Preliminary Hazard Analysis of Gas Pipelines Risk to New Primary School at Gregory Hills, NSW

For School Infrastructure NSW

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Summary

School Infrastructure NSW (SINSW) has proposed Primary School be built at a site in Gregory Hills, NSW. The subject site is located in Dharawal Country, and located at 28 Wallarah Circuit, Gregory Hills NSW 2557.

The permanent school is a State Significant Development (SSD) and the NSW Minister for Planning, through the NSW Department of Planning and Environment (DPE) is the consent authority.

SINSW have engaged Arriscar Pty Limited (Arriscar) to undertake a Preliminary Hazard Analysis to determine the level of risk presented to the proposed school from three nearby high-pressure gas transmission pipelines:

1. Jemena Gas Central Trunk Pipeline (CTM).
2. Jemena Eastern Gas Pipeline (EGP).
3. APA Moomba-Sydney Ethane Pipeline (MSE).

Introduction

This report by Arriscar Pty Limited (Arriscar) accompanies an Environmental Impact Statement (EIS) pursuant to Part 4 of the Environmental Planning and Assessment Act 1979 (EP&A Act), in support of a State Significant Development Application (SSDA) for the construction and operation of a new primary school at Gregory Hills (SSD-41306367).

This report addresses the Secretary's Environmental Assessment Requirements (SEARs) issued for the project, notably:

SEARs Requirement	Response
Where there are dangerous goods and hazardous materials associated with the development, provide a preliminary risk screening in accordance with Chapter 3 of SEPP (Resilience and Hazards) 2021.	There will be insufficient dangerous goods or hazardous materials on site for the school to be considered a potentially hazardous or offensive industry.
Where required by SEPP (Resilience and Hazards) 2021, provide a Preliminary Hazard Analysis prepared in accordance with Hazardous Industry Planning Advisory Paper No.6 – Guidelines for Hazard Analysis.	The combined risk of all three gas pipelines did not exceed any locational specific risk in relation to fatality, injury, or property damage at the proposed school boundary. The proposed school will not contribute to societal risk arising from the three pipelines.
If the development is adjacent to or on land in a pipeline corridor, report on consultation outcomes with the operator of the pipeline, and prepare a hazard analysis.	A previous land use change Safety Management Study workshop (refer GHPS SSDA_15.2_Safety_Management_Study_October 2022) was held with representatives from Jemena and APA.

Proposal

The proposal is for a new primary school at Gregory Hills that generally comprises the following:

- 44 General Learning Spaces.
- 4 Support Learning Spaces.
- Administration, staff hub, amenity and building service areas.

- Library, communal hall and canteen.
- Outside School Hours Care (OSHC) services.
- Sport courts, outdoor play space, a Covered Outdoor Learning Area (COLA) and site landscaping.
- Dedicated bicycle and scooter parking.
- Three (3) kiss and drop spaces for Supported Learning Students (SLS) located on Wallarah Circuit.
- On-site car parking.
- Signage.
- Footpath widening on Wallarah Circuit.

Figure 1: Site Plan (source Bennett and Trimble)

Site Description and Location

The site is located in Dharawal Country at 28 Wallarah Circuit, Gregory Hills NSW 2557, and is legally described as Lot 3257 DP1243285.

The site is located within the Camden Local Government Area and is within the Turner Road Precinct of the South-West Growth Centre.

The site has an area of approximately 2.926ha (by Deposited Plan). This will be reduced to 2.907ha under approved DA2022/742/1 once Long Reef Circuit has been widened.

Topography is minimal with a fall from the south-east corner (RL116.5) to the north- west corner (RL113).

The site has three (3) street frontages:

- Wallarah Circuit (Southern boundary)
- Gregory Hills Drive (Northern boundary)
- Long Reef Circuit (Eastern boundary)

The site is primarily vacant land, with the exception of an existing group of trees in the southwest corner of the site that pre-date the subdivision and development of the precinct. There is also an existing electrical substation located on the south-eastern boundary.

There are easements of varying widths located to the northern boundary identified for drainage.

Figure 2: Locality Map (Six Maps)

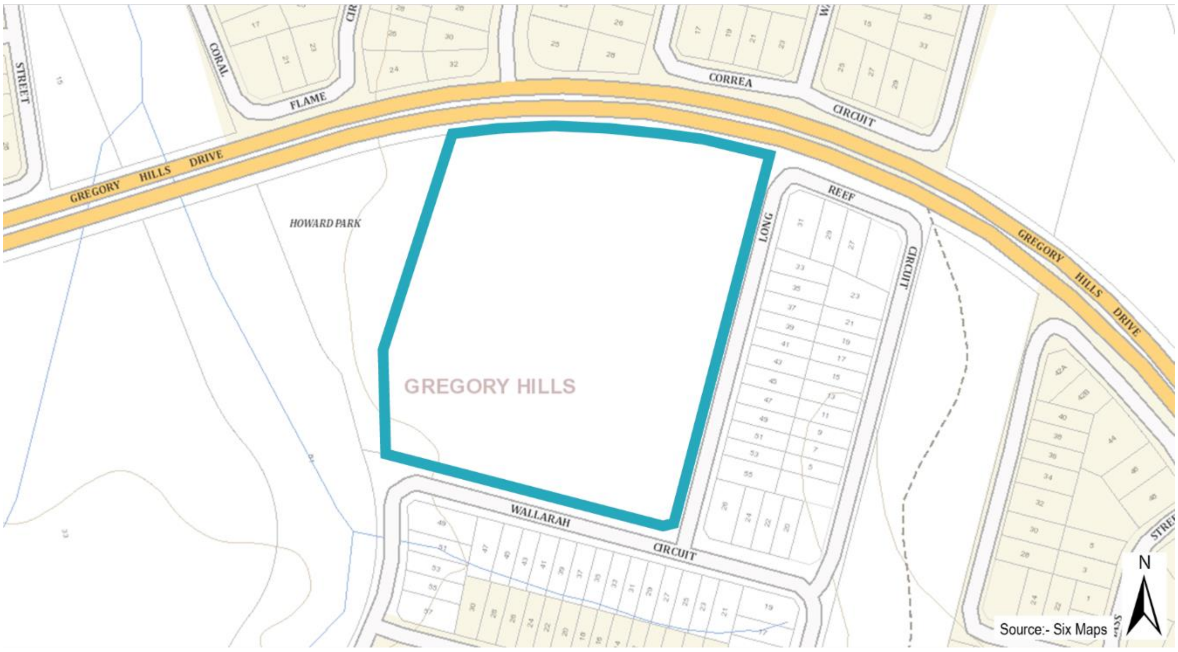

Figure 3: Site Aerial Map, (Source Bennett and Trimble)

Surrounding Development

To the north, east and south of the site is emerging and recently completed residential development.

To the east of the residential area fronting Long Reef Circuit are high voltage power lines within an easement which include pedestrian paths and cycleways.

To the west of the site, beyond Sykes Creek and Howard Park, is the Gregory Hills town centre. A pedestrian bridge links Wallarah Circuit with the town centre across Sykes Creek.

Figure 4: Surrounding Development (Nearmap)

Recommendations

The following recommendation has been made in relation to the proposed school:

1. The school emergency plan must include pipeline rupture as a scenario and develop an appropriate shelter in place policy to prevent the potential for injuries from people exposed to radiated heat flux in open.

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Notation

Abbreviation	Description
ALARP	As Low As Reasonably Practicable
ALB	Automatic Line Break
APD	Australian Pipeline Database
Arriscar	Arriscar Pty Limited
BoM	Bureau of Meteorology
CDL	Critical Defect Length
COLA	Covered Outdoor Learning Area
CTM	Central Trunk Main
DBYD	Dial Before You Dig
DPE	NSW Department of Planning and Environment
EGP	Eastern Gas Pipeline
EIS	Environmental Impact Statement
EP&A Act	Environmental Planning and Assessment Act 1979
FBR	Full-bore Rupture
HAZID	Hazard Identification
HDD	Horizontal Directional Drilling
HIPAP	Hazardous Industry Planning Advisory Paper
HSE	(UK) Health and Safety Executive
km	Kilometre
kPa	Kilopascal
LFL	Lower Flammable Limit
LSIR	Location Specific Individual Risk
m	Metre
MAE	Major Accident Event
MAOP	Maximum Allowable Operating Pressure
MLV	Main Line Valve
mm	millimetre
MPag	Mega-Pascal gauge
MSE	Moomba-Sydney Ethane Pipeline
OSHC	Outside School Hours Care
PHA	Preliminary Hazard Analysis
QRA	Quantitative Risk Assessment

Abbreviation	Description
RR	Research Report
SEARs	Secretary's Environmental Assessment Requirements
SEPP	State Environmental Planning Policy
SINSW	School Infrastructure New South Wales
SMS	Safety Management Study
SSD	State Significant Development
SSDA	State Significant Development Application
TPA	Third Party Activity
VCE	Vapour Cloud Explosion
µm	Micro-metre

1 INTRODUCTION

1.1 Background

School Infrastructure NSW (SINSW) has proposed Primary School be built at a site in Gregory Hills, NSW. The subject site is located in Dharawal Country, and located at 28 Wallarah Circuit, Gregory Hills NSW 2557.

The permanent school is a State Significant Development (SSD) and the NSW Minister for Planning, through the NSW Department of Planning and Environment (DPE) is the consent authority.

SINSW have engaged Arriscar Pty Limited (Arriscar) to undertake a Preliminary Hazard Analysis (PHA) to determine the level of risk presented to the proposed school from three nearby high-pressure gas transmission pipelines.

This report by Arriscar Pty Ltd accompanies an Environmental Impact Statement (EIS) pursuant to Part 4 of the Environmental Planning and Assessment Act 1979 (EP&A Act), in support of the State Significant Development Application (SSDA) for the construction and operation of a new primary school at Gregory Hills (SSD-41306367).

This report addresses the Secretary's Environmental Assessment Requirements (SEARs) issued for the project as listed below [1].

"15 ***Hazards and Risks***

- *Where there are dangerous goods and hazardous materials associated with the development, provide a preliminary risk screening in accordance with Chapter 3 of SEPP (Resilience and Hazards) 2021.*
- *Where required by SEPP (Resilience and Hazards) 2021, provide a Preliminary Hazard Analysis prepared in accordance with Hazardous Industry Planning Advisory Paper No.6 – Guidelines for Hazard Analysis.*
- *If the development is adjacent to or on land in a pipeline corridor, report on consultation outcomes with the operator of the pipeline, and prepare a hazard analysis."*

1.2 Scope

The scope of the study included undertaking a preliminary hazard analysis (PHA) on the impact on the proposed development from the following high pressure gas pipelines, in accordance with a review of SEPP (Resilience and Hazards) [2] and Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 [3].

1. Jemena Gas Central Trunk Pipeline (CTM).
2. Jemena Eastern Gas Pipeline (EGP).
3. APA Moomba-Sydney Ethane Pipeline (MSE).

This assessment also included:

4. A Safety Management Study (SMS) as required under AS 2885-2008 [4] for change in land use in the vicinity of the pipelines.
5. An evaluation of the suitability of the proposed location for a school after an assessment of the risks to the proposed school from the pipelines in accordance with HIPAP No. 10 [5].

There are three pipelines in the one corridor; therefore, the potential for incident escalation between the two pipelines is also included in the assessment.

1.3 Objectives

The principal objective of the study was to perform a PHA covering the pipelines and in accordance with the NSW HIPAP guidelines [3]. This included:

- Identification of gas release hazards from the high-pressure gas pipelines in the vicinity of the development;
- Development of gas release scenarios that may impact on the proposed school structures;
- Quantification of the harmful effects of fires and explosions from gas releases.
- Assessment of structural impact on the school infrastructure.
- Details of consultation with Pipeline Operators and other stakeholders [4].

2 DESCRIPTION OF PROPOSED DEVELOPMENT AND SURROUNDING LAND USES

2.1 Site Location

The subject site is in Dharawal Country, within the Camden Local Government Area and is within the Turner Road Precinct of the South-West Growth Centre.

The site is located at 28 Wallarah Circuit, Gregory Hills NSW 2557and is legally described as Lot 3257 DP1243285.

The site has an area of approximately 2.9ha and falls from the south-east corner (RL116.5) to the north- west corner (RL113).

The site has three (3) street frontages:

- Wallarah Circuit (southern boundary)
- Gregory Hills Drive (northern boundary)
- Long Reef Circuit (eastern Boundary)

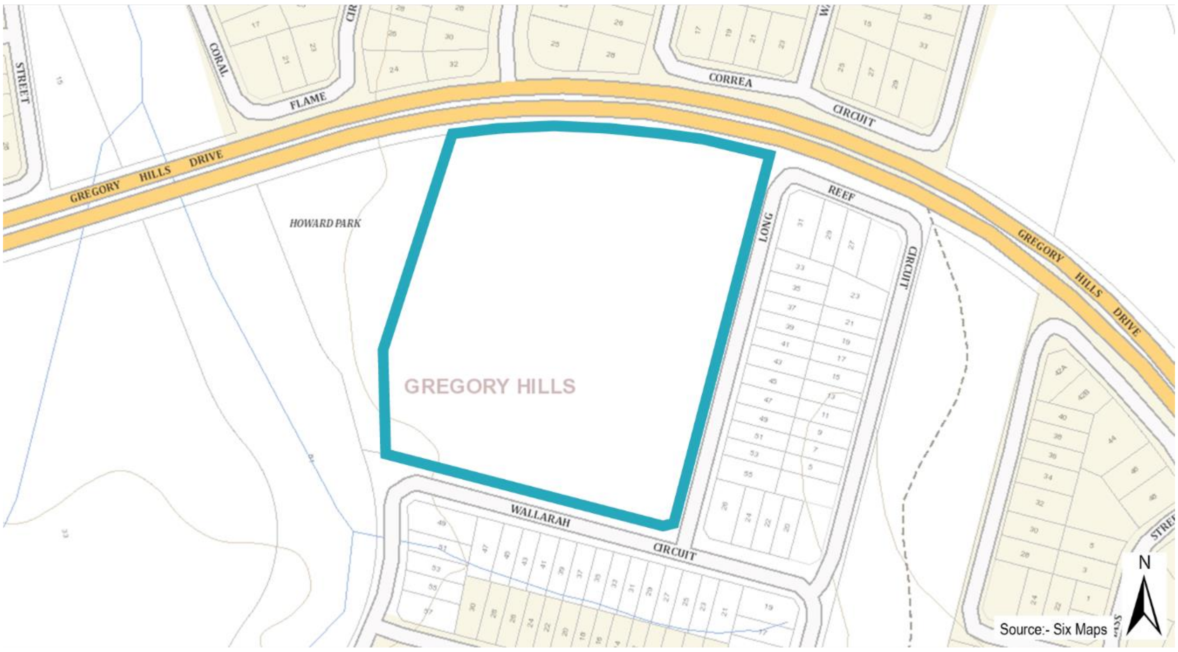
Howard Park and the riparian corridor along Sykes Creek are located to the west of the site.

To the north, east and south of the site is emerging and recently completed residential development. To the west of the site, beyond Sykes Creek and Howard Park, is the Gregory Hills town centre. A pedestrian bridge links Wallarah Circuit with the town centre across Sykes Creek.

To the east of the residential area fronting Long Reef Circuit are high voltage power lines within an easement which include pedestrian paths and cycleways. Further east is an easement for high pressure gas infrastructure.

A locality map is shown in Figure 5.

Figure 5: Locality Map of Gregory Hills Primary School Site



A site aerial map is shown in Figure 6.

Figure 6: Gregory Hills Primary School Site Aerial Map

2.2 Site Description

The site is a gently sloping vacant lot, bounded to the north by Gregory Hills Drive, to the east by Long Reef Circuit, to the south by Wallarah Circuit and to the west by the Howard Park, the riparian corridor and beyond to the Gregory Hills Town Centre.

An existing group of trees (Cumberland plain woodland) has been retained in the southwest corner of the site that pre-dates the subdivision and development of the precinct.

The southwest corner of the site is subject to potential bushfire risk due to its proximity to the heavily vegetated riparian corridor. As a result, all buildings on the lot have been recommended to be built for BAL 12.5.

The site is within the edge of the measurement length of a nearby high-pressure gas pipeline to the east of the site.

There is an existing electrical substation located on the south-eastern boundary.

There are easements of varying widths located to the northern boundary identified for drainage.

2.3 Outline of Gregory Hills Primary School Infrastructure

The proposal is for a new primary school at Gregory Hills that generally comprises the following:

- 44 General Learning Spaces.
- 4 Support Learning Spaces.
- Administration, staff hub, amenity and building service areas.
- Library, communal hall and canteen.
- Outside School Hours Care (OSHC) services.
- Sport courts, outdoor play space, a Covered Outdoor Learning Area (COLA) and site landscaping.
- Dedicated bicycle and scooter parking.

- Short stay parking located along Long Reef Circuit in an indented bay.
- On-site car parking.

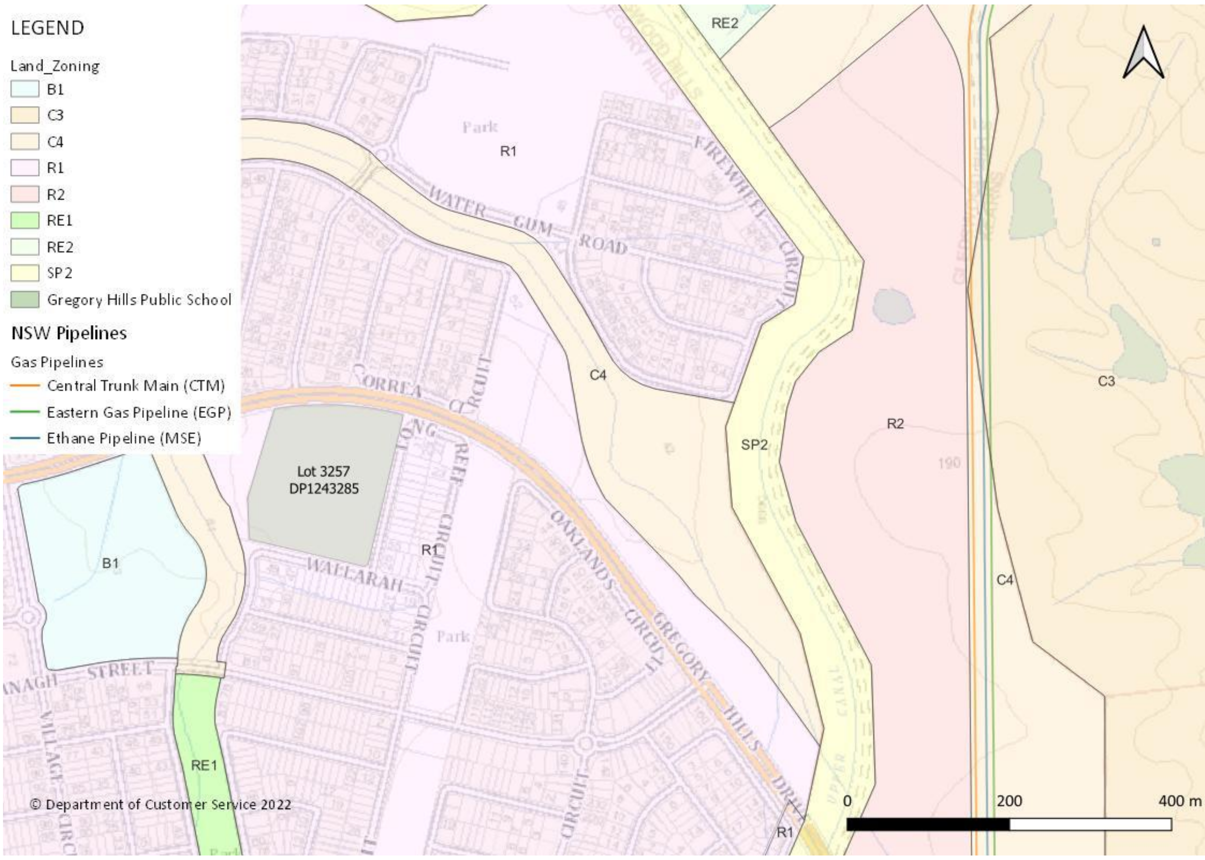
A concept layout diagram is shown in Figure 7.

Figure 7: School Layout

2.4 Surrounding Development

The proposed school lies within land zoned R1, general residential. To the north, south and east of the site is residential development comprising one (1) and two (2) storey dwellings. Howard Park adjoins the site to the west. A natural water course (Sykes Creek) and riparian area are mapped between Howard Park and Gregory Hills Town Centre which is to the west of Sykes Creek. The surrounding land uses are shown in Figure 8. The pipelines are shown on the right in Figure 8.

Figure 8: Surrounding Land Uses



A map of the surrounding developments is shown in Figure 9.

Figure 9: Developments Surrounding the Gregory Hills Primary School Site

2.5 Meteorology

Meteorology used for the analysis is based on Camden Airport (ID: 068192), and is presented in Table 1.

Table 1: Average Temperature, Relative Humidity and Solar Radiation

Weather Category	Stability Class	Wind Speed (m/s)	Average Temp (°C)	Average Solar Radiation (kW/m^2)	Average Relative Humidity
1.8B	B	1.8	20.6	0.6	0.58
7.5D	D	7.5	21.7	0.4	0.42
3.9D	D	3.9	18.9	0.2	0.61
1.0D	D	1	13.1	0	0.84
2.6E	E	2.6	16.5	0	0.71
1.0F	F	1	12.1	0	0.87

The distribution of the weather categories in relation to wind direction is shown in Table 2.

Table 2: Directional Distribution of Weather Categories

Wind Direction	Weather Category						Total
	1.8B	7.5D	3.9D	1.0D	2.6E	1.0F	
N	1.67%	0.15%	1.64%	1.38%	0.23%	0.56%	**5.63%**
NNE	1.50%	0.25%	1.39%	1.14%	0.16%	0.32%	**4.76%**
NE	0.83%	0.76%	2.56%	1.07%	0.37%	0.53%	**6.12%**
ENE	0.65%	0.25%	2.59%	1.93%	0.65%	0.81%	**6.88%**
E	0.40%	0.06%	1.50%	1.31%	0.41%	0.78%	**4.45%**
ESE	0.47%	0.25%	1.86%	2.67%	0.39%	0.63%	**6.27%**

Wind Direction	Weather Category						Total
	1.8B	7.5D	3.9D	1.0D	2.6E	1.0F	
SE	0.53%	0.50%	2.59%	3.08%	0.47%	1.02%	**8.18%**
SSE	0.80%	0.54%	4.03%	6.71%	0.59%	1.83%	**14.50%**
S	0.43%	0.33%	2.89%	3.06%	0.33%	0.66%	**7.71%**
SSW	0.33%	0.41%	2.12%	2.01%	0.37%	0.53%	**5.76%**
SW	0.32%	1.30%	1.92%	1.44%	0.22%	0.53%	**5.72%**
WSW	0.56%	1.63%	1.85%	1.72%	0.18%	0.29%	**6.23%**
W	0.21%	0.46%	0.48%	0.70%	0.08%	0.07%	**1.99%**
WNW	0.43%	0.62%	0.63%	1.03%	0.08%	0.39%	**3.17%**
NW	0.90%	0.22%	0.82%	1.00%	0.08%	0.32%	**3.34%**
NNW	2.50%	0.35%	2.11%	3.34%	0.24%	0.74%	**9.29%**
Total	**12.5%**	**8.1%**	**31.0%**	**33.6%**	**4.8%**	**10.0%**	**100.0%**

2.6 Gas Pipelines

2.6.1 Introduction

Three existing pipelines (other than typical street utilities) were identified:

1. Jemena Central Trunk Pipeline (CTM).
2. Jemena Eastern Gas Pipeline (EGP).
3. APA Moomba-Sydney Ethane Pipeline (MSE).

Jemena and the APA Group provided relevant data for the pipeline (Refer to Section 2.6.2).

2.6.2 Moomba to Sydney Ethane Pipeline

The Moomba to Sydney Ethane Pipeline is located in an easement to the east of the proposed school site.

Information provided by the pipeline owner (APA) for the Ethane Pipeline is listed in Table 3 [6].

Table 3: Ethane Pipeline

Pipeline Owner	Gorodok Pty Ltd (part of APA Group)
Pipeline Name	Moomba to Sydney Ethane Pipeline
Material/Product Transferred	Ethane (liquefied)
Licence No.	Area of this development is only NSW. SA Licence No 7, Queensland Licence No 21, and New South Wales Licence No 15.
MAOP	10,000 kPa
Normal Operating Pressure	8,200 kPa
Operating Temperature	Typical approx. 20°C
Flowrate	Typical approx. 30 tonne per hour
Pipeline Material	API -5L grade X60

Pipeline Diameter	200mm NB
Wall Thickness	8.1 mm
Depth of Cover	>1200 mm
Cathodic Protection	Impressed Current Cathodic Protection applied
External Coating	HDPE (Yellowjacket)
Leak Detection	No (ALBs online valves either side of this development, which close on sensing low pressure)
Locations of Nearest Isolation Valves	South West - Raby Road Line Valve KP1328 North East – Moorebank Avenue Line Valve KP1344
Leak Detection Time	Line valves on both sides of development have Automatic Line Break systems (ALB) in place and each mainline valve would close the valve when the local pressure falls below the set pressure (as would be the case of a major leak in the pipeline). Local APA staff response time is estimated as 2 hrs from detection.
Leak Isolation Time	The pipeline section is isolated either automatically by ALB operation or by local staff.
Inspections	Ground Patrol Daily (Monday to Friday). Aerial Patrol Fortnightly.
Control Measures for 3rd Party Interference	8.1mm pipe wall thickness. > 1.2m depth of cover. 25mm Concrete Coating of pipeline (Rock jacket). Top slabbing (except through the riparian corridor area). Section of pipeline located within a Riparian Corridor (restricted access for excavation activities). Marker Posts. Dial before-you-dig (DBYD) provisions. Patrols Aerial patrol fortnightly. Daily ground patrol. Liaison with Councils, telecommunications companies, Electricity companies. Section of pipeline located within a Riparian Corridor (restricted access for excavation activities).
Pigging	Metal Loss intelligent pigging carried out on a risk basis program but is undertaken at 5 yearly presently
Current Condition of Pipeline	No wall thickness loss has been found in this section of pipeline
Distance from Jemena pipeline	Approximately 8m, and a at lower depth

2.6.3 Natural Gas Pipelines

Information for the HP natural gas pipelines is listed in Table 4 [7].

Table 4: Natural Gas Pipelines

	Jemena Central Trunk Pipeline	Jemena Eastern Gas Pipeline (EGP)
Pipeline Owner	Jemena	Jemena
Pipeline Name	Central trunk: Wilton to Horsley Park	Eastern Gas Pipeline
Material/Product Transferred	Natural Gas	Natural Gas
Licence No.	Licence 1	PL 26
MAOP	6.895 MPa	14.895MPa
Normal Operating Pressure	4.5 – 5 MPa	14.895 MPa
Operating Temperature	15°C	15°C
Flowrate	NA	NA
Pipeline Material	API5LX65	Carbon Steel API 5LX 70
Pipeline Diameter	DN850	DN450
Wall Thickness	At school location 13.3 mm	At school location 11.8 mm
Depth of Cover	1200 mm	900 mm
Cathodic Protection	Impressed current	Impressed current
External Coating	Coal Tar Enamel	Fusion Bonded Epoxy
Leak Detection	NA	NA
Locations of Nearest Isolation Valves	Catherine Fields ALBV (Raby Rd), Cecil Park ALBV (off Seoul Ave)	Horsley Park kp795, Menangle Park MLV kp762
Leak Detection Time	NA	NA
Leak Isolation Time	NA	NA
Inspections	Weekly	Weekly, six weekly, annually
Control Measures for 3rd Party Interference	DOC, Wall thickness, Warning Signage, DBYD, patrols	DBYD, pipeline patrols
Pigging	Yes 2014, every 10 years	ILI every 10 years or as required

2.6.4 Separation Distances

The closest any of the three pipelines approach the proposed school is 702 m of the CTM to the north-east corner of the property. This is a significant distance in mitigating the potential impact of a major pipeline fire.

2.6.5 Measurement Length

The "Measurement Length" is a technical term referred to in AS 2885.6-2018 [8], that determines the extent to which the Land Use Change SMS is applicable.

"The Measurement Length is defined as the distance from the centre of pipeline to a distance to 4.7 kW/m^2 thermal radiation intensity, from a full-bore rupture of the pipeline and ignition."

The section of the pipeline within one Measurement Length of the proposed Gregory Hills Primary School (GHPS) is shown in Figure 10. The reported measurement length is 759m. This reaches the GHPS school site.

The Measurement Lengths for the MSE and the EGP do not reach the school. While this means the EGP and MSE do not present a significant risk to the proposed school, they have been included in the analysis to demonstrate nature of the total risk.

Figure 10: Proximity of High-Pressure Transmission Pipelines to Proposed School

3 ASSESSMENT OF SEPP (RESILIENCE AND HAZARDS) APPLICABILITY

The applicability of SEPP was assessed using “Guidelines for Applying SEPP 33” [9] (noting the document title refers to the previous title of the SEPP, which has not changed after the change of SEPP title to Resilience and Hazards). It is based on several criteria. Each of the criteria below were examined to assess if they applied to the proposed school development.

The primary purpose of the proposed school is education, and not for the storage, handling or processing of dangerous goods or hazardous materials. Dangerous goods and hazardous materials, if present, will be ancillary to the primary purpose of education, and are not realistically expected to exceed SEPP thresholds. No major users of these materials, such as swimming pools or large kitchens requiring large storages of fuel are proposed.

4 RISK ASSESSMENT METHODOLOGY

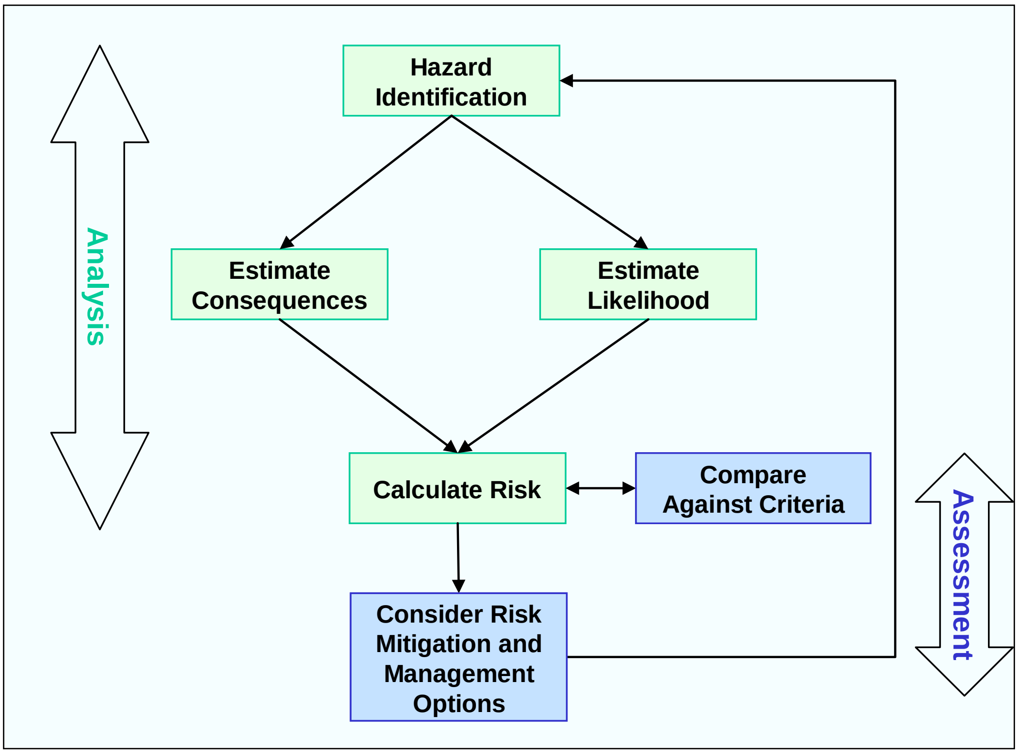
4.1 Introduction

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 DPIE's guidelines for undertaking this type of assessment [3].

Diagrammatically, the QRA process is as follows:

Figure 11: Overview of QRA Process [3]



4.2 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 hazard 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 DPE has defined an acceptable risk criterion – Refer to Section 4.8).

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.

4.3 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,
- for fire and explosion events when ignition occurs.

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 Pasquil 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 Pasquil 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 (v.8.61) was used for all consequence modelling and the generation of the risk contours.

4.4 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 in 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 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 5 [3].

Table 5: 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 6 [3]. The vulnerability criteria used in the risk analysis are included in Appendix A.6.

Table 6: Effects of Thermal Radiation

Heat Radiation [kW/m²]	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 combusting 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.

4.5 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. 5.0×10^{-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 7 and Appendix C.1.

4.6 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: 0.5x10-6 per year, 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 SAFETI 8.61 software package was used to generate the iso-risk contours / transects and societal risk results (Refer to Section 8).

4.7 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 [3], 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 0.

4.8 Quantitative Risk Criteria

4.8.1 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 adopted by the NSW DPE [5] and [10].

Table 7: Individual Fatality Risk Criteria

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

Land Use	Risk Criterion [per million per year]
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 DPE has adopted a fatality risk criterion of 1 x 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 residential area, viz. 0.5 x 10^{-6} pe year.

4.8.2 Injury Risk

The DPE 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 [10] for potential injury caused by exposure to heat radiation, explosion overpressure and toxic gas/ smoke/dust.

The DPE'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 DPE'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 DPE'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.*

4.8.3 Risk of Property Damage and Accident Propagation

Heat radiation exceeding 23 kW/m² 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 DPIE's criteria for risk of damage to property and accident propagation are as follows [10]:

- *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/m² heat flux level.*
- *Incident explosion overpressure at neighbouring potentially hazardous installations, at land zoned to accommodate such installations or at nearest Primary buildings should not exceed a risk of 50 in a million per year for the 14 kPa explosion overpressure level.*

4.8.4 Societal Risk

It is possible that an incident at a hazardous facility may affect more than a single individual off-site, especially in the case of a full-bore rupture of a high-pressure gas pipeline, and the potential exists for multiple fatalities.

The societal risk concept evolved from the concept of 'risk aversion', i.e. society is prepared to tolerate incidents that cause single fatalities at a more frequent interval (e.g. motor vehicle accidents) than for incidents causing multiple fatalities (e.g. an aircraft accident).

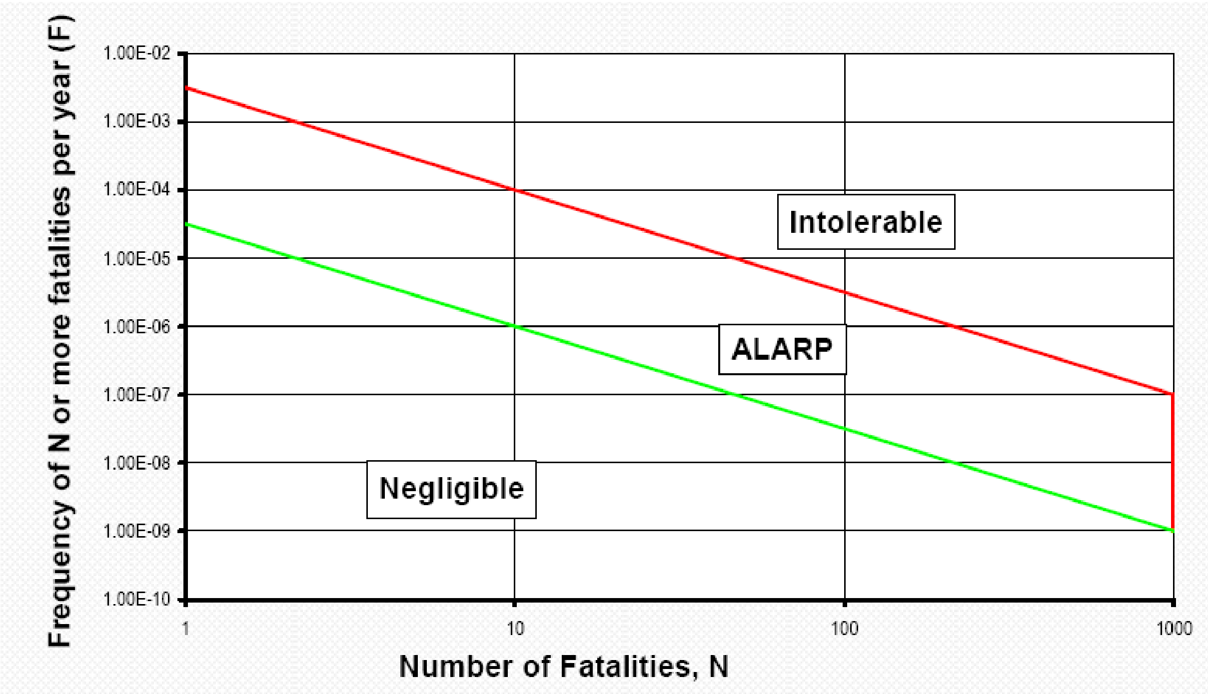
Two parameters are required to define societal risk: (a) Number of fatalities that may result from an incident; and (b) the frequency (likelihood) of occurrence of the incident.

Societal risk can be represented by F-N curves, which are plots of the cumulative frequency (F) of various accident scenarios against the number (N) of casualties associated with the modelled incidents. In other words, 'F' represents the frequency of exceedance of number of fatalities, N.

The F-N plot is cumulative in the sense that, for each frequency on the plot, N is the number of fatalities that could be equalled ***or exceeded***, and F is the frequency of exceedance of the specified number of fatalities.

The DPE's suggested societal risk criteria (Refer to Figure 12), 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 [10] are met, the risks from the activity would be considered tolerable in the ALARP region.

Figure 12: 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 [10] also states that the criteria in Figure 12 are an indicative criteria and provisional only and do not represent a firm requirement in NSW.

4.9 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 [10] 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.

4.10 Approach to Achieving Study Objectives

To provide SINSW with sufficient risk-based land use safety information to understand the extent and magnitude of the potential risks from HP pipelines to the proposed school and develop suitable approaches to mitigate risks, the following approach has been taken:

1. Generate individual risk contours of sections of pipelines within 1 km of the proposed school to identify any restrictions on the land being considered for the proposed school based upon the individual risk criteria.
2. Review consequence distances of pipeline failure events to determine if the school would contribute to societal risk arising from the pipelines, if any.
3. Provide a summary of the consultation that has occurred between the operators of the pipelines.

5 HAZARD IDENTIFICATION

5.1 Introduction

The hazard identification was based on a review of the following:

- information on the Ethane and Natural Gas pipelines (Refer to Section 2.6.2);
- properties of Ethane and Natural Gas; and,
- potential failure modes and consequences if a leak were to occur from a pipeline.

These findings are presented as follows:

Section 5.2 - Properties of Ethane and Natural Gas.

Section 5.3 - Pipeline Failure Modes.

Section 5.4 - Consequences.

Section 5.5 - Control Measures.

The representative MAEs carried forward to the consequence analysis are listed in Section 5.6.

5.2 Properties of Ethane and Natural Gas

5.2.1 Ethane

Ethane is principally used as a raw material for the manufacture of ethylene. It is modelled as 100% Ethane in the QRA.

Physical properties are listed in Table 8.

Table 8: Physical Properties of Ethane

Boiling Point	-88.6 °C
Autoignition Temperature	515 °C
Relative Density (Air =1)	1.05
Lower Flammability Limit in air (vol. %)	2.4%
Upper Flammability Limit in air (vol. %)	14.3%

Ethane is:

- A gas at ambient conditions;
- Flammable;
- A similar density to air at ambient temperatures; and
- Colourless and non-toxic.

Ethane is transported by pipeline as a liquefied gas under pressure.

5.2.2 Natural Gas

Natural Gas is principally used as a fuel. It typically contains 95 to 97% methane (CH_4) and is modelled as methane in the risk analysis.

Physical properties are listed in Table 9.

Table 9: Physical Properties of Methane

Boiling Point	-162 °C
Flash Point	-218 °C

Autoignition Temperature	540 °C
Relative Density (Air =1)	0.55
Lower Flammability Limit in air (vol. %)	4.4%
Upper Flammability Limit in air (vol. %)	16.5%

Methane is:

- A gas at ambient conditions;
- A gas at typical operating conditions for Natural Gas pipelines;
- Flammable;
- Lighter than air at ambient temperatures; and
- Colourless, odourless and non-toxic.

5.3 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 [11]:

- **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 Section C.2.3 (Appendix C) for underground pipelines.

5.3.1 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 three HP pipelines; however, historical incident data for other pipelines (Refer to Appendix C.1) indicates this is generally a low likelihood failure mode, particularly for more recently manufactured pipelines (i.e. post 1980).

5.3.2 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 three HP pipelines; however, historical incident data for other pipelines (Refer to Appendix C.1) 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).

5.3.3 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 three HP pipelines; however, the local topography is such that this is expected to be lower likelihood than would apply for areas with more potential for ground movement.

5.3.4 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 three HP pipelines.

5.4 Consequences of Gas Release

5.4.1 Asphyxiation

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

Methane and Ethane are simple asphyxiants 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 [12]) 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 641,000 mg/m^3 for Ethane and 342,000 mg/m^3 for Methane).

Oxygen deficiency from exposure to Ethane or Methane should not be a major issue because the fire hazards are usually the dominant effects in most locations (the LFL for Ethane is approximately one-twentieth, or 5%, of the fatal asphyxiant concentration and the LFL for methane is approximately one-tenth 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.

5.4.2 Jet Fire

Release of Ethane or Methane released 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.

5.4.3 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.

5.4.4 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.).

In the case of a gas release from the gas pipelines in the vicinity of the school, a gas cloud explosion is less likely than a flash fire due to the relatively open areas and absence of congestion surrounding the three HP pipelines; however, some built up areas (residences) were included in the QRA as potential congestion areas sources to model vapour cloud explosion.

5.4.5 Gas Ingress into Buildings

The gas plume would disperse downwind, once the momentum effect is lost. If the wind direction were oriented towards the school buildings, there is potential for flammable gas to be drawn into the buildings through ventilation air intake, and through open windows. If the gas reaches lower flammability limit, an ignition within the building would result in a confined explosion with serious harm to occupants and structural damage.

5.4.6 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. Ethane and Methane are relatively clean burning fuels and the potential for injury due to smoke exposure was not carried forward to the consequence, likelihood and risk estimation steps of the QRA. The smoke plume would rise above the building roof height.

5.4.7 Incident Escalation in Pipeline Easement

A major fire on one pipeline may result in the failure of an adjacent pipeline. Underground pipelines are typically protected by the surrounding soil but may be exposed if a large release creates a crater.

The potential for propagation and escalation was carried forward in the risk analysis for the two underground pipelines in the common easement.

5.5 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 [13] 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.

5.5.1 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 [14] 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.

The three HP pipelines are inspected using 'intelligent pigging' (Refer to Section 2.6.2) and no loss of wall thickness has been reported [15].

5.5.2 Corrosion Prevention

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 as per Section 6 of AS 2885.3:2012, as part of the pipeline management system. This 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 Moomba to Sydney Ethane Pipeline is inspected using 'intelligent pigging' (Refer to Section 2.6.2) and has a significant wall thickness (8.1 mm). It is equipped with a cathodic protection system and a double layered HDPE coating (Refer to Section 2.6.2).

Both the Jemena gas pipelines are cathodically protected (impressed current) and monitored. The JGN Trunk pipeline has coal tar enamel coating and the EGP has epoxy fusion coating for corrosion protection.

5.5.3 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 AS2885.1:2012). To comply with AS2885.1:2012 [16], 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).

All the pipelines have adequate wall thicknesses for the operating pressure and are located on flat stable land in the vicinity of the school. The potential for ground movement is low.

5.5.4 Prevention of Damage due to Third Party Activity

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to undertake a Safety Management Study (as per Section 11 of AS 2885.3:2012) to assess the risks associated with threats to the pipeline and to instigate appropriate measures to manage the identified threats. The safety management study is reported in Ref. [15].

Two key control measures are typically implemented by pipeline operators to minimise the likelihood of impact from TPA: the 'Dial Before You Dig' (DBYD) process and daily / weekly patrols.

Statistical data indicates that the pipelines in NSW are 100% cathodically protected with effectiveness between 95 and 100%, and that over 96% of parties contacted DBYD before any excavation work [17].

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

5.5.5 Mitigation Control Measures

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to develop and implement an Emergency Response Plan (as per Section 11 of AS 2885.3:2012) as part of the pipeline management system.

The Emergency Response Plan should 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 HP pipelines can be isolated by closing automated and/or manual valves (Refer to Section 2.6.2 for locations of upstream and downstream isolation valves).

5.6 MAEs for Risk Analysis

The list of MAEs included in the risk analysis is provided in Table 10.

Table 10: List of MAEs

MAE	Potential Consequences
Release of High Pressure Ethane from APA Moomba-Sydney Ethane Pipeline	Jet Fire, Flash Fire or Explosion
Release of High Pressure Natural Gas (Methane) from Jemena Eastern Gas Pipeline (EGP)	Jet Fire, Flash Fire or Explosion
Release of High Pressure Natural Gas (Methane) from Jemena Central Trunk Pipeline (CTP)	Jet Fire, Flash Fire or Explosion

6 HAZARD CONSEQUENCE ANALYSIS

6.1 Release of Flammable Liquid / Gas

6.1.1 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.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 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.
- There is insufficient historical incident data for Ethane 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.

Table 11: Representative Hole Diameters Selected for Consequence Analysis

Pipeline	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)
MSE	202.9	10 or 25*	75	110	Full bore
EGP	433.6	10 or 25*	75	110	Full bore
CTM	836.8	10 or 25*	75	110	Full bore

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

6.1.2 Rate of Release

Release events were modelled using the 'Long Pipeline' model in SAFETI. The estimated release rates are presented in Appendix B.2.

6.1.3 Height and Orientation of Release

The release of high-pressure gas or liquefied gas from a buried pipeline would result a crater and gas would be released vertically from the crater [18].

Where above ground assets have been modelled (ALBVs and MLVs), the release has been assumed to be horizontal in the same direction as the wind, from a distance 1m above ground level. There are no above ground facilities within the area of interest.

6.1.4 Duration of Release

Methane and ethane are 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 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.

6.2 Fire Modelling

The SAFETI software package (Version 8.61) 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.

6.2.1 Jet Fire

Example distances to heat radiation levels of 4.7, 12.5, 23 and 35 kW/m^2 are tabulated in Appendix B.1.2 for representative jet fire events included in the risk analysis.

The worst fire case was for a full-bore rupture (FBR) of the CTM, because of its diameter, resulting in a large release rate.

6.2.2 Flash Fire

Example distances to the lower flammability limit (LFL) concentration are tabulated in Appendix B.1.2 for representative flash fire events included in the risk analysis.

6.3 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).

The 3-D obstruction model in SAFETI was used to estimate the overpressure for a VCE.

7 FREQUENCY AND LIKELIHOOD ANALYSIS

7.1 Likelihood of Gas Release

The likelihood of a gas release (i.e. leak) from each of the HP pipelines is tabulated in Appendix C.1 and 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* [19]. This includes data for all licensed pipelines in NSW for the 5-year period: 2013/14 to 2017/18.
- UK Health and Safety Executive (HSE), Research Report (RR) 1035 [11].
- British Standards Institute (2013) [20].
- US Department of Transportation (DoT) (2018) [21].

7.2 Probability of Ignition

The ignition probabilities adopted in the risk analysis are based on Scenario 3 “Pipe Gas LPG Industrial” described in the International Association of Offshore Oil & Gas Producers Risk Assessment Data Directory – Ignition Probabilities [22] after a review of relevant ignition probability data and ignition probability correlations (Refer to Appendix C.1.3).

7.3 Likelihood of Escalation in Pipeline Easement

All three pipelines are located in the same corridor. If any pipeline falls within the crater created by a rupture of the other, then the second pipeline would be exposed, with a potential for failure.

The likelihood of propagation and escalation was estimated based on a review of historical incidents by Silva et al. [23]. Estimated crater dimensions from SAFETI and have been used to estimate the likelihood of escalation to a second pipeline. The length of the crater developed was used to determine potential escalation from a release at the centreline of the pipeline in the vertical direction, while the half-width of a crater developed by a full-bore rupture (located on the centreline of the pipeline in the direction of travel). Within the area of interest, none of the pipelines cross paths, hence the potential of escalation is deemed not credible given the separation distances between each pipeline. Refer Table 12.

Table 12: Pipeline Crater Dimensions and Potential Escalation

Pipeline	Length of Crater Developed by 110 m Mid-point Release (m)	½ width of Crater Developed by Full-bore Rupture (m)	Closest Pipeline	Separation Distance	Escalation?
CTM	2.9	7.77	MSE	13.6	No
MSE	2.8	2.8	EGP	8.5	No
EGP	2.9	5.8	EGP	8.5	No

7.4 Likelihood of Representative MAEs

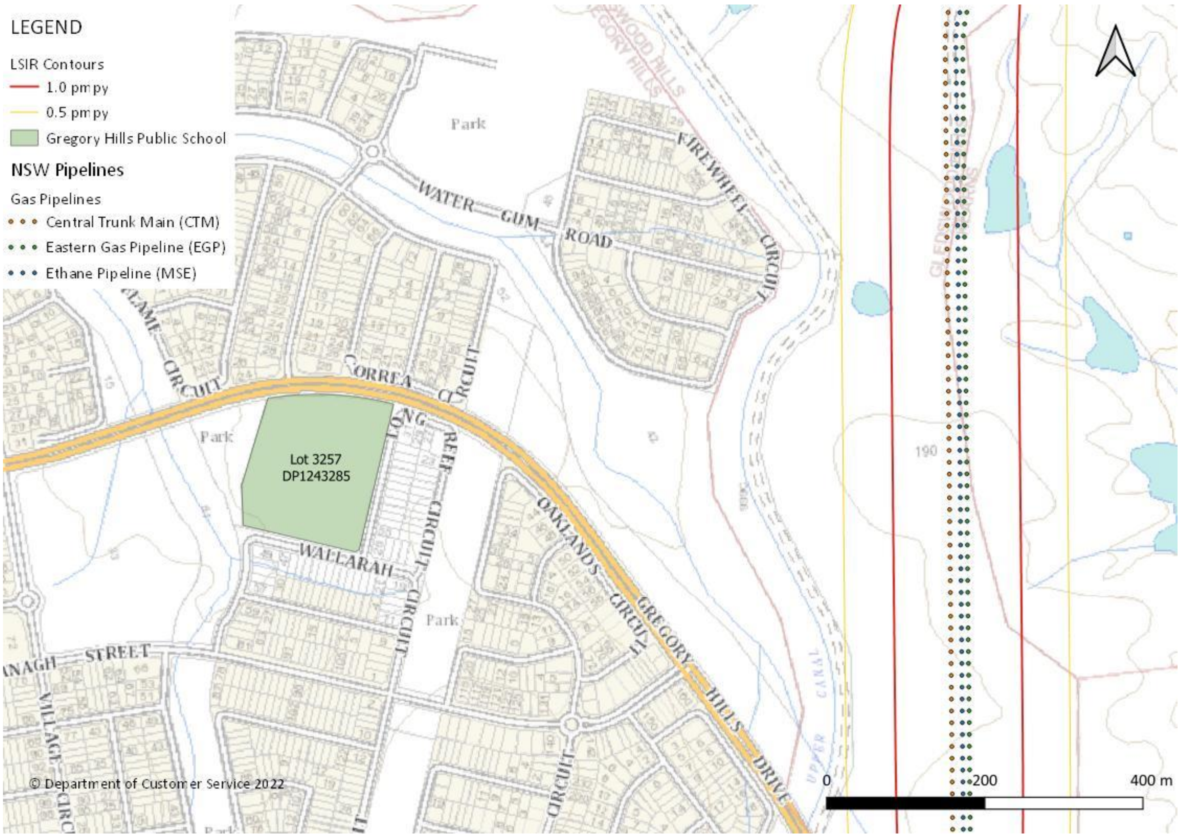
The likelihood of each representative release scenario included in the risk analysis is tabulated in Appendix C.2.4.

8 Risk Analysis

8.1 Individual Risk of Fatality

The combined individual risk of fatality contours for a representative segment of the three pipelines is shown in Figure 13. All three pipelines combined generate individual risk levels greater than of the risk criteria for sensitive land uses and residential land use as described in HIPAP No.10 [5], but not at the location of the proposed school. Therefore, based on the DPIE individual risk criteria, the land is suitable for sensitive land uses such as schools.

Figure 13: Cumulative LSIR Contours for All three Pipelines Combined



8.2 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 5.4.6); therefore any future proposed development will comply with the relevant DPE toxic injury risk and irritation criteria with respect to the high pressure transmission pipelines (Refer to Section 4.8.2).

8.3 Risk of Property Damage and Accident Propagation (Exceeding 14 kPa)

The cumulative risk of property damage and accident propagation (Overpressure exceeding 14 kPa) does not reach 50 x 10^{-6} per annum; therefore, any future proposed development will comply with the DPE property damage and accident propagation criteria with respect to the high pressure transmission pipelines (Refer to Section 4.8.3).

8.4 Risk of Property Damage and Accident Propagation (Exceeding 23 kW/m^2)

The cumulative risk of property damage and accident propagation (Heat radiation exceeding 23 kW/m^2) does not reach 50 x 10^{-6} per annum; therefore, any future proposed development will comply with the DPE property damage and accident propagation criteria with respect to the high pressure transmission pipelines (Refer to Section 4.8.3).

8.5 Risk of Injury (Exceeding 7 kPa)

The cumulative risk of injury (Overpressure exceeding 7 kPa) does not reach 50 x 10^{-6} per annum; therefore, any future proposed development will comply with the relevant DPE risk criterion (Refer to Section 4.8.2) with respect to the high pressure gas transmission pipelines.

8.6 Risk of Injury (Exceeding 4.7 kW/m²)

The cumulative risk of injury (Heat radiation exceeding 4.7 kW/m^2) does not reach 50 x 10^{-6} per annum; therefore, any future proposed development will comply with the relevant DPE risk criterion (Refer to Section 4.8.2) with respect to the high-pressure gas transmission pipelines.

8.7 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 pipelines are existing facilities and cannot be relocated to avoid risk exposure.
- 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 – This study has demonstrated the proposed location of the school does not significantly increase the existing risk.

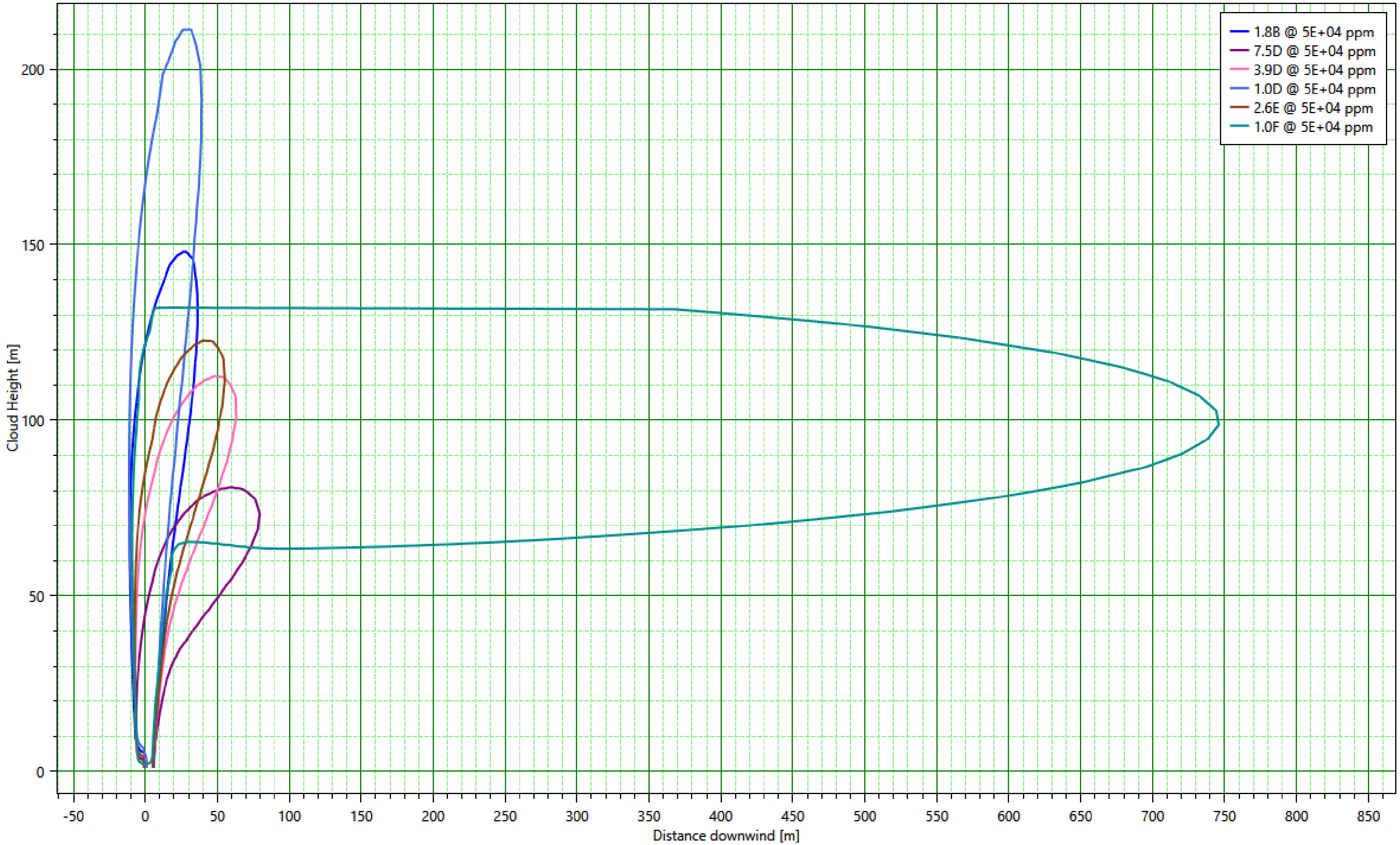
8.8 Societal Risk

Societal risk was analysed from only a qualitative perspective. This was due to the insignificant contribution the proposed school would have on societal risk as discussed below:

1. While SAFETI predicts a cloud over the proposed school (Table 27, Scenario CTM-FBR), at 50 m beyond the CTM the height of the lower boundary of the cloud is always greater than 50 m for all weather conditions (refer Figure 14). People at the school would therefore not be engulfed by a flammable atmosphere.
2. The Weather Category for the dispersion to carry the cloud to the school (at a height of 87 m) is 1.0F. This is a night-time weather condition, and therefore it is not expected that significant numbers of people will not be present at periods where such a large dispersion could occur.
3. Radiated heat flux from jet fires is insufficient to cause fatality without long exposure (much greater than 30 s). It is expected people in the open should be able to seek shelter from direct radiation from any jet fires. This is especially true given the school is on a down slope, and its elevation is less than the height of the ground above the three pipelines.

From the above three points, the proposed school does not contribute to societal risk at the location under consideration.

Figure 14: Side View of CTM Full Bore Rupture Dispersion to Lower Flammable Limit



8.9 Risk Reduction Measures

The school emergency plan must consider the potential for a pipeline failure to ensure there is a coordinated response, and actions in response to a failure do not increase the potential risk. In the case of a pipeline failure, the school should adopt a shelter in place response until advised otherwise by emergency services.

Risk reduction measures needed to be considered in the design of the proposed school are minimal. It is already recommended that structures on the property be suitable for a location with a BAL 12.5. This will further facilitate the shelter in place option advised above.

Facilitating the effort to reduce exposure to injurious heat flux, the design and construction of the proposed school buildings could include orienting windows so they are not directly exposed to heat flux from possible fires from the closest approach of the CTM to the school, and also incorporating other design mechanisms to attenuate radiated heat flux experienced inside school buildings.

9 CONSULTATION WITH PIPELINE OPERATORS

AS 2885.6 (2007) [24] requires that any land use changes in the vicinity of the pipeline be subject to a Safety Management System (SMS) review, jointly by the Stakeholders. The SMS methodology outlined in AS 2885.6 [8] was followed. The stakeholders in the proposed new GHPS project are: SINSW as the developer, Jemena as the Central Trunk Pipeline Operator and Jacobs Group, the project managers for the school design and construction project. A representative from APA also was involved in the consultation process.

An SMS for the new GHPS development was facilitated and validated by Arriscar in a stakeholder workshop on the 17th of June 2022, and an SMS report issued [4].

The workshop covered threat identification and evaluation of safeguards for the pipeline, location class categorisation (AS 2885.6) and validation of 'no resistance' design.

9.1 Conclusions of Consultation Workshop

The following conclusions were reached in the change in land use SMS review:

1. The Measurement Length for the Central Trunk falls within the GHPS school boundary (~760m from the pipeline). This finding triggered the SMS review.
2. There is a change in Location Class for the GHPS site, from T1, CIC to T1, CIC, S. This requires the requirements of Location Class T2 to be applied to the site.
3. The pipeline satisfies the 'No rupture' requirement for Location Class T1, S. While the hoop stress exceeds 30% SMYS, the critical defect length (CDL) is not exceeded in the penetration assessment for interference during excavation and hence a full-bore rupture is prevented. This is largely due to the 13.3mm wall thickness of Central Trunk Pipeline.
4. For some release sizes, the heat release rate exceeds the 1GJ/s limit of AS 2885.1, for the changed Location Class T1, S. Jemena SMS calculations for the 13.3 mm wall thickness pipeline [25] indicate penetrations causing leaks may occur with a 55T excavator employing a penetration tooth, or single tiger tooth. The largest hole size calculated is a 70 mm hole from the penetration tooth, and thermal heat flux would reduce to 4.7 kW/m^2 at 77m from the pipeline, this length is short of the proposed Gregory Hills Primary School site.
5. A qualitative risk assessment was carried out using the risk matrix and rule sets in AS 2885.6. The risk assessment found that there were no 'Extreme' or 'High' risk items and two (2) intermediate risk items.
6. One intermediate risk item relating to corrosion is managed by Jemena through planned integrity digs and cathodic protection monitoring.
7. Intelligent pigging of the Central Trunk Pipeline was carried out in 2014, and no major adverse findings were made. A new assessment is due in 2024 (10-yearly).

The SMS workshop and consultation process demonstrated that the pipeline integrity is managed at ALARP risk levels.

9.2 Summary of Consultation Outcomes

The following recommendations were made to Jemena arising from the SMS.

1. Extend the T1, CIC, S classification for the Gregory Hills development starting at KP 24.2 to KP 28.0 and update the Licence 1 pipeline (Central Trunk) database accordingly. This will encompass the section of pipeline within one ML of the new GHPS and eliminate the section of pipeline classed T1, CIC in the Gregory Hills development area.

2. Reduce the maximum spacing of pipeline markers in the section of pipeline within 1 ML of the proposed new GHPS to 50 m, consistent with AS 2885.1, Table 4.10.1.

10 THERMAL RADIATION IMPACT ON SCHOOL BUILDINGS

Examining Table 25, specifically the scenario for CTM FBR, reveals that a radiated heat flux of 4.7 kW/m^2 just reaches the site boundary, while radiated heat flux of 12.6 kW/m^2 extends only 447 m from the CTM.

Buildings built to withstand 5 kW/m^2 should be able to withstand any pipeline failure event. With reference to the "New Primary School at Gregory Hills – Concept Design Report" Page 06.3, all buildings within the site should be built to comply with BAL 12.5.

Bush Fire Level (BAL) 12.5 means that the buildings (Class 9B) must be capable of withstanding a thermal radiation of 12.5 kW/m^2. This implicitly means that a thermal radiation of 5 kW/m^2 from a pipeline rupture fire would not adversely affect the building infrastructure.

11 FINDINGS AND RECOMMENDATIONS

11.1 Findings

The findings of the assessment are that based on individual risk of fatality, and individual risk of injury, the land on which the proposed school is to be built is appropriate for sensitive use development.

The school is not expected to contribute to the societal risk arising from pipeline failure.

The radiated heat flux experienced at the school is sufficiently low that buildings suitable for a BAL 12.5 area should be capable of withstanding all pipeline failure events.

11.2 Meeting SEARs

The Planning Secretary's Environmental Assessment Requirements (SEARs) state the following:

15. Hazards and Risks

- *Where there are dangerous goods and hazardous materials associated with the development provide a preliminary risk screening in accordance with Chapter 3 of SEPP (Resilience and Hazards) 2021.*
- *Where required by SEPP (Resilience and Hazards) 2021, provide Preliminary Hazard Analysis prepared in accordance with Hazardous Industry Planning Advisory Paper No.6 – Guidelines for Hazard Analysis.*
- *If the development is adjacent to or on land in a pipeline corridor, report on consultation outcomes with the operator of the pipeline, and prepare a hazard analysis.*

The new GHPS is an educational facility and as such there are no dangerous goods and hazardous materials associated with the development. Therefore, the SEPP (Resilience and Hazards) do not apply to the development.

The development is adjacent to a pipeline corridor. Therefore, consultation was held with the pipeline Operator and other stakeholders in the form of a Safety Management Study (SMS) workshop. This has been in compliance with AS 2885.6 – 2018 [8]. A separate report on the consultation has been prepared [4].

A hazard analysis has been prepared (the current report), in compliance with the requirements of HIPAP No.6 [3].

The SEARs have been complied with.

11.3 Recommendations

The following recommendations are made as a result of the preliminary hazard analysis of pipelines in the vicinity of the proposed school:

1. The school emergency plan must include pipeline rupture as a scenario and develop an appropriate shelter in place policy to prevent the potential for injuries from people exposed to radiated heat flux in open.

12 REFERENCES

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[25] Jemena Limited, “Licence 1 Pipeline SMS Calculation for 13.3mm thickness pipe,” 29 April 2020.

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 Major Accident Events (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 Sections 2.6.2 and 2.6.3.
Justification and Impact/s of Assumption/s: • All operational data for the Ethane pipeline was provided by the pipeline owner (APA Group). • All operational data for the Natural Gas pipelines (CTM and EGP) was provided by the pipeline operator, Jemena Limited. • 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 • Data provided by Jemena Limited

Assumption No. 2 Pipeline Utilisation
Subject: Operational Data
Assumption/s: • The Ethane pipeline is utilised 100% of the time. • The Natural Gas pipelines (CTM and EGP) are 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 • Data provided by Jemena Limited).

A.2 Locational Data

Assumption No. 3: Representative Weather Categories and Directional Distribution
Subject: Locational Data
Assumption/s: • Camden Airport AWS (ID: 068192) weather data is a suitable representation for meteorology at the proposed school • The probabilistic distribution of wind speed and wind direction for the representative stability classes is provided in Section 2.5. • 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. • The distribution of stability classes is presented in Section 2.5.
Justification and Impact/s of Assumption/s: • Meteorological data (mean cloud cover, temperature, wind speeds) is collected by the Bureau of Meteorology (BoM) for the Camden Automatic Weather Station weather station for the period 1995-2014. This raw data was rationalised into a set of wind speed/weather stability classes for dispersion calculations. The Camden Airport weather station was selected as being the closest to the proposed school with sufficient data and most representative. • 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).
MAE/s Affected: • All.
Reference/s: • BoM meteorological data for Camden Airport weather station, ID: 068192.

Assumption No. 4: Surface Roughness Length

Subject: Locational Data

Assumption/s:

- The roughness length for different surface types, as listed in the SAFETI user manual, is shown below in Table 13.

Table 13: 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

- A conservative roughness length of 0.5 m is applicable for the proposed school. While it is nominally in a suburban area, currently there is significant undeveloped land and parkland in the area.

Justification and Impact/s of Assumption/s:

- 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.
- While it is nominally in a suburban area, currently there is significant undeveloped land and parkland in the 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 all three pipelines is sourced from the APGA Australian Pipeline Database

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.

A.3 Risk Analysis Methodology

Assumption No. 6: Location and Segmentation of Pipelines
Subject: Risk Analysis Methodology
Assumption/s: • Representative release events are modelled using the ‘Long Pipeline’ model in SAFETI. • Events along the pipelines were spaced at 20 m
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 pipelines was set at 20 m to minimise the potential for iso-risk “rings” to appear along the pipeline. • 20 m interval spacing was sufficient to prevent these from forming. For consequence impacts at the school, the 20 m spacing was sufficiently small to have no impact on the larger consequence distances.
MAE/s Affected: • All.

Assumption No. 6: Location and Segmentation of Pipelines
Reference/s: SAFETI software documentation.

A.4 Consequence Analysis

Assumption No. 7: Representative Materials
Subject: Consequence Analysis
Assumption/s: • Ethane is modelled as 100% Ethane. • Natural gas 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 natural gas in the pipelines has been processed for domestic and industrial consumption. As part of the processing, valuable by products such as ethane, propane and butane have been removed at several major producers such as Moomba and Longford. Heavier hydrocarbons are also typically removed to prevent condensation. • Natural gas typically contains 85 to 95% methane. In 1996-97, the composition of natural gas used in Melbourne was 91.2% methane. • The ethane pipeline carries ethane which has been processed to serve as a petrochemical feed stock.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group. • Natural Gas: Energy for the New Millennium, Research Paper 5 1998-99, Mike Roarty, Science, Technology, Environment and Resources Group' December 1998.

Assumption No. 8: Pressure and Flow for Release Modelling
Subject: Consequence Analysis
Assumption/s: • A release of Ethane from the Moomba to Sydney Ethane Pipeline is modelled at 8.2 MPag (Operating pressure), compared to an MAOP of 10 MPag. • A release of Natural Gas from the Jemena Eastern Gas pipeline (EGP) is modelled at 14.895 MPag, which is also the MAOP for the pipeline. • A release of Natural Gas from the (CTM) is modelled at 5 MPag (operating pressure is between 4.5 and 5 MPag), compared to an MAOP of 6.895 MPag. • Release events are modelled using the 'Long Pipeline' model in SAFETI and may be based on a time varying release rate (depending on hole size). • All pipelines have assumed zero flow.
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 (Refer to Sections 2.6.2 and 2.6.3). • 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 initial release rate. • Providing a flow will slow the rate of pressure reduction calculated by the long pipeline model, but this is insignificant for the initial 30 second release, the basis of which the impact for jet fire has been assumed. • A flow will increase the residual pressure the long pipeline model calculates, but as it will take much longer than 30 seconds to reach residual pressure, this is not relevant.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group. • Data provided by Jemena Limited.

Assumption No. 9: Representative Hole Diameters for Release Modelling

Subject: Consequence Analysis

Assumption/s:

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

Table 14: 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	Ethane	202.9	10 or 25*	75	110	Full bore
Jemena Eastern Gas Pipeline (EGP)	Natural Gas	433.6	10 or 25*	75	110	Full bore
Jemena Gas Network CTM	Natural Gas	836.8	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), 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.
    - There is insufficient historical incident data for Ethane 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). Ethane is transported as a liquefied flammable gas.

MAE/s Affected:

- All.

Reference/s:

- Refer to Appendix B.1.

Assumption No. 10: 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).
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^{o} 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.
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. 11: 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.

- For the materials under consideration, flash fires are not expected to be a major contributor because the gases involved are either buoyant, or have a neutral buoyancy, and should ignition occur, effects from jet fires are expected to dominate.

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. 12: 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. • Isolation times were included for the MSE, but analysis has shown the rationalised discharge scenarios used on the model were the same for isolated and no isolation release.
Justification and Impact/s of Assumption/s: • Ethane and natural gas are 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. 13: 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.
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. 19).
MAE/s Affected: • All MAEs with a pool fire or jet fire as a potential outcome.
Reference/s: • SAFETI software documentation.

Assumption No. 14: 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 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.

Assumption No. 15: Escalation due to Propagation Between Adjacent Pipelines
Subject: Consequence Analysis
Assumption/s: • Escalation between pipelines will only occur if the radius of the crater created by a pipeline failure is larger than the distance between the failed pipeline and the pipeline subject to escalation. • Propagation is non-credible to/from underground pipelines in different corridors. • Escalation only occurs when there is propagation before sufficient mitigation of the initial fire.
Justification and Impact/s of Assumption/s: • Escalation MAEs are generally lower likelihood and higher consequence events, which may affect the cumulative risk (Particularly the societal risk). • The likelihood of propagation and escalation was estimated based on a review of historical incidents, primarily from Ref. [23], estimated crater dimensions from SAFETI, and the separation distance between the CTM and the MSE in the common easement. Based on this review, propagation and escalation was not considered a credible event for inclusion in the risk assessment. • In a review of buried pipeline rupture incidents, it was found that there was 1 escalation in 8 cases of rupture when an adjacent pipeline was exposed [23].
MAE/s Affected: • Escalation MAEs only.
Reference/s: • E.P. Silva, M. Nele, P. F.Frutuoso e Melo, and L. Könözsy, *Underground parallel pipelines domino effect: An analysis based on pipeline crater models and historical accidents*, Journal of Loss Prevention in the Process Industries, June 2016.

A.5 Likelihood Analysis

Assumption No. 16: Likelihood of Release (Loss of Containment)
Subject: Likelihood Analysis
Assumption/s: • The likelihood of each representative release is provided in Appendix C.1.3. • The UK HSE pipeline failure rate data is the primary data used for the risk assessment. • The contribution to pipeline failure from ground movement has been adjusted down to allow for local conditions.
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.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.1.

Assumption No. 17: Ignition Probability
Subject: Likelihood Analysis
Assumption/s: • The probability of ignition for each representative release is based on the OGP Risk Assessment Data Directory Report No. 434 – 6.1 "Ignition Probabilities", Scenario 3 – Pipe Gas LPG Industrial and provided in Appendix C.2.1.
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 description of Scenario 3 as "Releases of flammable gases, vapour or liquids significantly above their normal (Normal Atmospheric Pressure (NAP)) boiling point from onshore cross-country pipelines running through industrial or urban areas" most closely matches the scenario involving the school and pipelines. • Further justification for the data used in this risk analysis is provided in Appendix C.2.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.2.

Assumption No. 18: 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. 19: 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:

Table 15: 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.

Assumption No. 19: 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 16: 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.

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. 20: 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. 21: 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 17 (Person located outdoors) and Table 18 (Person located indoors).

Table 17: Probability of Fatality from Exposure to Peak Side on-Overpressure (Outdoor)

Overpressure (kPa)	Probability of Fatality	Source
30	1.0	SAFETI software (default value)

Table 18: Probability of Fatality from Exposure to Peak Side on-Overpressure (Indoor)

Overpressure (kPa)	Probability of Fatality	Source
10	0.025	SAFETI software (default value)
30	1.0	SAFETI software (default value)

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 DPI&E'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 Consequence Analysis – Example Data and Results

B.1 Representative Hole Diameters

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 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 19: 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

Fault ID	Discovery Date	Product	Wall Thickness (mm)	Diameter (in)	Diameter (mm)	Equivalent Hole Diameter (mm)	Cause
1388	1998	NG	8	18	457	2.3	Ground movement/Other
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 20: Dimensions of Rupture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)

MAOP		Pipe Diameter (in)	Rupture Length (in)	Rupture Width (in)	Approx. Rupture Area (sq.in)	% of Cross-Section Area	Equiv. Hole Diameter (mm)	Cause
(psig)	(kPag)							
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 21: Dimensions of Puncture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)

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	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

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)							
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
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

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)							
225	1653	12	7	6.3	34.6	30.6	168.7	Excavation Damage
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

B.2 Consequence Analysis Results for Representative Release Scenarios

Consequence results from the analysis are presented in the following sections. Some tables refer to a model, and have a coded tag for the model scenario:

AAA -XXXmm-BBB Release Scenario Y

AAA- Three letter code for the pipeline – MSE, CTM, or EGP as used in the body of the report.

XXX – Hole size, in mm (if not a full-bore rupture).

BBB – Location of the pipeline breach, TOP (top of pipeline), MID (90° from the top), or FBR (Full Bore Rupture)

B.2.1 Auto-Sectioning Results

SAFETI 8.61 sections the pipeline based on pressures and the location of valves. As the section of pipeline considered was relatively short (approximately 1.5 km), SAFETI determined only one representative sub-section for each pipeline.

Table 22: Sub-Section Distances for the MSE

Pipeline	Sub-section start distance from upstream end [m]	Sub-section end distance from upstream end [m]	Sub-section midpoint distance from upstream end [m]	Sub-section length [m]	Failure frequency [per km per year]
CTM	25,630	27,140	26,380	1,512	5.061×10^{-5}
EGP	28,520	29.980	29,250	1,465	5.061×10^{-5}
MSE	25,770	27,250	26,510	1,485	2.124×10^{-4}

Table 23: Sub-section Pressures

Pipeline	Pressure at sub-section start [bar abs]	Pressure at sub-section end [bar abs]	Pressure at sub-section mid-point [bar abs]
CTM	69.96	69.96	69.96
EGP	150	150	150
MSE	83.01	82.93	82.97

B.2.2 Section Breach Discharge Results

Discharge rates for the initial dispersion time period are shown in Table 24. It should be noted that for the larger hole sizes (full bore rupture for the CTM and EGP, and 75 mm or greater for the MSE), the dispersion calculations used multiple release rates to represent the reduction of flowrate over time as the pipelines depressurise.

Table 24: Discharge Results

Scenario	Peak Release Rate (kg/s)	Velocity (m/s)	Droplet Diameter (µm)	Temperature (°C)	Liquid Fraction	Release Phase
CTM-10mm MID	0.9017	44.74	0	-124.9	0	Vapour
CTM-25mm MID	5.636	44.74	0	-124.9	0	Vapour
CTM-75mm MID	50.72	63.97	0	-124.9	0	Vapour
CTM-75mm TOP	50.72	291.2	0	-124.9	0	Vapour
CTM-110mm MID	109.1	90.65	0	-124.9	0	Vapour
CTM-110mm TOP	109.1	366.1	0	-124.9	0	Vapour
CTM-FBR	4550	141.5	0	-96.84	0	Vapour
EGP-10mm MID	2.112	41.64	0	-149.1	0	Vapour
EGP-25mm MID	13.2	41.64	0	-149.1	0	Vapour
EGP-75mm MID	118.8	104.7	0	-149.1	0	Vapour
EGP-75mm TOP	118.8	339.5	0	-149.1	0	Vapour
EGP-110mm MID	255.6	150.6	0	-149.1	0	Vapour
EGP-110mm TOP	255.6	367.1	0	-149.1	0	Vapour
EGP-FBR	2272	103.8	0	-109.4	0	Vapour

Scenario	Peak Release Rate (kg/s)	Velocity (m/s)	Droplet Diameter (µm)	Temperature (°C)	Liquid Fraction	Release Phase
MSE-10mm MID	3.476	27.87	12.02	-88.57	0.5305	Two phase
MSE-25mm MID	21.72	28.07	12.02	-88.57	0.5305	Two phase
MSE-75mm MID	90.38	45.47	148.7	-88.57	0.3576	Two phase
MSE-75mm TOP	90.38	125.5	148.7	-88.57	0.3576	Two phase
MSE-110mm MID	170.3	57.69	166.2	-88.57	0.378	Two phase
MSE-110mm TOP	170.3	131.6	166.2	-88.57	0.378	Two phase
MSE-FBR	306.2	17.81	172.4	-88.57	0.4278	Two phase

B.2.3 Jet Fire Results

Results for jet fire scenarios are tabulated in Table 25 for releases from the CTM, EGP and MSE.

Table 25: Distances Downwind (m) to Selected Radiated Heat Flux

Scenario	Weather	Flame length [m]	Distance downwind to 3 kW/m² [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 12.6 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
CTM-10mm MID	1.8B	15.53	19.07	14.78	4.769	1.174	0.3953
	7.5D	10.86	22.95	19.69	14.11	11.33	10.36
	3.9D	12.53	21.26	17.2	11.78	6.898	2.788
	1.0D	17.31	16.24	10.65	1.681	n/a	n/a
	2.6E	14.02	19.93	16.56	8.609	3.067	1.566
	1.0F	17.28	16.27	10.75	1.705	n/a	n/a
CTM-25mm MID	1.8B	33.5	44.74	34.72	12.06	3.447	n/a
	7.5D	23.41	52.25	43.86	28.81	23.81	19.8
	3.9D	27.03	47.98	39.33	25.55	14.34	5.803
	1.0D	37.33	39.45	27.13	5.602	n/a	n/a
	2.6E	30.23	46.42	38.14	19.85	7.583	2.18
	1.0F	37.27	39.54	27.23	5.652	n/a	n/a
CTM-75mm MID	1.8B	81.26	120	92.56	33.8	12.23	n/a
	7.5D	56.79	137.2	112.9	73.06	57.67	44.92
	3.9D	65.57	126.8	104.2	65.05	39.21	20.17
	1.0D	90.56	109.9	78.49	22.38	n/a	n/a
	2.6E	73.34	125	100.7	52.01	17.51	9.262
	1.0F	90.43	110.1	78.76	22.54	n/a	n/a
CTM-75mm TOP	1.8B	68.18	92.3	67.04	18.07	n/a	n/a
	7.5D	47.65	105	85.72	53.35	34.48	18.4
	3.9D	55.01	101.5	80.3	38.89	13.7	n/a
	1.0D	75.96	84.97	57.79	n/a	n/a	n/a

Scenario	Weather	Flame length [m]	Distance downwind to 3 kW/m² [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 12.6 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
	2.6E	61.52	97.52	74.33	26.64	n/a	n/a
	1.0F	75.84	85.21	58.02	n/a	n/a	n/a
CTM-110mm MID	1.8B	108.4	164.6	126.1	45.75	16.54	n/a
	7.5D	75.79	187.7	153.3	99.16	76.45	57.91
	3.9D	87.5	174.9	143.4	85.9	51.29	25.81
	1.0D	120.9	152.8	109.8	33.09	n/a	n/a
	2.6E	97.87	171.8	136.6	67.77	25.48	12.32
	1.0F	120.7	153.1	110.2	33.35	n/a	n/a
CTM-110mm TOP	1.8B	91.58	125.8	91.42	25.67	n/a	n/a
	7.5D	64	143.1	116.7	70.22	43.22	18.91
	3.9D	73.88	138	108.5	51.24	19.18	n/a
	1.0D	102	116.7	80.3	n/a	n/a	n/a
	2.6E	82.63	132.5	100.7	37.29	n/a	n/a
	1.0F	101.9	117	80.62	n/a	n/a	n/a
CTM-FBR	1.8B	482.7	855.9	667.2	317.5	161.1	70.26
	7.5D	337.3	843.6	689.4	447.2	322.6	233.7
	3.9D	389.5	874.9	709.7	414	252.8	142.6
	1.0D	538	824.3	624.1	268.8	102.2	n/a
	2.6E	435.6	883.4	703.9	373.2	200.7	119.5
	1.0F	537.1	826.7	626.2	270.3	103.9	n/a
EGP-10mm MID	1.8B	22.36	28.59	22.26	7.464	1.969	n/a
	7.5D	15.63	33.77	28.68	19.68	16.1	14.06
	3.9D	18.04	31.16	25.38	16.94	9.571	3.941
	1.0D	24.92	24.74	16.69	3.003	n/a	n/a
	2.6E	20.18	29.63	24.53	12.69	4.452	2.018
	1.0F	24.88	24.79	16.76	3.033	n/a	n/a

Scenario	Weather	Flame length [m]	Distance downwind to 3 kW/m² [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 12.6 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
EGP-25mm MID	1.8B	48.09	67.23	52.57	20.23	6.135	1.617
	7.5D	33.61	76.97	64.16	41.94	34.09	27.62
	3.9D	38.8	70.88	58.28	37.61	21.94	9.888
	1.0D	53.59	60.2	42.51	10.33	n/a	n/a
	2.6E	43.4	69.26	56.82	30.26	12.46	3.837
	1.0F	53.51	60.33	42.65	10.32	n/a	n/a
EGP-75mm MID	1.8B	110.8	168	128.2	46.67	14.64	n/a
	7.5D	77.46	191.7	156.2	101.1	77.24	57.77
	3.9D	89.43	178.9	146.3	85.79	48.88	21.08
	1.0D	123.5	156.3	112	33.03	n/a	n/a
	2.6E	100	175.5	138.9	66.95	25.86	9.549
	1.0F	123.3	156.7	112.4	33.32	n/a	n/a
EGP-75mm TOP	1.8B	96.07	133.6	97.55	29.11	n/a	n/a
	7.5D	67.14	151.4	123.5	75.04	47.16	23.2
	3.9D	77.51	146.2	115.2	55.45	21.9	n/a
	1.0D	107	124.1	85.91	n/a	n/a	n/a
	2.6E	86.69	140.6	107.2	40.56	n/a	n/a
	1.0F	106.9	124.5	86.25	n/a	n/a	n/a
EGP-110mm MID	1.8B	147.4	228.1	173.2	66.35	n/a	n/a
	7.5D	103	257.6	208.3	135.3	99.83	72.69
	3.9D	118.9	244.1	197.3	110.8	58.61	27.34
	1.0D	164.2	214.5	154.6	47.04	n/a	n/a
	2.6E	133	237.9	186.8	86.85	36.64	2.451
	1.0F	164	215.1	155.1	47.48	n/a	n/a
EGP-110mm TOP	1.8B	132	188.9	138.9	43.79	n/a	n/a
	7.5D	92.22	212.9	173.6	104.4	65.29	32.24

Scenario	Weather	Flame length [m]	Distance downwind to 3 kW/m² [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 12.6 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
	3.9D	106.5	205.4	161.9	78.89	33.69	n/a
	1.0D	147	176.9	124.4	n/a	n/a	n/a
	2.6E	119.1	198	151.4	60.38	n/a	n/a
	1.0F	146.8	177.4	124.8	n/a	n/a	n/a
EGP-FBR	1.8B	369.6	646.1	504.9	234.5	118	56.93
	7.5D	258.3	663.8	537.2	352.9	261.8	194.7
	3.9D	298.2	677.9	554.5	334.6	216.1	133.6
	1.0D	412	617.8	466.3	196.3	76.14	n/a
	2.6E	333.6	667.2	534	288.1	148.2	87.71
	1.0F	411.3	619.4	467.8	197.4	77.26	n/a
MSE-10mm MID	1.8B	22.07	39.74	32.8	20.15	10.82	5.294
	7.5D	15.41	42.91	36.45	25.92	21.09	17.8
	3.9D	17.85	42.52	35.16	22.88	18.4	14.89
	1.0D	24.87	38.58	30.52	12.97	4.537	2.546
	2.6E	20.04	41.07	33.14	22.22	15.7	9.467
	1.0F	24.87	38.61	30.55	13	4.545	2.549
MSE-25mm MID	1.8B	47.27	93	76.44	46.63	26.93	13.53
	7.5D	33	99.33	83.24	56.66	43.9	37.37
	3.9D	38.23	97.93	80.16	51.77	40.64	32.11
	1.0D	53.26	91.08	72.33	34.02	12.35	6.22
	2.6E	42.91	94.7	77.1	25.06	11.57	6.908
	1.0F	53.26	91.18	72.42	34.09	12.38	6.232
MSE-75mm MID	1.8B	82.8	176.9	144.5	85.1	48.9	23.87
	7.5D	57.8	172.1	142.8	93.44	72.25	62.23
	3.9D	66.97	184.5	150	97.17	74.68	58.53
	1.0D	93.3	173.1	136.5	65.05	22.92	9.994

Scenario	Weather	Flame length [m]	Distance downwind to 3 kW/m² [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 12.6 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
	2.6E	75.17	178.3	146.7	94.35	65.85	43.18
	1.0F	93.3	173.3	136.7	65.22	23.02	10.02
MSE-75mm TOP	1.8B	75.12	157.4	125.5	66.02	28.17	9.759
	7.5D	52.45	148	121.9	78.12	61.85	51.34
	3.9D	60.77	145.2	118.9	74.83	50.27	30.27
	1.0D	84.65	157	121.8	52.5	12.02	4.169
	2.6E	68.21	152.2	123.3	70.94	39.39	16.66
	1.0F	84.65	157.3	122	52.67	12.08	4.182
MSE-110mm MID	1.8B	105.9	234.3	190.3	110.3	62.92	30.83
	7.5D	73.91	216.2	178.6	114.7	90.48	76.5
	3.9D	85.64	226.9	183.6	120.3	90.15	67.82
	1.0D	119.3	229.2	180.6	87.03	30.81	12.4
	2.6E	96.12	234.3	192.1	121.6	83.18	53.42
	1.0F	119.3	229.6	180.9	87.26	30.96	12.45
MSE-110mm TOP	1.8B	97.87	200.2	159	81.55	31.96	10.94
	7.5D	68.33	188.1	154.4	99.41	78.05	63.21
	3.9D	79.17	185.4	151.6	93.78	60.81	34.03
	1.0D	110.3	207.5	161.2	70.64	16.62	5.345
	2.6E	88.86	194	156.6	88.21	47.43	18.5
	1.0F	110.3	207.8	161.5	70.87	16.72	5.367
MSE-FBR	1.8B	140.8	310.2	254.9	158.9	103.8	64.28
	7.5D	98.3	271.2	225.1	146.1	115.8	97.66
	3.9D	113.9	313.5	255.4	165.9	127.6	100.6
	1.0D	158.7	309.5	250.3	138.3	71.75	38.27
	2.6E	127.8	313.5	256.4	167.1	120.6	85.99
	1.0F	158.7	309.9	250.6	138.6	71.99	38.38

B.2.4 Flash Fire Results

Results for distances to LFL concentrations are tabulated in Table 26 and Table 27 for release from the MSE, CTM and EGP.

Table 26: Downwind distance [m] to LFL at Height of Interest (1.8 m)

Scenario	Weather	Distance downwind to LFL [m]
CTM-10mm MID	1.8B	0.293
	7.5D	0.4003
	3.9D	0.3185
	1.0D	0.2755
	2.6E	0.283
	1.0F	0.2546
CTM-25mm MID	1.8B	0.5486
	7.5D	0.6054
	3.9D	0.5598
	1.0D	0.5286
	2.6E	0.5213
	1.0F	0.4883
CTM-75mm MID	1.8B	1.218
	7.5D	1.236
	3.9D	1.214
	1.0D	1.194
	2.6E	1.215
	1.0F	1.336
CTM-75mm TOP	1.8B	0.5065
	7.5D	0.5165
	3.9D	0.5092
	1.0D	0.4941
	2.6E	0.4819
	1.0F	0.4472
CTM-110mm MID	1.8B	1.401
	7.5D	1.396
	3.9D	1.381
	1.0D	1.361
	2.6E	1.367
	1.0F	1.482
CTM-110mm TOP	1.8B	0.6027
	7.5D	0.6108
	3.9D	0.605
	1.0D	0.5861
	2.6E	0.574
	1.0F	0.5295

Scenario	Weather	Distance downwind to LFL [m]
CTM-FBR	1.8B	7.982
	7.5D	7.39
	3.9D	7.388
	1.0D	7.352
	2.6E	7.318
	1.0F	
EGP-10mm MID	1.8B	0.3804
	7.5D	0.4585
	3.9D	0.3992
	1.0D	0.3628
	2.6E	0.3644
	1.0F	0.3347
EGP-25mm MID	1.8B	0.7761
	7.5D	0.8236
	3.9D	0.7807
	1.0D	0.7479
	2.6E	0.7321
	1.0F	0.6915
EGP-75mm MID	1.8B	1.264
	7.5D	1.265
	3.9D	1.253
	1.0D	1.238
	2.6E	1.256
	1.0F	1.388
EGP-75mm TOP	1.8B	0.609
	7.5D	0.6016
	3.9D	0.5961
	1.0D	0.5705
	2.6E	0.5639
	1.0F	0.5141
EGP-110mm MID	1.8B	1.418
	7.5D	1.403
	3.9D	1.394
	1.0D	1.38
	2.6E	1.383
	1.0F	1.511
EGP-110mm TOP	1.8B	0.771
	7.5D	0.7658
	3.9D	0.761
	1.0D	0.7561
	2.6E	0.7184
	1.0F	0.6873

Scenario	Weather	Distance downwind to LFL [m]
EGP-FBR	1.8B	6.803
	7.5D	6.338
	3.9D	6.336
	1.0D	6.307
	2.6E	6.255
	1.0F	
MSE-10mm MID	1.8B	0.4058
	7.5D	0.4897
	3.9D	0.4252
	1.0D	0.3859
	2.6E	0.3858
	1.0F	0.3528
MSE-25mm MID	1.8B	0.8805
	7.5D	0.9223
	3.9D	0.8811
	1.0D	
	2.6E	0.8261
	1.0F	1.131
MSE-75mm MID	1.8B	1.295
	7.5D	1.32
	3.9D	1.289
	1.0D	
	2.6E	1.29
	1.0F	1.447
MSE-75mm TOP	1.8B	0.6276
	7.5D	0.6263
	3.9D	0.6182
	1.0D	0.5964
	2.6E	0.5779
	1.0F	0.5344
MSE-110mm MID	1.8B	1.465
	7.5D	1.459
	3.9D	1.443
	1.0D	
	2.6E	1.429
	1.0F	1.578
MSE-110mm TOP	1.8B	0.7929
	7.5D	0.789
	3.9D	0.7821
	1.0D	0.7696
	2.6E	0.7315
	1.0F	1.178

Scenario	Weather	Distance downwind to LFL [m]
MSE-FBR	1.8B	133.1
	7.5D	5.354
	3.9D	5.305
	1.0D	215.8
	2.6E	110.4
	1.0F	160.5

Table 27: Maximum distance to LFL fraction at any height

Scenario	Weather	Max flash fire distance [m]	Height of the max flash fire distance [m]	Time [s]
CTM-10mm MID	1.8B	1.362	5.621	83.76
	7.5D	1.839	3.386	562.7
	3.9D	1.62	4.421	0.8855
	1.0D	1.216	7.562	158.9
	2.6E	1.464	5.276	2.555
	1.0F	1.156	7.959	2.556
CTM-25mm MID	1.8B	3.36	11.8	2.557
	7.5D	5.068	6.6	593
	3.9D	4.426	9.23	593.4
	1.0D	3.278	16.85	5.711
	2.6E	3.88	10.77	5.706
	1.0F	2.779	16.06	5.711
CTM-75mm MID	1.8B	8.055	31.46	5.713
	7.5D	13.39	17.12	2.556
	3.9D	11.33	23.77	44.01
	1.0D	8.105	43.02	529.3
	2.6E	9.961	27.55	5.71
	1.0F	7.347	38.25	84.1
CTM-75mm TOP	1.8B	4.215	32.66	159
	7.5D	6.482	19.25	563.1
	3.9D	5.689	25.79	158.9
	1.0D	4.079	38.99	301
	2.6E	5.062	28.93	526.1
	1.0F	3.649	35.37	2.557
CTM-110mm MID	1.8B	10.14	45.86	159.5
	7.5D	17.34	25.36	5.707
	3.9D	14.49	34.44	159.2
	1.0D	10.32	61.67	454.2
	2.6E	12.73	39.21	5.711
	1.0F	9.529	52.45	11.68
CTM-110mm TOP	1.8B	5.689	44.62	413.8
	7.5D	8.937	27.16	158.8

Scenario	Weather	Max flash fire distance [m]	Height of the max flash fire distance [m]	Time [s]
	3.9D	7.791	36.81	2.556
	1.0D	5.593	55.74	159.3
	2.6E	6.971	40.31	159
	1.0F	5.124	50.11	594.6
CTM-FBR	1.8B	56.89	271	11.72
	7.5D	115.4	190.3	11.68
	3.9D	94.96	256.2	11.7
	1.0D	64.4	401.3	23.16
	2.6E	87.29	259.2	11.7
	1.0F	748	98.73	385.7
EGP-10mm MID	1.8B	2.133	7.857	2.556
	7.5D	3.056	4.495	83.72
	3.9D	2.694	6.124	43.94
	1.0D	1.997	10.73	5.708
	2.6E	2.389	7.281	2.556
	1.0F	1.775	11.19	300.9
EGP-25mm MID	1.8B	5.446	17.01	5.71
	7.5D	8.391	8.985	450.6
	3.9D	7.429	13.03	5.707
	1.0D	5.516	24.53	377.4
	2.6E	6.527	15.59	44
	1.0F	4.827	22.38	11.67
EGP-75mm MID	1.8B	10.25	48.15	11.67
	7.5D	17.23	26.62	159
	3.9D	14.44	36.13	5.71
	1.0D	10.51	64.44	11.69
	2.6E	12.77	41.1	44.05
	1.0F	9.715	54.86	11.68
EGP-75mm TOP	1.8B	6.314	47.97	301
	7.5D	9.806	28.57	2.556
	3.9D	8.627	37.91	159
	1.0D	6.25	60.18	595.4
	2.6E	7.698	42.88	5.708
	1.0F	5.673	51.8	83.95
EGP-110mm MID	1.8B	13.03	68.81	84.16
	7.5D	22.3	38.81	159
	3.9D	18.61	52.74	489.7
	1.0D	13.57	91.48	44.25
	2.6E	16.45	57.41	565.4
	1.0F	12.86	76.09	597.2
EGP-110mm TOP	1.8B	9.332	67.91	159.4
	7.5D	14.86	39.94	593.7

Scenario	Weather	Max flash fire distance [m]	Height of the max flash fire distance [m]	Time [s]
	3.9D	12.98	54.59	159.1
	1.0D	9.418	85.71	159.6
	2.6E	11.64	59.98	5.71
	1.0F	8.754	74.53	84.06
EGP-FBR	1.8B	44.42	193.8	5.733
	7.5D	90.65	145.7	11.67
	3.9D	75.15	182.5	11.69
	1.0D	51.99	283.6	11.76
	2.6E	71.96	202.3	11.69
	1.0F	425	100.9	136.1
MSE-10mm MID	1.8B	3.357	9.318	5.708
	7.5D	4.52	4.909	450.4
	3.9D	4.243	6.937	158.9
	1.0D	3.788	13.13	527.7
	2.6E	3.904	8.617	83.82
	1.0F	3.379	12.87	11.66
MSE-25mm MID	1.8B	11.13	19.62	11.68
	7.5D	12.85	9.661	5.707
	3.9D	13.45	14.48	5.711
	1.0D	14.46	23.81	343
	2.6E	13.6	17.92	490.1
	1.0F	14.18	23.43	340.8
MSE-75mm MID	1.8B	21.45	36.25	84.46
	7.5D	27.8	20.48	5.71
	3.9D	29.16	28.15	84.14
	1.0D	27.26	48.93	23.15
	2.6E	28.5	32.72	84.23
	1.0F	28.51	41.71	84.58
MSE-75mm TOP	1.8B	10.83	45.54	5.715
	7.5D	17.01	25.21	5.707
	3.9D	14.53	34.33	5.709
	1.0D	12.17	61.3	44.22
	2.6E	12.98	39.07	5.711
	1.0F	10.95	51.81	44.13
MSE-110mm MID	1.8B	24.93	45.67	84.46
	7.5D	37.43	30.45	5.71
	3.9D	36.26	37.62	44.12
	1.0D	33.66	71.68	23.15
	2.6E	34.33	40.32	84.22
	1.0F	34.1	57.22	44.31
MSE-110mm TOP	1.8B	15.76	60.9	5.714
	7.5D	25.89	35.22	5.706

Scenario	Weather	Max flash fire distance [m]	Height of the max flash fire distance [m]	Time [s]
	3.9D	22.3	48.23	5.709
	1.0D	18.15	86.23	11.69
	2.6E	19.37	52.79	11.66
	1.0F	16.59	69.16	11.67
MSE-FBR	1.8B	114.7	1.505	44.4
	7.5D	82.88	25.35	11.67
	3.9D	68.05	23.11	22.96
	1.0D	227.8	0	166.8
	2.6E	102	1.298	44.28
	1.0F	165.8	0	165.2

B.2.5 Explosion Results

Explosion results are tabulated Table 28.

Table 28: Explosion scenarios for worst-case maximum downwind distance to defined overpressures

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
CTM-75mm MID	7.5D	0.07 0.14 0.21	25.76 Not reachable Not reachable	43.44 0 0
	3.9D	0.07 0.14 0.21	28.85 Not reachable Not reachable	50.79 0 0
CTM-110mm MID	1.8B	0.07 0.14 0.21	41.47 Not reachable Not reachable	77.77 0 0
	7.5D	0.07 0.14 0.21	31.71 Not reachable Not reachable	55.16 0 0
	3.9D	0.07 0.14 0.21	34.11 Not reachable Not reachable	62.05 0 0
	1.0D	0.07 0.14 0.21	47.1 Not reachable Not reachable	89.52 0 0
	2.6E	0.07 0.14 0.21	37.95 Not reachable Not reachable	69.55 0 0
CTM-FBR	1.8B	0.07 0.14 0.21	222.8 Not reachable Not reachable	432.2 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
	7.5D	0.07 0.14 0.21	264.1 Not reachable Not reachable	431.8 0 0
	3.9D	0.07 0.14 0.21	286.8 Not reachable Not reachable	500.3 0 0
	1.0D	0.07 0.14 0.21	279.3 Not reachable Not reachable	539.4 0 0
	2.6E	0.07 0.14 0.21	277 Not reachable Not reachable	493.8 0 0
	1.0F	0.07 0.14 0.21	713.9 Not reachable Not reachable	917.2 0 0
EGP-75mm MID	1.8B	0.07 0.14 0.21	42.27 Not reachable Not reachable	79.51 0 0
	7.5D	0.07 0.14 0.21	32.55 Not reachable Not reachable	56.81 0 0
	3.9D	0.07 0.14 0.21	34.76 Not reachable Not reachable	63.46 0 0
	1.0D	0.07 0.14 0.21	47.83 Not reachable Not reachable	91.15 0 0
	2.6E	0.07 0.14 0.21	38.56 Not reachable Not reachable	70.87 0 0
EGP-110mm MID	1.8B	0.07 0.14 0.21	46.59 Not reachable Not reachable	89.79 0 0
	7.5D	0.07 0.14 0.21	50.1 Not reachable Not reachable	85.41 0 0
	3.9D	0.07 0.14 0.21	38.13 Not reachable Not reachable	71.84 0 0
	1.0D	0.07 0.14 0.21	50 Not reachable Not reachable	97.57 0 0
	2.6E	0.07 0.14 0.21	41.02 Not reachable Not reachable	77.86 0 0
	1.0F	0.07 0.14 0.21	51.88 Not reachable Not reachable	99.55 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
EGP-110mm TOP	7.5D	0.07 0.14 0.21	39.61 Not reachable Not reachable	71.32 0 0
	3.9D	0.07 0.14 0.21	39.42 Not reachable Not reachable	74.28 0 0
	2.6E	0.07 0.14 0.21	44.2 Not reachable Not reachable	83.43 0 0
EGP-FBR	1.8B	0.07 0.14 0.21	176.4 Not reachable Not reachable	342.4 0 0
	7.5D	0.07 0.14 0.21	217.4 Not reachable Not reachable	361 0 0
	3.9D	0.07 0.14 0.21	230.5 Not reachable Not reachable	403.6 0 0
	1.0D	0.07 0.14 0.21	242.5 Not reachable Not reachable	465.5 0 0
	2.6E	0.07 0.14 0.21	235.2 Not reachable Not reachable	413.2 0 0
	1.0F	0.07 0.14 0.21	459.2 Not reachable Not reachable	530.3 0 0
MSE-25mm MID	1.8B	0.07 0.14 0.21	28.6 Not reachable Not reachable	51.01 0 0
	7.5D	0.07 0.14 0.21	21.6 Not reachable Not reachable	35.46 0 0
	3.9D	0.07 0.14 0.21	25.35 Not reachable Not reachable	43.06 0 0
	1.0D	0.07 0.14 0.21	35.86 Not reachable Not reachable	64.43 0 0
	2.6E	0.07 0.14 0.21	27.53 Not reachable Not reachable	47.82 0 0
	1.0F	0.07 0.14 0.21	34.27 Not reachable Not reachable	61.24 0 0
MSE-75mm MID	1.8B	0.07 0.14 0.21	54.5 Not reachable Not reachable	96.91 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
	7.5D	0.07 0.14 0.21	43.37 Not reachable Not reachable	69.56 0 0
	3.9D	0.07 0.14 0.21	48.76 Not reachable Not reachable	81.96 0 0
	1.0D	0.07 0.14 0.21	68.88 Not reachable Not reachable	123.3 0 0
	2.6E	0.07 0.14 0.21	52.15 Not reachable Not reachable	89.5 0 0
	1.0F	0.07 0.14 0.21	62.55 Not reachable Not reachable	111 0 0
MSE-75mm TOP	1.8B	0.07 0.14 0.21	40.94 Not reachable Not reachable	76.79 0 0
	7.5D	0.07 0.14 0.21	31.39 Not reachable Not reachable	54.45 0 0
	3.9D	0.07 0.14 0.21	34.61 Not reachable Not reachable	62.59 0 0
	1.0D	0.07 0.14 0.21	45.63 Not reachable Not reachable	86.88 0 0
	2.6E	0.07 0.14 0.21	38.19 Not reachable Not reachable	69.84 0 0
	1.0F	0.07 0.14 0.21	46.04 Not reachable Not reachable	85.97 0 0
MSE-110mm MID	1.8B	0.07 0.14 0.21	71.35 Not reachable Not reachable	129.3 0 0
	7.5D	0.07 0.14 0.21	60.21 Not reachable Not reachable	96.16 0 0
	3.9D	0.07 0.14 0.21	68.47 Not reachable Not reachable	114.4 0 0
	1.0D	0.07 0.14 0.21	95.46 Not reachable Not reachable	169.9 0 0
	2.6E	0.07 0.14 0.21	71.23 Not reachable Not reachable	121.3 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
	1.0F	0.07 0.14 0.21	83.79 Not reachable Not reachable	146.8 0 0
MSE-110mm TOP	1.8B	0.07 0.14 0.21	45.13 Not reachable Not reachable	86.79 0 0
	7.5D	0.07 0.14 0.21	49.95 Not reachable Not reachable	83.7 0 0
	3.9D	0.07 0.14 0.21	57.05 Not reachable Not reachable	99.82 0 0
	1.0D	0.07 0.14 0.21	50.6 Not reachable Not reachable	98.46 0 0
	2.6E	0.07 0.14 0.21	41.6 Not reachable Not reachable	78.2 0 0
	1.0F	0.07 0.14 0.21	50.08 Not reachable Not reachable	96.08 0 0
MSE-FBR	1.8B	0.07 0.14 0.21	140.7 Not reachable Not reachable	236.3 0 0
	7.5D	0.07 0.14 0.21	137.6 Not reachable Not reachable	200.2 0 0
	3.9D	0.07 0.14 0.21	144.3 Not reachable Not reachable	228.8 0 0
	1.0D	0.07 0.14 0.21	230 Not reachable Not reachable	286.1 0 0
	2.6E	0.07 0.14 0.21	146.4 Not reachable Not reachable	234.3 0 0
	1.0F	0.07 0.14 0.21	200.3 Not reachable Not reachable	262.5 0 0

Appendix C Likelihood Analysis - Data and Results

C.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).

C.1.1 Ethane

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 is no leak frequency data specifically for Ethane in 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 Ethane pipeline (Refer to Table 29).

Table 29: 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	

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 (Refer to Table 30). 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 30 may be underestimated.

For leaks or ruptures due to 'Ground Movement / Other', the landslide potential in the study area was assumed to be "low to nil" in accordance with the description in Table C.15 of PD 8010-3:2009+A1:2013.

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 30: Approx. Leak Frequencies for Underground Ethane 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	

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 31.

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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 31: 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.
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		

C.1.2 Natural Gas

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 total leak frequency data reported in Section 7.1 of RR1035 for underground natural gas pipelines (e.g. 5.1E-05 per km per year for a ≥ 305 mm diameter pipeline with wall thickness ≥ 10 mm) is very comparable the average leak frequency from the 2018 NSW Performance Report and was adopted in the risk analysis for the HP Natural Gas pipelines (Refer to Table 32).

Table 32: Leak Frequencies for Underground Natural Gas 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	< 115	All	4.5E-04	1.0E-08	1.0E-08	1.0E-08	4.5E-04
	127 to < 273		1.5E-04	1.0E-08	1.0E-08	1.0E-08	1.5E-04
	≥ 305		8.7E-06	1.0E-08	1.0E-08	1.0E-08	8.7E-06
Corrosion	All	< 5	3.1E-04	1.0E-08	1.0E-08	1.0E-08	3.1E-04
		5 to < 10	3.3E-05	1.0E-08	1.0E-08	1.0E-08	3.3E-05
		≥ 10	1.0E-07	1.0E-08	1.0E-08	1.0E-08	1.3E-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 Frequency =	≥ 305	≥ 10	4.3E-05	4.9E-06	2.7E-07	2.6E-06	**5.1E-05**

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
% =			84.6	9.7	0.5	5.2	

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 HP Natural Gas Pipelines (Refer to Table 33 and Table 34). The data applicable for pipelines with a wall thickness > 10 mm to ≤ 15 mm was used.

The Jemena Gas Network pipeline was constructed prior to 1980, so the leak frequencies due to material and construction defects (mechanical failures) were not reduced by a factor of 5 for this pipeline (as per Section C.7 of PD 8010-3:2009+A1:2013).

The leak frequency for external corrosion is reported to be 0 for pipelines with a wall thickness > 10 mm to ≤ 15 mm. Leak frequency data is not reported for internal corrosion; therefore, the total leak frequencies reported in Table 33 and Table 34 may be underestimated.

For leaks or ruptures due to 'Ground Movement / Other', the landslide potential in the study area was assumed to be "low to nil" in accordance with the description in Table C.15 of PD 8010-3:2009+A1:2013.

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 pipelines (i.e. location, design factor, wall thickness and depth of cover).

Table 33: Approx. Leak Frequencies for Jemena Eastern Gas Pipeline (EGP)

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	1.7E-05	0.0E+00	0.0E+00	0.0E+00	1.7E-05
Corrosion	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ground Movement / Other	2.8E-07	2.8E-07	2.8E-07	2.2E-08	8.7E-07
TPA	3.8E-05	2.5E-05	1.3E-05	8.6E-05	1.6E-04
Total Leak Freq. =	5.5E-05	2.6E-05	1.3E-05	8.6E-05	**1.8E-04**
% =	30.8	14.3	7.2	47.8	

Table 34: Approx. Leak Frequencies for Jemena Gas Network (CTM) Trunk 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	1.7E-05	0.0E+00	0.0E+00	0.0E+00	1.7E-05
Corrosion	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ground Movement / Other	2.3E-07	2.3E-07	2.3E-07	6.8E-08	7.5E-07
TPA	1.3E-05	8.8E-06	4.4E-06	1.8E-05	4.4E-05
Total Leak Freq. =	3.0E-05	9.0E-06	4.6E-06	1.8E-05	**6.2E-05**
% =	49.3	14.6	7.5	28.6	

US Department of Transportation (DoT)

The Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Reported Data for Underground Natural Gas Steel Pipelines (January 2010 to September 2017) include incidents for Natural Gas transmission pipelines.

To enable a comparison with the UK data, the data for underground transmission pipelines 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 35.

Period of Recorded Incident Data =	7.75	years	(Jan 2010 to Sept 2017)
Total Length of Natural Gas Pipelines =	479980	km	Note: Average for 2010 to 2017

Table 35: Leak Frequencies for Underground Natural Gas Transmission Pipelines

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	2.2E-06	5.4E-07	2.7E-07	0.0E+00	3.0E-06
Corrosion	9.7E-06	0.0E+00	2.7E-07	0.0E+00	9.9E-06
Ground Movement / Other	4.0E-06	1.1E-06	0.0E+00	2.7E-07	5.4E-06
TPA	3.2E-06	7.0E-06	4.0E-06	4.0E-06	1.8E-05
Total Leak Freq. =	1.9E-05	8.6E-06	4.6E-06	4.3E-06	**3.7E-05**
% =	52.2	23.5	12.5	11.8	

C.1.3 Likelihood of Representative Release Scenarios

The estimated likelihood of each representative release scenario is listed in Table 36, Table 37 and Table 38.

Table 36: Release Frequency – Ethane Pipeline (MSE)

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

Table 37: Release Frequency – Jemena Eastern Gas Pipeline (EGP)

Leak Scenario	Release Frequency (per km per year)			Probability of scenario compared to total
	TPA	All Other Failure Modes	Total Release Frequency	
10mm MID		2.08E-05	2.08E-05	0.4110
10mm TOP		0.00E+00	0.00E+00	0.0000
25mm MID	2.20E-05		2.20E-05	0.4347
25mm TOP	0.00E+00		0.00E+00	0.0000
75mm MID	8.88E-07	9.32E-07	1.82E-06	0.0360
75mm TOP	1.51E-06	1.59E-06	3.10E-06	0.0612
110mm MID	3.70E-08	6.29E-08	9.99E-08	0.0020
110mm TOP	6.30E-08	1.07E-07	1.70E-07	0.0034
FBR	1.00E-07	2.52E-06	2.62E-06	0.0518
Total	2.46E-05	2.60E-05	**5.061E-05**	1.0000

Table 38: Release Frequency – Jemena Gas Network Central Trunk Main (CTM)

Leak Scenario	Release Frequency (per km per year)			
	TPA	All Other Failure Modes	Total Release Frequency	
10mm MID		2.08E-05	2.08E-05	0.4110
10mm TOP		0.00E+00	0.00E+00	0.0000
25mm MID	2.20E-05		2.20E-05	0.4347
25mm TOP	0.00E+00		0.00E+00	0.0000
75mm MID	8.88E-07	9.32E-07	1.82E-06	0.0360
75mm TOP	1.51E-06	1.59E-06	3.10E-06	0.0612

Leak Scenario	Release Frequency (per km per year)			
	TPA	All Other Failure Modes	Total Release Frequency	
110mm MID	3.70E-08	6.29E-08	9.99E-08	0.0020
110mm TOP	6.30E-08	1.07E-07	1.70E-07	0.0034
FBR	1.00E-07	2.52E-06	2.62E-06	0.0518
Total	2.46E-05	2.60E-05	**5.061E-05**	1.0000

C.2 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.2.1 - C.2.3).

Ethane

1. The total ignition probability was based on OGP Scenario 3, which is release rate dependent (Refer to Section C.2.1).

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

Natural Gas

1. The total ignition probability was based on OGP Scenario 3, which is release rate dependent (Refer to Section C.2.1).

   The correlation proposed by Acton & Baldwin (Refer to Section C.2.4) is more conservative for smaller leaks; however, the OGP data is more conservative for ruptures and is more consistent with the EGIG and UK HSE data (Refer to Section C.2.4) for the calculated full bore rupture release rates.

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

   The OGP data assumes an immediate ignition probability of 0.001. A 50:50 split appears to be more consistent with other data sources (e.g. Acton & Baldwin, UK HSE – Refer to Section C.2.4).

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.2.1 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 39: Ignition Probability - UKOPA

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

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 40: 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
50	0.1057

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

C.2.2 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 41: Ignition Probability – US DoT

Liquid	Leak			Mechanical Puncture			Other			Rupture			Total		
	# with Ignition	# with no ignition	ProC. of Ignition	# with Ignition	# with no ignition	ProC. of Ignition	# with Ignition	# with no ignition	ProC. of Ignition	# with Ignition	# with no ignition	ProC. of Ignition	# with Ignition	# with no ignition	ProC. 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.2.3 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 42: 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.2.4 Ignition Probability Data for Underground Cross-Country Pipelines – Natural Gas

Acton M R and Baldwin P J - Ignition Probability for High Pressure Gas Transmission Pipelines (7th International Pipeline Conference, IPC2008-64173, Sept 29 – Oct 3, 2008)

Note: Cited in IGEM/TD/2, Assessing the Risks from High Pressure Natural Gas Pipelines and HSE CRR 1034.

An analysis of historical data for rupture incidents shows the ignition probability increases linearly with pd^2. The correlation derived for rupture releases takes the form:

$$P_{ign} = 0.0555 + 0.0137\ pd^2;\ 0 \le pd^2 \le 57$$

$$P_{ign} = 0.81;\ pd^2 > 57$$

P_{ign} = probability of ignition

p = pipeline operating pressure (bar)

d = pipeline diameter for ruptures (m)

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 43: Ignition Probability – Acton & Baldwin

Pipeline Diameter (mm)	Operating Pressure (bar)	Equivalent Hole Diameter (mm)	pd^2	Probability of Immediate Ignition	Probability of Delayed Ignition	Total Ignition Probability
433.6	148.95	FBR	28.00	0.220	0.220	0.439
		110	1.80	0.034	0.034	0.068
		75	0.84	0.031	0.031	0.061
		25	0.09	0.028	0.028	0.056
		10	0.01	0.028	0.028	0.056
836.8	50	FBR	35.01	0.268	0.268	0.535
		110	77.03	0.030	0.030	0.060
		75	52.52	0.029	0.029	0.057
		25	0.03	0.028	0.028	0.056
		10	0.01	0.028	0.028	0.056

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 44: 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 45: 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 46: 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