwater Pipe Section_MSEP 110mm MID	METHANE	173.934	149.362
Underwater Pipe Section_MSEP 110mm TOP	METHANE	173.934	409.822
Underwater Pipe Section_MSEP 25mm MID	METHANE	5.60251	45.3574
Underwater Pipe Section_MSEP 75mm MID	METHANE	80.8579	115.541
Underwater Pipe Section_MSEP 75mm TOP	METHANE	80.8579	361.91
Underwater Pipe Section_MSEP FBR	METHANE	591.785	50.1001

D.2 Jet Fire Results

Table 43 Jet Fire Consequence Modelling Results

Scenario	Weather	Flame length (m)	Distance downwind to intensity level 1 (3 kW/m2) (m)	Distance downwind to intensity level 2 (4.7 kW/m2) (m)	Distance downwind to intensity level 3 (23 kW/m2) (m)	Distance downwind to intensity level 4 (35 kW/m2) (m)
Marsh St 110mm	2.2B (Day)	88.813	185.948	164.302	113.402	102.923
	8.5D (Day)	97.4346	182.964	164.295	121.484	113.87
	4.2D (Day)	91.1914	185.18	164.395	115.963	106.778
	1.6D (Day)	87.5971	185.09	163.318	111.946	101.646
	8.3D (Night)	96.6743	182.834	164.031	120.917	113.254
	4.2D (Night)	90.8407	184.41	163.722	115.517	106.377
	1.0D (Night)	86.6461	184.418	162.535	110.714	100.12

	3.3E (Night)	89.4255	184.686	163.555	114.187	104.699
	1.0F (Night)	86.5116	184.601	162.649	110.724	100.151
Marsh St 25mm	2.2B (Day)	24.3634	40.986	37.3005	28.7429	27.1601
	8.5D (Day)	25.9967	39.464	36.5206	29.7708	28.5684
	4.2D (Day)	24.7934	40.4901	37.0272	29.0269	27.5725
	1.6D (Day)	24.0823	40.9889	37.2398	28.5324	26.9158
	8.3D (Night)	25.7998	39.3764	36.409	29.6102	28.4007
	4.2D (Night)	24.6888	40.3811	36.9219	28.9356	27.4872
	1.0D (Night)	23.8781	41.0263	37.2206	28.3718	26.7229
	3.3E (Night)	24.3957	40.5815	37.0085	28.7514	27.2444
	1.0F (Night)	23.8387	41.0433	37.2263	28.3584	26.7103
Marsh St 75mm	2.2B (Day)	71.5822	145.787	129.311	90.7574	83.314
	8.5D (Day)	78.4708	142.621	128.642	96.6068	90.9219
	4.2D (Day)	73.48	145.127	129.338	92.6794	85.8527
	1.6D (Day)	70.5846	145.073	128.499	89.6344	82.0356
	8.3D (Night)	77.8387	142.586	128.485	96.1749	90.4486
	4.2D (Night)	73.1821	144.49	128.776	92.2969	85.5056
	1.0D (Night)	69.8101	144.559	127.889	88.6892	80.6026
	3.3E (Night)	72.038	144.651	128.596	91.2444	84.1988
	1.0F (Night)	69.6965	144.654	127.939	88.6679	80.604
Marsh St FBR	2.2B (Day)	104.227	222.857	196.361	133.731	121.051
	8.5D (Day)	114.193	219.75	196.688	143.673	134.203
	4.2D (Day)	106.969	221.945	196.462	136.889	125.421
	1.6D (Day)	102.837	221.886	195.247	132.096	119.077
	8.3D (Night)	113.326	219.012	195.906	142.769	133.268
	4.2D (Night)	106.571	221.061	195.692	136.39	124.977
	1.0D (Night)	101.749	221.082	194.32	130.731	117.643
	3.3E (Night)	104.944	221.479	195.577	134.803	122.941
	1.0F (Night)	101.595	221.355	194.503	130.772	117.65
Pipeline on Redevelopment_MSEP 10mm MID	2.2B (Day)	14.7265	19.5003	15.6846	1.08027	Not reached at height of interest
	8.5D (Day)	10.6297	22.7755	19.6494	11.4151	10.5407
	4.2D (Day)	12.2383	21.3033	17.2675	7.03005	2.32946
	1.6D (Day)	15.8513	18.2439	13.5614	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	10.6062	22.7336	19.5865	11.34	10.4334
	4.2D (Night)	12.1898	21.2893	17.2674	7.11479	2.36895
	1.0D (Night)	17.339	15.6083	9.71507	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	13.0174	20.1816	16.7549	3.50014	1.23835
	1.0F (Night)	17.3112	15.691	9.81245	Not reached at height of interest	Not reached at height of interest
Pipeline on Redevelopment_MSEP 110mm MID	2.2B (Day)	101.276	161.58	124.174	14.5139	Not reached at height of interest
	8.5D (Day)	73.1014	180.996	147.663	72.6938	54.4281
	4.2D (Day)	84.1632	170.111	138.103	41.7908	17.3327

	1.6D (Day)	109.009	155.021	115.196	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	72.9389	180.528	147.135	72.2683	53.7947
	4.2D (Night)	83.8285	169.884	137.955	42.0689	17.4424
	1.0D (Night)	119.239	144.636	101.812	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	89.5193	168.9	134.802	27.7492	12.2974
	1.0F (Night)	119.048	145.628	102.679	Not reached at height of interest	Not reached at height of interest
Pipeline on Redevelopment_MSEP 110mm TOP	2.2B (Day)	88.5303	129.544	95.9211	Not reached at height of interest	Not reached at height of interest
	8.5D (Day)	63.8998	143.088	116.753	44.3281	19.6496
	4.2D (Day)	73.5656	139.277	109.687	20.167	Not reached at height of interest
	1.6D (Day)	95.2801	123.886	87.9545	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	63.7507	142.98	116.64	43.8733	19.0521
	4.2D (Night)	73.2666	139.146	109.632	20.3642	Not reached at height of interest
	1.0D (Night)	104.217	114.85	78.056	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	78.2364	136.974	106.004	10.7301	Not reached at height of interest
	1.0F (Night)	104.046	115.674	78.832	Not reached at height of interest	Not reached at height of interest
Pipeline on Redevelopment_MSEP 25mm MID	2.2B (Day)	31.7623	45.6254	36.5167	3.605	0.745946
	8.5D (Day)	22.9264	51.94	43.8906	24.043	20.7368
	4.2D (Day)	26.3963	48.162	39.1805	15.2142	5.7939
	1.6D (Day)	34.1893	43.2541	32.658	0.752344	Not reached at height of interest
	8.3D (Night)	22.8766	51.8291	43.7418	23.9025	20.4911
	4.2D (Night)	26.2923	48.1169	39.1317	15.3423	5.8844
	1.0D (Night)	37.3985	38.3917	25.8357	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	28.0778	46.6796	38.6123	9.65205	3.34033
	1.0F (Night)	37.339	38.6028	26.0607	Not reached at height of interest	Not reached at height of interest
Pipeline on Redevelopment_MSEP 75mm MID	2.2B (Day)	83.4041	131.375	101.481	12.6978	Not reached at height of interest
	8.5D (Day)	60.2016	148.34	121.77	61.3042	47.268
	4.2D (Day)	69.3119	137.614	112.665	37.45	14.483
	1.6D (Day)	89.7741	125.744	93.5664	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	60.0686	147.943	121.317	60.8864	46.6775
	4.2D (Night)	69.0369	137.445	112.533	37.6529	14.7711

	1.0D (Night)	98.1993	116.519	81.1957	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	73.724	137.032	110.231	23.9426	10.7076
	1.0F (Night)	98.042	117.284	81.9477	Not reached at height of interest	Not reached at height of interest
Pipeline on Redevelopment_MSEP 75mm TOP	2.2B (Day)	71.9346	104.042	76.9738	Not reached at height of interest	Not reached at height of interest
	8.5D (Day)	51.9213	115.022	93.8897	37.2935	18.813
	4.2D (Day)	59.7752	112.099	88.5031	15.1171	Not reached at height of interest
	1.6D (Day)	77.4193	99.2783	70.123	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	51.8003	114.944	93.8048	36.8774	18.2117
	4.2D (Night)	59.5324	111.996	88.4608	15.8169	Not reached at height of interest
	1.0D (Night)	84.6807	91.5569	61.7176	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	63.5707	110.201	85.4156	Not reached at height of interest	Not reached at height of interest
	1.0F (Night)	84.5418	92.2391	62.3215	Not reached at height of interest	Not reached at height of interest
Pipeline on Redevelopment_MSEP FBR	2.2B (Day)	133.505	226.457	181.225	38.1702	20.1136
	8.5D (Day)	96.3669	245.945	202.799	104.072	84.2167
	4.2D (Day)	110.954	230.36	190.029	79.8536	46.757
	1.6D (Day)	143.713	218.65	169.501	28.7268	8.09446
	8.3D (Night)	96.1611	245.49	202.255	103.605	83.2079
	4.2D (Night)	110.52	230.118	189.774	80.0382	47.0605
	1.0D (Night)	157.205	203.46	149.353	9.11436	Not reached at height of interest
	3.3E (Night)	118.028	230.46	189.603	68.2999	36.9945
	1.0F (Night)	156.957	204.767	150.569	9.44301	Not reached at height of interest
Pipeline Upstream of Cooks River_MSEP 10mm MID	2.2B (Day)	14.7502	19.5349	15.7123	1.08278	Not reached at height of interest
	8.5D (Day)	10.6468	22.8145	19.6821	11.4326	10.5558
	4.2D (Day)	12.258	21.3391	17.2957	7.03997	2.333
	1.6D (Day)	15.8768	18.2768	13.5865	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	10.6233	22.7725	19.6191	11.3573	10.4579
	4.2D (Night)	12.2094	21.3251	17.2956	7.12481	2.37256
	1.0D (Night)	17.3669	15.6377	9.73515	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	13.0384	20.2159	16.7837	3.50635	1.24009
	1.0F (Night)	17.3391	15.7206	9.8327	Not reached at height of interest	Not reached at height of interest

Pipeline Upstream of Cooks River_MSEP 110mm MID	2.2B (Day)	101.444	161.867	124.391	14.5365	Not reached at height of interest
	8.5D (Day)	73.2229	181.304	147.908	72.8022	54.4992
	4.2D (Day)	84.3031	170.418	138.344	41.8391	17.3695
	1.6D (Day)	109.191	155.299	115.404	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	73.06	180.836	147.379	72.375	53.8651
	4.2D (Night)	83.9678	170.19	138.196	42.1179	17.4796
	1.0D (Night)	119.437	144.902	102.009	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	89.668	169.201	135.036	27.8087	12.3147
	1.0F (Night)	119.245	145.897	102.877	Not reached at height of interest	Not reached at height of interest
Pipeline Upstream of Cooks River_MSEP 110mm TOP	2.2B (Day)	88.6945	129.807	96.1195	Not reached at height of interest	Not reached at height of interest
	8.5D (Day)	64.0183	143.373	116.985	44.4143	19.696
	4.2D (Day)	73.702	139.555	109.907	20.221	Not reached at height of interest
	1.6D (Day)	95.4568	124.14	88.142	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	63.8689	143.265	116.872	43.959	19.0982
	4.2D (Night)	73.4025	139.423	109.851	20.4181	Not reached at height of interest
	1.0D (Night)	104.41	115.091	78.2285	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	78.3815	137.249	106.218	10.8285	Not reached at height of interest
	1.0F (Night)	104.239	115.916	79.0062	Not reached at height of interest	Not reached at height of interest
Pipeline Upstream of Cooks River_MSEP 25mm MID	2.2B (Day)	31.813	45.7067	36.5823	3.61408	0.751547
	8.5D (Day)	22.9631	52.0287	43.9641	24.081	20.7668
	4.2D (Day)	26.4384	48.2446	39.2485	15.242	5.80837
	1.6D (Day)	34.244	43.3325	32.7188	0.75938	Not reached at height of interest
	8.3D (Night)	22.9131	51.9177	43.815	23.9404	20.5207
	4.2D (Night)	26.3343	48.1994	39.1995	15.3702	5.89902
	1.0D (Night)	37.4583	38.4639	25.8885	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	28.1227	46.7616	38.6799	9.67406	3.34975
	1.0F (Night)	37.3987	38.6754	26.114	Not reached at height of interest	Not reached at height of interest
Pipeline Upstream of Cooks River_MSEP 75mm MID	2.2B (Day)	83.5523	131.627	101.671	12.7197	Not reached at height of interest
	8.5D (Day)	60.3086	148.615	121.99	61.4037	47.3326
	4.2D (Day)	69.435	137.878	112.879	37.4932	14.4802

	1.6D (Day)	89.9336	125.988	93.7462	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	60.1753	148.217	121.535	60.9851	46.7415
	4.2D (Night)	69.1596	137.71	112.746	37.6967	14.767
	1.0D (Night)	98.3738	116.753	81.3623	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	73.855	137.297	110.437	23.9671	10.7268
	1.0F (Night)	98.2162	117.52	82.116	Not reached at height of interest	Not reached at height of interest
Pipeline Upstream of Cooks River_MSEP 75mm TOP	2.2B (Day)	72.0679	104.245	77.124	Not reached at height of interest	Not reached at height of interest
	8.5D (Day)	52.0175	115.247	94.0685	37.3483	18.8234
	4.2D (Day)	59.8861	112.316	88.6717	15.1504	Not reached at height of interest
	1.6D (Day)	77.5628	99.4739	70.2628	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	51.8963	115.168	93.9876	36.9318	18.2198
	4.2D (Night)	59.6428	112.213	88.6293	15.8517	Not reached at height of interest
	1.0D (Night)	84.8377	91.7406	61.8467	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	63.6885	110.414	85.5793	Not reached at height of interest	Not reached at height of interest
	1.0F (Night)	84.6986	92.4244	62.4519	Not reached at height of interest	Not reached at height of interest
Pipeline Upstream of Cooks River_MSEP FBR	2.2B (Day)	133.881	227.169	181.798	38.3478	20.2027
	8.5D (Day)	96.6381	246.697	203.414	104.38	84.4616
	4.2D (Day)	111.266	231.073	190.621	80.1169	46.9411
	1.6D (Day)	144.117	219.344	170.047	28.8546	8.15788
	8.3D (Night)	96.4318	246.241	202.868	103.913	83.4527
	4.2D (Night)	110.831	230.83	190.365	80.3015	47.2452
	1.0D (Night)	157.647	204.119	149.856	9.19624	Not reached at height of interest
	3.3E (Night)	118.36	231.182	190.197	68.5272	37.1504
	1.0F (Night)	157.399	205.43	151.075	9.52771	Not reached at height of interest
Underwater Pipe Section_MSEP 10mm MID	2.2B (Day)	14.733	19.7545	16.2131	3.60601	2.228
	8.5D (Day)	10.6344	22.8326	19.8024	12.5883	10.9133
	4.2D (Day)	12.2437	21.7239	17.9156	9.29317	5.5651
	1.6D (Day)	15.8583	18.784	14.4925	2.34674	1.89571
	8.3D (Night)	10.611	22.7983	19.7464	12.4519	10.8297
	4.2D (Night)	12.1952	21.7066	17.9096	9.32341	5.63317
	1.0D (Night)	17.3467	16.5844	11.446	0.793587	Not reached at height of interest
	3.3E (Night)	13.0232	20.7427	17.0705	6.6118	2.43327

	1.0F (Night)	17.3189	16.6578	11.5241	0.803411	Not reached at height of interest
Underwater Pipe Section_MSEP 110mm MID	2.2B (Day)	101.322	162.153	124.994	17.6241	Not reached at height of interest
	8.5D (Day)	73.1349	181.342	148.108	73.4369	55.8879
	4.2D (Day)	84.2018	170.339	138.469	44.074	18.2669
	1.6D (Day)	109.059	155.755	116.206	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	72.9723	180.876	147.582	72.9412	55.2605
	4.2D (Night)	83.8669	170.109	138.318	44.3233	18.3708
	1.0D (Night)	119.294	145.554	102.725	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	89.5603	169.25	135.315	29.4812	14.4775
	1.0F (Night)	119.102	146.537	103.584	Not reached at height of interest	Not reached at height of interest
Underwater Pipe Section_MSEP 110mm TOP	2.2B (Day)	88.5755	130.255	96.9651	Not reached at height of interest	Not reached at height of interest
	8.5D (Day)	63.9324	143.306	116.981	45.8967	24.5873
	4.2D (Day)	73.6032	139.7	110.29	21.8599	Not reached at height of interest
	1.6D (Day)	95.3287	124.756	89.1572	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	63.7833	143.203	116.875	45.4656	24.0375
	4.2D (Night)	73.304	139.566	110.231	22.0425	Not reached at height of interest
	1.0D (Night)	104.27	115.827	79.1705	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	78.2764	137.5	106.751	15.5153	Not reached at height of interest
	1.0F (Night)	104.099	116.696	79.9363	Not reached at height of interest	Not reached at height of interest
Underwater Pipe Section_MSEP 25mm MID	2.2B (Day)	31.7763	45.9202	37.0672	7.15212	3.24857
	8.5D (Day)	22.9366	52.1031	44.1619	24.4274	21.6989
	4.2D (Day)	26.4079	48.6164	39.3956	17.465	8.76846
	1.6D (Day)	34.2044	43.7953	33.5486	3.69548	1.14236
	8.3D (Night)	22.8867	52.0002	44.0202	24.3042	21.5149
	4.2D (Night)	26.3039	48.5819	39.3436	17.5596	8.8729
	1.0D (Night)	37.415	39.3082	27.3903	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	28.0902	46.8571	38.8195	4.25294	3.74241
	1.0F (Night)	37.3555	39.5101	27.596	Not reached at height of interest	Not reached at height of interest
Underwater Pipe Section_MSEP 75mm MID	2.2B (Day)	83.465	131.937	102.278	14.8999	Not reached at height of interest
	8.5D (Day)	60.2456	148.706	122.232	61.9985	48.6987
	4.2D (Day)	69.3624	137.907	112.983	39.8573	19.4426

	1.6D (Day)	89.8396	126.48	94.633	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	60.1124	148.311	121.781	61.5929	48.1243
	4.2D (Night)	69.0873	137.736	112.848	40.0143	19.6974
	1.0D (Night)	98.2709	117.455	82.6361	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	73.7778	137.353	110.707	27.5633	12.0585
	1.0F (Night)	98.1136	118.212	83.3703	Not reached at height of interest	Not reached at height of interest
Underwater Pipe Section_MSEP 75mm TOP	2.2B (Day)	71.9897	104.78	78.0224	Not reached at height of interest	Not reached at height of interest
	8.5D (Day)	51.961	115.227	94.1945	38.7429	22.1934
	4.2D (Day)	59.821	112.513	89.0916	17.2676	Not reached at height of interest
	1.6D (Day)	77.4786	100.16	71.4891	Not reached at height of interest	Not reached at height of interest
	8.3D (Night)	51.8399	115.153	94.0332	38.3496	21.7452
	4.2D (Night)	59.578	112.407	89.0456	17.412	Not reached at height of interest
	1.0D (Night)	84.7456	92.705	62.8541	Not reached at height of interest	Not reached at height of interest
	3.3E (Night)	63.6194	110.722	86.1483	12.4056	Not reached at height of interest
	1.0F (Night)	84.6066	93.3751	63.4481	Not reached at height of interest	Not reached at height of interest
Underwater Pipe Section_MSEP FBR	2.2B (Day)	133.595	226.904	181.839	41.762	20.8596
	8.5D (Day)	96.4315	246.333	203.261	104.665	84.9631
	4.2D (Day)	111.028	230.939	190.386	81.3021	48.9665
	1.6D (Day)	143.809	219.275	170.347	29.2178	10.1571
	8.3D (Night)	96.2256	245.882	202.721	104.206	84.7093
	4.2D (Night)	110.594	230.696	190.128	81.4743	49.2632
	1.0D (Night)	157.31	204.337	150.591	11.4917	Not reached at height of interest
	3.3E (Night)	118.107	230.8	189.945	69.4304	39.7564
	1.0F (Night)	157.062	205.636	151.794	11.843	Not reached at height of interest

D.3 Flash Fire Results

Table 44 Flash Fire Consequence Modelling Results

Scenario	Weather	Maximum distance (at height of interest) to LFL (m)	Maximum distance (at height of interest) to UFL (m)	Max flash fire distance for all heights (m)	Height at max flash fire distance for all heights (m)
Marsh St 110mm	2.2B (Day)	145.061	25.0835	145.692	1.11182
	8.5D (Day)	151.611	24.0157	151.611	1.32291
	4.2D (Day)	134.402	24.5428	134.564	1.38463
	1.6D (Day)	123.431	24.8666	123.431	1.91601
	8.3D (Night)	140.66	23.7863	140.711	2.07201
	4.2D (Night)	127.796	24.3519	128.058	2.16671
	1.0D (Night)	118.26	24.8313	119.348	2.59982
	3.3E (Night)	122.558	24.9563	123.017	2.0326
	1.0F (Night)	105.919	25.1275	106.302	1.88764
Marsh St 25mm	2.2B (Day)	14.2051		16.0368	0.982327
	8.5D (Day)	11.7074		13.2124	0.989317
	4.2D (Day)	13.7145		15.1688	0.979438
	1.6D (Day)	15.2837		16.7078	1.02201
	8.3D (Night)	11.6443		13.1482	0.99051
	4.2D (Night)	13.6034		15.0539	0.980742
	1.0D (Night)	15.6295		16.9926	1.0212
	3.3E (Night)	14.378		15.5382	1.01553
	1.0F (Night)	14.947		16.1297	1.0009
Marsh St 75mm	2.2B (Day)	101.175	16.6196	102.054	1.00411
	8.5D (Day)	104.264	15.7634	104.413	1.06405
	4.2D (Day)	95.3463	16.5329	95.4106	1.10642
	1.6D (Day)	89.601	16.9772	89.6718	1.39125
	8.3D (Night)	100.038	15.6531	100.054	1.42468
	4.2D (Night)	92.6493	16.3742	92.6493	1.47797
	1.0D (Night)	87.2783	17.0135	87.5626	1.66387
	3.3E (Night)	89.3921	17.0715	89.7685	1.50261
	1.0F (Night)	78.4175	17.6907	78.7135	1.38978
Marsh St FBR	2.2B (Day)	175.288	33.8396	178.774	2.90966
	8.5D (Day)	186.455	32.4833	186.799	2.28694
	4.2D (Day)	166.707	32.6394	167.187	2.41279
	1.6D (Day)	152.409	32.7226	153.776	3.11156
	8.3D (Night)	170.874	32.1506	174.205	3.02367
	4.2D (Night)	155.966	32.3766	159.216	3.38167
	1.0D (Night)	143.746	32.5964	147.393	4.19454
	3.3E (Night)	149.286	32.8236	151.291	3.20522
	1.0F (Night)	129.348	32.3957	130.225	2.65282
Pipeline Upstream of Cooks River_MSEP 10mm MID	2.2B (Day)	0.255692	0.182562	1.41303	5.38119
	8.5D (Day)	0.294641	0.212381	1.73265	3.38625
	4.2D (Day)	0.263042	0.189095	1.60731	4.5602
	1.6D (Day)	0.248401	0.178257	1.39557	6.57108

Scenario	Weather	Maximum distance (at height of interest) to LFL (m)	Maximum distance (at height of interest) to UFL (m)	Max flash fire distance for all heights (m)	Height at max flash fire distance for all heights (m)
	8.3D (Night)	0.292793	0.210952	1.71568	3.39772
	4.2D (Night)	0.262965	0.188968	1.59756	4.44097
	1.0D (Night)	0.245721	0.176251	1.29217	7.67536
	3.3E (Night)	0.246156	0.183329	1.54376	4.83935
	1.0F (Night)	0.227314	0.173887	1.22972	7.78151
Pipeline Upstream of Cooks River_MSEP 110mm MID	2.2B (Day)	1.13019	0.82931	9.69648	44.0562
	8.5D (Day)	1.13453	0.831834	15.1949	25.3426
	4.2D (Day)	1.12461	0.823234	12.7991	34.6459
	1.6D (Day)	1.11965	0.819024	10.5538	52.6002
	8.3D (Night)	1.13243	0.829991	14.9627	25.4258
	4.2D (Night)	1.12363	0.822349	12.6848	34.4989
	1.0D (Night)	1.11881	0.818227	9.49427	61.9657
	3.3E (Night)	1.13987	0.801926	11.5419	36.9638
	1.0F (Night)	1.2952	0.787725	8.24411	54.2416
Pipeline Upstream of Cooks River_MSEP 110mm TOP	2.2B (Day)	0.604078	0.474437	6.60026	43.1821
	8.5D (Day)	0.603682	0.477929	9.43121	26.171
	4.2D (Day)	0.597947	0.472834	8.38746	35.7769
	1.6D (Day)	0.594968	0.470258	7.04878	51.3214
	8.3D (Night)	0.603571	0.477818	9.32679	26.2159
	4.2D (Night)	0.598223	0.473035	8.32362	35.6635
	1.0D (Night)	0.594565	0.469789	6.3846	55.3603
	3.3E (Night)	0.56486	0.457864	7.63244	37.7921
	1.0F (Night)	0.539978	0.445526	5.53419	50.3901
Pipeline Upstream of Cooks River_MSEP 25mm MID	2.2B (Day)	0.514592	0.374322	3.65698	10.9411
	8.5D (Day)	0.543331	0.397262	5.04619	6.44316
	4.2D (Day)	0.516124	0.378375	4.58902	8.94893
	1.6D (Day)	0.502977	0.369161	3.86953	13.6657
	8.3D (Night)	0.540813	0.395405	4.99255	6.47633
	4.2D (Night)	0.515487	0.377837	4.55097	8.90837
	1.0D (Night)	0.500369	0.367304	3.54923	16.95
	3.3E (Night)	0.486752	0.368975	4.17598	9.85045
	1.0F (Night)	0.461372	0.358653	2.94396	16.1364
Pipeline Upstream of Cooks River_MSEP 75mm MID	2.2B (Day)	0.994333	0.742952	8.24936	34.1688
	8.5D (Day)	1.04553	0.749053	12.6957	20.0405
	4.2D (Day)	0.977137	0.739395	10.7757	27.2766
	1.6D (Day)	0.970622	0.734499	8.86916	42.2164
	8.3D (Night)	1.04311	0.746967	12.53	19.7236
	4.2D (Night)	0.975913	0.738425	10.6943	27.0927
	1.0D (Night)	1.02654	0.733535	8.074	50.0385
	3.3E (Night)	1.0542	0.721184	9.70717	28.8592
	1.0F (Night)	0.892916	0.708926	6.87895	44.4455

Scenario	Weather	Maximum distance (at height of interest) to LFL (m)	Maximum distance (at height of interest) to UFL (m)	Max flash fire distance for all heights (m)	Height at max flash fire distance for all heights (m)
Pipeline Upstream of Cooks River_MSEP 75mm TOP	2.2B (Day)	0.513322	0.401631	5.2906	33.7777
	8.5D (Day)	0.51585	0.406681	7.37346	20.6334
	4.2D (Day)	0.50964	0.4012	6.61979	28.7393
	1.6D (Day)	0.506277	0.398285	5.52371	40.128
	8.3D (Night)	0.515657	0.406455	7.28901	20.6818
	4.2D (Night)	0.509754	0.4013	6.56798	27.9949
	1.0D (Night)	0.505877	0.397887	5.07698	44.248
	3.3E (Night)	0.481157	0.388556	5.99639	29.682
	1.0F (Night)	0.459336	0.377929	4.31082	40.2664
Pipeline Upstream of Cooks River_MSEP FBR	2.2B (Day)	2.7768	1.94963	20.0342	49.186
	8.5D (Day)	2.76077	1.97183	36.0422	26.0458
	4.2D (Day)	2.68786	1.92735	30.9663	39.5543
	1.6D (Day)	2.65223	1.90546	23.2004	62.8755
	8.3D (Night)	2.75172	1.96543	35.4043	26.9268
	4.2D (Night)	2.68432	1.9246	30.3764	39.3365
	1.0D (Night)	2.64498	1.901	20.1249	78.1028
	3.3E (Night)	2.60255	1.85913	26.7993	42.0414
	1.0F (Night)	2.62637	1.8059	18.6429	64.838
Underwater Pipe Section_MSEP 10mm MID	2.2B (Day)	0.448194	0.278487	1.32687	4.30133
	8.5D (Day)	0.90033	0.37779	1.45434	2.35487
	4.2D (Day)	0.515226	0.315499	1.42044	3.52936
	1.6D (Day)	0.409717	0.262265	1.32723	5.63216
	8.3D (Night)	0.878786	0.376738	1.4479	2.44899
	4.2D (Night)	0.51656	0.315438	1.41037	3.41012
	1.0D (Night)	0.392665	0.252439	1.24872	6.74107
	3.3E (Night)	0.456175	0.299575	1.43197	4.02298
	1.0F (Night)	0.369191	0.258098	1.19986	7.02977
Underwater Pipe Section_MSEP 110mm MID	2.2B (Day)	1.28106	0.944065	9.63568	43.0259
	8.5D (Day)	1.29765	0.961627	14.8368	24.333
	4.2D (Day)	1.27175	0.941308	12.6345	33.6492
	1.6D (Day)	1.25849	0.930773	10.4848	51.5641
	8.3D (Night)	1.29505	0.959463	14.6017	24.4267
	4.2D (Night)	1.27112	0.940652	12.5195	33.5096
	1.0D (Night)	1.2562	0.928928	9.45321	60.9592
	3.3E (Night)	1.27241	0.91885	11.4251	36.0828
	1.0F (Night)	1.40324	1.04451	8.19462	53.3432
Underwater Pipe Section_MSEP 110mm TOP	2.2B (Day)	0.779306	0.604427	6.56126	42.247
	8.5D (Day)	0.787121	0.616567	9.29175	25.2261
	4.2D (Day)	0.772243	0.604314	8.30832	34.8124
	1.6D (Day)	0.764545	0.597896	7.01659	50.3254
	8.3D (Night)	0.787221	0.616437	9.19084	25.2697

Scenario	Weather	Maximum distance (at height of interest) to LFL (m)	Maximum distance (at height of interest) to UFL (m)	Max flash fire distance for all heights (m)	Height at max flash fire distance for all heights (m)
	4.2D (Night)	0.77316	0.604894	8.24886	34.6633
	1.0D (Night)	0.763602	0.59705	6.35487	54.4195
	3.3E (Night)	0.73138	0.587129	7.57829	36.8523
	1.0F (Night)	1.09439	0.571094	5.50041	49.4407
Underwater Pipe Section_MSEP 25mm MID	2.2B (Day)	0.693536	0.483037	3.50721	9.9715
	8.5D (Day)	0.843228	0.584072	4.44445	5.32731
	4.2D (Day)	0.716818	0.504462	4.26039	7.98143
	1.6D (Day)	0.661828	0.468442	3.76086	12.7135
	8.3D (Night)	0.836323	0.579513	4.40069	5.36256
	4.2D (Night)	0.71685	0.504196	4.21852	7.94733
	1.0D (Night)	0.651503	0.461603	3.48282	15.9942
	3.3E (Night)	0.666696	0.487742	3.95667	8.91645
	1.0F (Night)	0.606206	0.45729	2.88576	15.2242
Underwater Pipe Section_MSEP 75mm MID	2.2B (Day)	1.18446	0.854701	8.17065	33.1357
	8.5D (Day)	1.21567	0.881874	12.3049	18.6018
	4.2D (Day)	1.18326	0.856064	10.6007	26.3159
	1.6D (Day)	1.16635	0.842674	8.80289	41.2045
	8.3D (Night)	1.21275	0.879262	12.1462	18.749
	4.2D (Night)	1.18263	0.855349	10.5221	26.0751
	1.0D (Night)	1.1633	0.840107	8.02535	49.0402
	3.3E (Night)	1.18802	0.836323	9.56575	27.9398
	1.0F (Night)	1.3174	0.817854	6.83369	43.5343
Underwater Pipe Section_MSEP 75mm TOP	2.2B (Day)	0.683451	0.52591	5.25576	32.8032
	8.5D (Day)	0.695377	0.540106	7.23918	19.7098
	4.2D (Day)	0.679519	0.527253	6.54738	27.8169
	1.6D (Day)	0.671252	0.520496	5.49267	39.1524
	8.3D (Night)	0.695181	0.539808	7.1597	19.7559
	4.2D (Night)	0.680274	0.527689	6.49482	27.0718
	1.0D (Night)	0.670241	0.519541	5.05518	43.2615
	3.3E (Night)	0.643767	0.512936	5.94167	28.7915
	1.0F (Night)	0.614424	0.498926	4.28784	39.3004
Underwater Pipe Section_MSEP FBR	2.2B (Day)	2.77057	1.94515	19.9627	49.0375
	8.5D (Day)	2.75527	1.96754	35.9328	25.9859
	4.2D (Day)	2.68206	1.92317	30.8814	39.4596
	1.6D (Day)	2.64638	1.90115	23.1032	62.7793
	8.3D (Night)	2.74605	1.9612	35.2911	26.8648
	4.2D (Night)	2.67845	1.9204	30.2758	39.2402
	1.0D (Night)	2.63915	1.89666	20.075	77.9779
	3.3E (Night)	2.59695	1.85498	26.6998	41.9441
	1.0F (Night)	2.62038	1.80228	18.5829	64.7568

Scenario	Weather	Maximum distance (at height of interest) to LFL (m)	Maximum distance (at height of interest) to UFL (m)	Max flash fire distance for all heights (m)	Height at max flash fire distance for all heights (m)
Pipeline on Redevelopment_MSEP 10mm MID	2.2B (Day)	0.255376	0.182319	1.40956	5.37631
	8.5D (Day)	0.294345	0.212158	1.72918	3.3835
	4.2D (Day)	0.262732	0.188856	1.60459	4.5551
	1.6D (Day)	0.248085	0.178015	1.39377	6.55993
	8.3D (Night)	0.292494	0.21073	1.7128	3.395
	4.2D (Night)	0.262656	0.18873	1.59485	4.43588
	1.0D (Night)	0.245402	0.176008	1.29004	7.66876
	3.3E (Night)	0.245864	0.183099	1.54101	4.83466
	1.0F (Night)	0.227026	0.173655	1.22797	7.77477
Pipeline on Redevelopment_MSEP 110mm MID	2.2B (Day)	1.1294	0.828584	9.68171	43.9833
	8.5D (Day)	1.13381	0.831157	15.1687	25.2961
	4.2D (Day)	1.12386	0.822531	12.776	34.5848
	1.6D (Day)	1.11891	0.818311	10.5334	52.5193
	8.3D (Night)	1.1317	0.829281	14.9377	25.3796
	4.2D (Night)	1.12288	0.821694	12.6621	34.4375
	1.0D (Night)	1.11808	0.81754	9.47907	61.8721
	3.3E (Night)	1.13908	0.801208	11.5251	36.8766
	1.0F (Night)	1.29455	0.787045	8.22927	54.1573
Pipeline on Redevelopment_MSEP 110mm TOP	2.2B (Day)	0.603242	0.473746	6.58275	43.1573
	8.5D (Day)	0.602952	0.477219	9.40901	26.1311
	4.2D (Day)	0.597087	0.472142	8.36479	35.7285
	1.6D (Day)	0.594127	0.469603	7.03402	51.2613
	8.3D (Night)	0.602796	0.477143	9.305	26.1764
	4.2D (Night)	0.597397	0.472375	8.30127	35.6149
	1.0D (Night)	0.593769	0.469158	6.36812	55.2984
	3.3E (Night)	0.564093	0.457227	7.61802	37.7072
	1.0F (Night)	0.539189	0.444899	5.51873	50.3344
Pipeline on Redevelopment_MSEP 25mm MID	2.2B (Day)	0.513789	0.373723	3.64736	10.926
	8.5D (Day)	0.542533	0.396669	5.03508	6.43596
	4.2D (Day)	0.515355	0.377778	4.57882	8.94182
	1.6D (Day)	0.502193	0.368562	3.86042	13.656
	8.3D (Night)	0.540003	0.394823	4.97308	6.32115
	4.2D (Night)	0.514715	0.377241	4.537	8.89724
	1.0D (Night)	0.499573	0.36671	3.54259	16.929
	3.3E (Night)	0.485999	0.368389	4.16648	9.83865
	1.0F (Night)	0.460666	0.358088	2.93798	16.1218
Pipeline on Redevelopment_MSEP 75mm MID	2.2B (Day)	0.993644	0.742371	8.2338	34.108
	8.5D (Day)	1.04494	0.748484	12.6807	19.9982

Scenario	Weather	Maximum distance (at height of interest) to LFL (m)	Maximum distance (at height of interest) to UFL (m)	Max flash fire distance for all heights (m)	Height at max flash fire distance for all heights (m)
	4.2D (Day)	0.976537	0.738822	10.7586	27.1857
	1.6D (Day)	0.969986	0.733921	8.85388	42.1404
	8.3D (Night)	1.04252	0.746425	12.5092	19.6799
	4.2D (Night)	0.975317	0.737855	10.6764	27.0425
	1.0D (Night)	1.02591	0.732962	8.056	49.9556
	3.3E (Night)	1.05361	0.720654	9.69037	28.8048
	1.0F (Night)	0.892388	0.708383	6.86338	44.4126
Pipeline on Redevelopment_MSEP 75mm TOP	2.2B (Day)	0.51284	0.40123	5.28095	33.725
	8.5D (Day)	0.515392	0.406281	7.35815	20.5954
	4.2D (Day)	0.509174	0.400821	6.60435	28.6913
	1.6D (Day)	0.505801	0.397882	5.51342	40.0681
	8.3D (Night)	0.515163	0.40606	7.27504	20.6443
	4.2D (Night)	0.509263	0.400903	6.5525	27.9306
	1.0D (Night)	0.505403	0.397478	5.06888	44.1843
	3.3E (Night)	0.480725	0.388181	5.98418	29.6242
	1.0F (Night)	0.458991	0.377571	4.30261	40.1991
Pipeline on Redevelopment_MSEP FBR	2.2B (Day)	2.7686	1.9438	19.9444	48.9809
	8.5D (Day)	2.7535	1.96627	35.7932	25.9705
	4.2D (Day)	2.68019	1.92184	30.8548	39.43
	1.6D (Day)	2.64443	1.89973	23.0971	62.7049
	8.3D (Night)	2.74423	1.95987	35.2595	26.848
	4.2D (Night)	2.67661	1.91906	30.2242	39.2105
	1.0D (Night)	2.63729	1.89529	20.0444	78.0505
	3.3E (Night)	2.59512	1.85367	26.6847	41.954
	1.0F (Night)	2.6185	1.8012	18.5729	64.7083

D.4 Explosion Results

Table 45 Explosion Consequence Modelling Results

Scenario	Weather	Distance to 0.07 bar (m)	Distance to (0.1 bar) (m)	Distance to 0.14 bar (m)	Max diameter at 0.07 bar (m)	Max diameter at 0.1 bar (m)	Downwind distance to Explosion centre (m)
Marsh St 110mm	2.2B (Day)	93.9709	83.5121	Not reached	49.3704	28.453	69.2857
	8.5D (Day)	93.5821	83.684	Not reached	46.724	26.9278	70.2201
	4.2D (Day)	88.3682	78.5356	Not reached	46.4147	26.7495	65.1609
	1.6D (Day)	85.78	75.9777	Not reached	46.2717	26.6671	62.6442
	8.3D (Night)	90.627	80.853	Not reached	46.138	26.5901	67.558
	4.2D (Night)	85.2103	75.5507	Not reached	45.5983	26.279	62.4112
	1.0D (Night)	82.6589	73.0075	Not reached	45.5597	26.2567	59.8791

Scenario	Weather	Distance to 0.07 bar (m)	Distance to (0.1 bar) (m)	Distance to 0.14 bar (m)	Max diameter at 0.07 bar (m)	Max diameter at 0.1 bar (m)	Downwind distance to Explosion centre (m)
	3.3E (Night)	84.9889	75.2911	Not reached	45.7784	26.3828	62.0997
	1.0F (Night)	77.1983	68.0397	Not reached	43.2332	24.916	55.5817
Marsh St 25mm	2.2B (Day)	11.8244	10.3753	Not reached	6.84054	3.94231	8.40412
	8.5D (Day)	10.096	8.77969	Not reached	6.2136	3.58099	6.9892
	4.2D (Day)	11.3725	9.95212	Not reached	6.70497	3.86418	8.02003
	1.6D (Day)	12.3827	10.885	Not reached	7.06997	4.07453	8.84769
	8.3D (Night)	10.0553	8.74083	Not reached	6.20514	3.57612	6.95277
	4.2D (Night)	11.2971	9.88104	Not reached	6.68443	3.85234	7.95487
	1.0D (Night)	12.5828	11.0688	Not reached	7.14662	4.11871	9.00945
	3.3E (Night)	11.817	10.3483	Not reached	6.93313	3.99567	8.35043
	1.0F (Night)	12.2094	10.7005	Not reached	7.12277	4.10496	8.64797
Marsh St 75mm	2.2B (Day)	67.6769	60.0259	Not reached	36.1166	20.8146	49.6186
	8.5D (Day)	65.1691	57.9711	Not reached	33.9783	19.5822	48.1799
	4.2D (Day)	62.8937	55.703	Not reached	33.9435	19.5622	45.922
	1.6D (Day)	60.0465	52.9562	Not reached	33.4699	19.2892	43.3116
	8.3D (Night)	64.942	57.7456	Not reached	33.9706	19.5778	47.9566
	4.2D (Night)	62.7248	55.5404	Not reached	33.9136	19.545	45.7679
	1.0D (Night)	60.1287	53.013	Not reached	33.5899	19.3584	43.3338
	3.3E (Night)	59.5889	52.5381	Not reached	33.2833	19.1817	42.9472
	1.0F (Night)	55.5808	48.8271	Not reached	31.881	18.3735	39.6403
Marsh St FBR	2.2B (Day)	117.574	104.465	Not reached	61.8798	35.6623	86.634
	8.5D (Day)	116.27	104.008	Not reached	57.8826	33.3587	87.3287
	4.2D (Day)	110.276	98.051	Not reached	57.706	33.2569	81.4226
	1.6D (Day)	107.649	95.4017	Not reached	57.814	33.3191	78.7422
	8.3D (Night)	112.61	100.5	Not reached	57.1645	32.9448	84.0277
	4.2D (Night)	106.931	94.8794	Not reached	56.8874	32.7851	78.4869
	1.0D (Night)	104.577	92.4555	Not reached	57.2191	32.9763	75.9674
	3.3E (Night)	106.815	94.7367	Not reached	57.0135	32.8578	78.3078
	1.0F (Night)	98.5736	87.0502	Not reached	54.3961	31.3493	71.3755
Pipeline on Redevelopment_ MSEP 110mm MID	8.5D (Day)	19.309	13.3622	Not reached	28.0718	16.1782	5.27311
	4.2D (Day)	19.3733	12.725	Not reached	31.3833	18.0867	3.68161
	1.6D (Day)	21.9748	13.8787	Not reached	38.2177	22.0254	2.86594
	8.3D (Night)	19.2393	13.2828	Not reached	28.1173	16.2045	5.18062
	4.2D (Night)	19.3324	12.6939	Not reached	31.3374	18.0602	3.66376
	3.3E (Night)	19.5793	12.7106	Not reached	32.4239	18.6864	3.36734
Pipeline on Redevelopment_ MSEP 75mm MID	8.5D (Day)	16.0548	11.1909	Not reached	22.96	13.2322	4.57479
	4.2D (Day)	16.8	11.2026	Not reached	26.4224	15.2276	3.58881
	8.3D (Night)	15.9938	11.1197	Not reached	23.0082	13.26	4.48967

Scenario	Weather	Distance to 0.07 bar (m)	Distance to (0.1 bar) (m)	Distance to 0.14 bar (m)	Max diameter at 0.07 bar (m)	Max diameter at 0.1 bar (m)	Downwind distance to Explosion centre (m)
	4.2D (Night)	16.7597	11.171	Not reached	26.3815	15.2041	3.56901
Pipeline on Redevelopment_ MSEP FBR	2.2B (Day)	19.3083	11.9398	Not reached	34.7828	20.0459	1.91689
	8.5D (Day)	33.8342	24.8185	Not reached	42.5589	24.5273	12.5548
	4.2D (Day)	36.2985	25.6561	Not reached	50.2374	28.9526	11.1798
	1.6D (Day)	35.1484	23.0342	Not reached	57.1849	32.9566	6.55595
	8.3D (Night)	33.9218	24.8524	Not reached	42.8118	24.6731	12.5159
	4.2D (Night)	36.1951	25.5737	Not reached	50.1381	28.8954	11.126
	1.0D (Night)	38.99	25.1651	Not reached	65.2604	37.6106	6.35982
	3.3E (Night)	33.0288	22.6262	Not reached	49.1054	28.3002	8.4761
	1.0F (Night)	23.3704	14.3683	Not reached	42.4941	24.49	2.12333
Pipeline Upstream of Cooks River_MSEP 110mm MID	8.5D (Day)	19.3592	13.3987	Not reached	28.1368	16.2157	5.29081
	4.2D (Day)	19.4198	12.7563	Not reached	31.455	18.128	3.6923
	1.6D (Day)	21.9807	13.8795	Not reached	38.2419	22.0394	2.85978
	8.3D (Night)	19.2879	13.318	Not reached	28.1812	16.2413	5.19732
	4.2D (Night)	19.3782	12.7246	Not reached	31.408	18.1009	3.67416
	3.3E (Night)	19.5967	12.7196	Not reached	32.4629	18.7089	3.36518
Pipeline Upstream of Cooks River_MSEP 75mm MID	8.5D (Day)	16.0891	11.2156	Not reached	23.0049	13.2581	4.58661
	4.2D (Day)	16.8287	11.2211	Not reached	26.4707	15.2555	3.59336
	8.3D (Night)	16.0304	11.1462	Not reached	23.0558	13.2874	4.50248
	4.2D (Night)	16.7878	11.1891	Not reached	26.4285	15.2311	3.57358
Pipeline Upstream of Cooks River_MSEP FBR	2.2B (Day)	33.4241	22.1213	Not reached	53.3549	30.7493	6.74665
	8.5D (Day)	33.8723	24.8398	Not reached	42.6378	24.5728	12.5534
	4.2D (Day)	36.3931	25.7211	Not reached	50.3773	29.0332	11.2044
	1.6D (Day)	35.1588	23.0329	Not reached	57.2399	32.9883	6.5388
	8.3D (Night)	33.9636	24.8776	Not reached	42.8908	24.7186	12.5183
	4.2D (Night)	36.2938	25.6412	Not reached	50.2856	28.9804	11.151
	1.0D (Night)	39.0417	25.1936	Not reached	65.3699	37.6737	6.35679
	3.3E (Night)	33.109	22.6798	Not reached	49.2309	28.3726	8.49352
	1.0F (Night)	23.331	14.339	Not reached	42.4469	24.4628	2.10758
Underwater Pipe Section_MSEP 110mm MID	8.5D (Day)	19.1325	13.183	Not reached	28.0844	16.1855	5.09031
	4.2D (Day)	19.3317	12.6712	Not reached	31.441	18.1199	3.61123
	1.6D (Day)	22.0366	13.9114	Not reached	38.3548	22.1045	2.85919
	8.3D (Night)	19.0729	13.1114	Not reached	28.1412	16.2182	5.00225

Scenario	Weather	Distance to 0.07 bar (m)	Distance to (0.1 bar) (m)	Distance to 0.14 bar (m)	Max diameter at 0.07 bar (m)	Max diameter at 0.1 bar (m)	Downwind distance to Explosion centre (m)
	4.2D (Night)	19.2925	12.6405	Not reached	31.4007	18.0967	3.59214
	3.3E (Night)	19.63	12.7262	Not reached	32.5896	18.7819	3.33525
Underwater Pipe Section_MSEP 75mm MID	8.5D (Day)	15.8391	10.9652	Not reached	23.0073	13.2595	4.33542
	4.2D (Day)	16.761	11.1446	Not reached	26.5122	15.2794	3.5049
	8.3D (Night)	15.7918	10.9082	Not reached	23.0527	13.2856	4.2654
	4.2D (Night)	16.7192	11.1117	Not reached	26.4704	15.2553	3.48407
Underwater Pipe Section_MSEP FBR	2.2B (Day)	19.2958	11.9308	Not reached	34.7665	20.0365	1.91252
	8.5D (Day)	33.8421	24.8226	Not reached	42.5763	24.5374	12.5539
	4.2D (Day)	36.3211	25.6717	Not reached	50.2707	28.9718	11.1858
	1.6D (Day)	35.1669	23.0452	Not reached	57.2203	32.9769	6.55677
	8.3D (Night)	33.9315	24.8577	Not reached	42.8332	24.6855	12.5149
	4.2D (Night)	36.2236	25.5941	Not reached	50.1764	28.9174	11.1354
	1.0D (Night)	38.982	25.1593	Not reached	65.2498	37.6045	6.35707
	3.3E (Night)	33.0405	22.6338	Not reached	49.1244	28.3112	8.47824
	1.0F (Night)	23.3561	14.3586	Not reached	42.4726	24.4776	2.11981