Wallgrove Business Hub
Pipeline Hazard and Risk Assessment

For Western Sydney Parklands Trust

13 June 2024

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A	1 Mar 2024	RF	First draft for client review.	PS	PS
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1	13 Jun 2024	RF	Updated masterplan as requested by client.	PS	PS

Summary

Overview

Arriscar Pty Ltd (Arriscar) was engaged by Western Sydney Parklands Trust (WSPT) to undertake a Quantitative Risk Assessment (QRA) for the proposed development of an industrial business hub at 97 – 123 & 125-151 Wallgrove Road, Cecil Park, New South Wales (NSW). The development is categorised as a State Significant Development (SSD).

The Development Application (SSD-50972718, Wallgrove Business Hub, Fairfield City) is for a concept layout and the first stage of development of the site including bulk earthworks, infrastructure delivery, road access and detailed design. The proposed hub will contain two industrial, warehouse and distribution buildings. Additional approvals will be sought later for the construction of individual buildings, ancillary facilities and their associated site works.

Three high pressure natural gas pipelines owned and operated by Jemena are present in the vicinity of the proposed business hub:

- Central Trunk Pipeline – Licence 1
- Eastern Gas Pipeline – PL No. 232 & PL No. 26
- Secondary Main Pipeline

Secretary's Environmental Assessment Requirements

The Secretary's Environmental Assessment Requirements (SEARs) for this development (SSD-50972718) include the following requirements for the assessment of hazards and risks [1]:

Requirement	Comments
A preliminary risk screening completed in accordance with Chapter 3 of the Resilience and Hazard SEPP 2021 and Applying SEPP 33 (DoP, 2011), that includes a clear indication of class, storage and handling quantities and location of all dangerous goods and hazardous materials associated with the proposal.	As noted above, the specific use at each lot is anticipated to include industrial warehousing and distribution facilities, and ancillary offices; however, the specific details (including types and quantities of Dangerous Goods, if present) are not known at this stage and will be addressed separately in later development applications. Consequently, it was not possible to undertake a preliminary risk screening in accordance with the State Environmental Planning Policy No. 33 (Applying SEPP 33) for the proposed industrial business hub facilities or to undertake a PHA for these facilities in accordance with HIPAP No. 6. Note: The risk exposure to potential populations within the development from the nearby high-pressure natural gas pipelines was assessed in accordance with HIPAP No. 6 (See below).

Requirement	Comments
A Preliminary Hazard Analysis (PHA) prepared in accordance with Hazardous Industry Planning Advisory Paper No. 6 – Guidelines for Hazard Analysis (DoP, 2011) and Multi-Level Risk Assessment (DoP, 2011), should the preliminary risk screening indicate that the project is "potentially hazardous".	See above comment.
A pipeline hazard analysis undertaken in accordance with the Department of Planning's Hazardous Industry Planning Advisory Paper No. 6, 'Hazard Analysis' and Multi-Level Risk Assessment (DoP, 2011). The hazard analysis must include, and not be limited to, assessment on risk exposures from both high pressure gas pipelines that is located near the development area to the proposed populations within the development and the population from the existing and approved development in the area. The risks established in the hazard analysis require to be compared against the relevant qualitative and quantitative risk criteria detailed in the Department of Planning's Hazardous Industry Planning Advisory Paper No. 10, 'Land Use Safety Planning'.	Three pipelines were identified to be credible external sources of risk to potential populations within the development. The risk at the proposed development from these pipelines was assessed against the risk criteria in HIPAP No. 10. It was determined that the risks at the proposed development from the pipelines are extremely low and well below the relevant DPHI risk criteria from HIPAP No. 10 (Refer to Section 8).

Findings and Recommendations

The following findings were made from the risk assessment (Refer to Section 8):

- The individual risk of fatality at the proposed development site is extremely low and complies with the relevant DPHI risk criteria.
- The injury, property damage and accident propagation risks do not reach and complies with the relevant DPHI risk criteria.
- The societal risk is within the 'ALARP' region but is well below the 'intolerable' risk region for all population estimates. Note that the population densities of 50 or more persons per hectare is expected to be conservative for the proposed development.

The following recommendations should be considered by WSPT to reduce risk levels:

1. Future DAs relating to the specific use of each lot (including construction of structures or buildings) in the proposed industrial business hub should consider the risks imposed from the three pipelines (particularly societal risk). If the development will result in significant changes to any key parameters used in this risk assessment (e.g. population estimates, etc.) then this should be addressed accordingly in the future DA.

2. Future occupied buildings in the proposed industrial business hub should be constructed with due regard of the fire and explosion hazards posed by the pipelines. In future detailed DAs, the proponent should demonstrate how reasonably practicable measures to protect the building occupants has been incorporated into the building design (e.g. through use of appropriate non-combustible materials (cladding etc.), fire-rated walls or other barriers, sizing and location of windows and balconies, measures to minimise smoke ingress, measures to prevent ingress of gas into underground basements / car parks / utilities, etc.).

3. Emergency refuge and/or egress arrangements should be provided for all future occupied areas in the proposed industrial business hub. This is to ensure the safety of the occupants in the event of an incident involving the pipelines. For future development applications, the proponent should demonstrate how this has been incorporated into the design (e.g. emergency egress stairwells, egress to a safe location on the far side of the building away from the pipeline, shelter-in-place facilities, etc.) and the occupier should prepare appropriate emergency response plan/s.

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Notation

Abbreviation	Description
APD	Australian Pipeline Database
APGA	Australian Pipeline and Gas Association
Arriscar	Arriscar Pty Limited
BYDA	Before You Dig Australia
CTP	Central Trunk Pipeline
DA	Development Application
DPHI	NSW Department of Planning, Housing and Infrastructure
EGP	Eastern Gas Pipeline
FBR	Full Bore Rupture
HDD	Horizontal Directional Drilling
HIPAP	Hazardous Industry Planning Advisory Paper
LSIR	Location-Specific Individual Risk
MAE/s	Major Accident Events
NSW	New South Wales
QRA	Quantitative Risk Assessment
SEARs	Secretary's Environmental Assessment Requirements
SEPP	State Environmental Planning Policies
SMP	Secondary Main Pipeline
SSD	State Significant Development
TPA	Third Party Activity
WSPT	Western Sydney Parklands Trust

1 INTRODUCTION

1.1 Background

Arriscar Pty Ltd (Arriscar) was engaged by Western Sydney Parklands Trust (WSPT) to undertake a Quantitative Risk Assessment (QRA) for the proposed development of an industrial business hub at 97 – 123 & 125-151 Wallgrove Road, Cecil Park, New South Wales (NSW). The development is categorised as a State Significant Development (SSD).

The Development Application (SSD-50972718, Wallgrove Business Hub, Fairfield City) is for a concept layout and the first stage of development of the site including bulk earthworks, infrastructure delivery, road access and detailed design. The proposed hub will contain two industrial, warehouse and distribution buildings. Additional approvals will be sought later for the construction of individual buildings, ancillary facilities and their associated site works.

Three high pressure natural gas pipelines owned and operated by Jemena are present in the vicinity of the proposed business hub:

- Central Trunk Pipeline – Licence 1
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- Secondary Main Pipeline

The Secretary's Environmental Assessment Requirements (SEARs) for this development (SSD-50972718) include the following requirements for the assessment of hazards and risks [1]:

> *The EIS must address the following specific matters:*
>
> *…..*
>
> ***Hazards and Risk***
>
> - *A preliminary risk screening completed in accordance with Chapter 3 of the Resilience and Hazard SEPP 2021 and Applying SEPP 33 (DoP, 2011), that includes a clear indication of class, storage and handling quantities and location of all dangerous goods and hazardous materials associated with the proposal;*
> - *A Preliminary Hazard Analysis (PHA) prepared in accordance with Hazardous Industry Planning Advisory Paper No. 6 – Guidelines for Hazard Analysis (DoP, 2011) and Multi-Level Risk Assessment (DoP, 2011), should the preliminary risk screening indicate that the project is "potentially hazardous";*
> - *A pipeline hazard analysis undertaken in accordance with the Department of Planning's Hazardous Industry Planning Advisory Paper No. 6, 'Hazard Analysis' and Multi-Level Risk Assessment (DoP, 2011). The hazard analysis must include, and not be limited to, assessment on risk exposures from both high pressure gas pipelines that is located near the development area to the proposed populations within the development and the population from the existing and approved development in the area. The risks established in the hazard analysis require to be compared against the relevant qualitative and quantitative risk criteria detailed in the Department of Planning's Hazardous Industry Planning Advisory Paper No. 10, 'Land Use Safety Planning'.*

1.2 Scope

The scope of this study included undertaking a pipeline hazard analysis for the proposed development in accordance with Hazardous Industry Planning Advisory Paper No. 6 – Guidelines for Hazard Analysis (HIPAP No. 6) [2] developed by the NSW Department of Planning, Housing and Infrastructure (DPHI). It also included an assessment of the risks in accordance with HIPAP No. 10 – Land Use Safety Planning [3].

1.3 Objectives

The principal objective of the study was to perform a risk assessment covering the scope outlined in Section 1.2 in accordance with the DPHI's HIPAP guidelines. This included:

- Identification of any potential hazards near the development (particularly from any dangerous goods pipelines);
- Identification of all 'Major Accident Events' (MAEs) that might impact upon the proposed development, and the appropriate and relevant representative scenarios for each MAE;
- Quantification of the consequences of potential harmful effects for each representative scenario, including the potential for impact on the proposed development;
- Quantification of the likelihood of occurrence of each representative scenario;
- Using assumptions that are appropriate and justified, with a focus on minimising uncertainty and obtaining the 'cautious best estimate';
- Generation of Location-Specific Individual Risk (LSIR) contours for comparison with the DPHI's risk criteria for land use safety planning (viz. as per HIPAP No. 4 and HIPAP No. 10); and
- Estimation of societal risk for comparison with the DPHI's indicative risk criteria for land use safety planning (viz. as per HIPAP No. 4 and HIPAP No. 10).

2 RISK ASSESSMENT METHODOLOGY

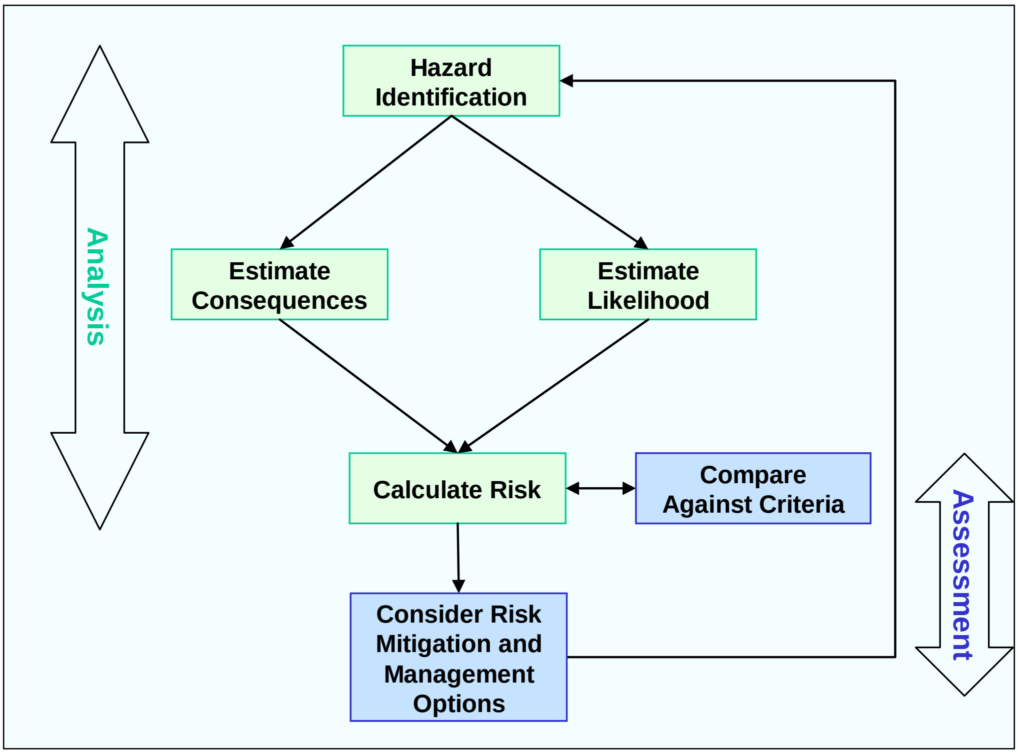
2.1 Introduction

A Quantitative Risk Assessment (QRA) involves the quantitative estimation of the consequences and likelihood of hazardous events to determine the risks generated by a facility. The risks of the facility are evaluated against risk criteria outlined regarding fatalities, injuries, and property damage, etc.

In developing the estimates for use in a QRA, it is important to ensure that any estimates fall on the side of conservatism, particularly where there is uncertainty in the underlying data and assumptions. This precautionary approach uses 'cautious best estimate' values, which, whilst conservative, are still realistic. This approach is consistent with the DPHI's guidelines for undertaking this type of assessment [2].

Diagrammatically, the QRA process is as follows:

Figure 1 Overview of QRA Process [2]



2.2 Overview of Methodology

The methodology for a QRA involves the following main steps:

1. System definition, in which information on the facility is collected and assimilated.
2. Hazard identification, in which site events and external events are identified which may lead to potential adverse effects beyond the boundary of the site.
3. Consequence modelling, in which all the possible consequences of each event are estimated.
4. Frequency and likelihood estimation, in which the frequency (i.e. likelihood per year of occurrence) of each of the hazardous events is estimated, based on historical failure data.
5. Risk estimation, in which the frequencies and consequences of each event are combined to determine levels of risk.
6. Risk assessment, in which the calculated risks are assessed against relevant risk criteria.

2.3 Description of Facilities, Operation and Surroundings

The location of the proposed or existing facility and the surrounding areas are described to enable an appropriate consideration of the potential impacts.

2.4 Hazard Identification

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, or exposure to stored energy etc.). The basis for any risk study is the identification of hazards present within a facility. Hazard identification (or HAZID) is crucial, as a hazard that is not identified will not be modelled and assessed.

There is no single definitive method for HAZID; however, it should be comprehensive and systematic to ensure critical hazards are not excluded from further analysis. A desktop review of layout drawings, engineering documentation and a literature review provide useful inputs. Examples of hazard identification techniques include simple checklists based on historical incidents and earlier analyses, more detailed “what-if” style analyses and the most detailed structured techniques such as a Hazard and Operability (HAZOP) study and Failure Modes and Effects Criticality Analysis (FMECA).

As well as identifying the hazards that exist, it is also important to identify how these hazards could lead to a hazardous scenario/event. In the context of a QRA, these potentially hazardous events are commonly described as ‘Major Accident Event’ (MAEs). A 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 an acceptable risk criterion has been defined by the DPHI– refer to Section 2.9).

As there is usually a large number of possible initiating events leading to a hazardous scenario, it would be impractical analyse all possibilities. Therefore, discrete initiating events are used to represent the range of possible hazardous scenarios that could occur. Generally, hazardous scenarios are represented by a limited number of leaks / hole sizes varying from small pin hole leaks to catastrophic ruptures.

When developing hazardous scenarios, the facility is first split into sections which are called isolatable sections. An isolatable section is a system of equipment and/or pipelines that contain similar materials under similar process conditions such as pressure and temperature. Preferably an isolatable section should be bounded by isolation points such as emergency shutdown valves (ESDVs) or motorised 'fail close' valves but this may not be possible for all cases.

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 materials properties;
- Inventory of hazardous materials that could contribute to the event;
- 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.

2.5 Hazard Consequence Analysis

The physical consequences of a hazardous scenario are generally dependent on the:

- State of the material (liquid or gas/vapour);
- Quantity released;
- Rate of release; and
- Ignition (for fire and explosion events).

The quantity released depends on the inventory, which is estimated from the isolatable sections, size of release (viz. assumed equivalent hole diameter) and duration of release (how soon can the release be detected and isolated).

The release rate from a hole is assumed to be from a circular orifice of equivalent diameter. This is the maximum flow rate for a given hole area and is used because it can be calculated readily and will produce the maximum release rate for a given hole area. The release rate is estimated from process conditions such as the pressure, temperature, and the state of the material (liquid or vapour) for pressurized equipment; while the liquid level is considered for atmospheric storage tanks.

The dispersion rate of gas/vapour depends on meteorological conditions such as the wind speed, wind direction and atmospheric stability conditions. Location-specific meteorological data is required to perform a consequence analysis. The representative wind directions, wind speeds and wind stability classes are typically determined from annual average of weather data available from the Bureau of Meteorology, for the local weather station.

The different types of consequences typically considered for a QRA are described below.

2.5.1 Pool Fires

Pool fires are a potential consequence related to a hazardous scenario that release flammable liquid onto the ground which may form an evaporating pool and/or accumulate in a bund/sump. Ignition will produce a turbulent diffusion flame that burns above the whole surface of the pool and emit heat radiation. The impacts of pool fires are modelled using the surface emissivity of the flame to produce contours of heat radiation levels. Fires impinging on adjacent equipment may cause structural failures and incident escalation.

2.5.2 Jet Fires

Jet fires are a potential consequence related to a hazardous scenario that release flammable vapour or liquid with a high momentum. Ignition will produce a turbulent diffusion flame which emits heat radiation. Similar to pool fires the impacts of jet fires are modelled using the surface emissivity of the flame to produce contours of heat radiation levels. Fires impinging on adjacent equipment may cause structural failures and incident escalation.

2.5.3 Flash Fires and Vapour Cloud Explosions

If a volatile flammable liquid releases onto the ground, then a vapour cloud may form and disperse in the air. Similarly, a release of flammable vapour/gas may form a cloud and disperse in the air. Ignition of the flammable gas-air mixture may result in a flash fire or vapour cloud explosion (VCE).

A flash fire is sudden, intense fire that lasts for a very short duration in which the flame propagation speed is less than the sonic velocity. 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.

It is possible for a VCE to occur instead of a flash fire if the cloud is within an area that is sufficiently congested. Flame acceleration increases above sonic velocity due to the turbulence caused by the congested region and produces a blast wave. This may occur inside buildings and around obstacles (e.g. buildings, vehicles, trees etc.). These are modelled to produce contours for different levels of overpressures generated by the explosion.

2.5.4 Fireballs and BLEVE

A fireball is an intense spherical fire resulting from a sudden release of pressurized liquid or gas that is immediately ignited and emits heat radiation. Boiling Liquid Expanding Vapour Explosion (BLEVE) is an explosion caused by the sudden release of superheated liquid from a vessel in which its integrity has been compromised. The boiling liquid rapidly expands due to the pressure drop resulting in an explosion producing overpressures and heat radiation.

2.5.5 Toxic Effects

If a toxic, or an asphyxiant vapour/gas is released, then the potential may exist for injury or fatality if exposed (typically via inhalation). The dispersion of flammable or toxic gas/vapour is modelled to produce a concentration profile in three dimensions (downwind, crosswind and elevation). For releases that are constant over time, this can be represented by a set of contours of constant concentration (isopleths) on a plan drawing and/or summarised in a tabular format.

2.6 Vulnerability Criteria

Vulnerability criteria have been developed by the DPHI for the effects of fires, explosions and toxic gas emissions and listed below [4]. The vulnerability parameters used in this analysis are included in Appendix A.6.

2.6.1 Heat Radiation

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 outlined in HIPAP No. 4 are presented in Table 1.

Table 1 Effects of Thermal Radiation [4]

Heat Radiation [kW/m^2]	Effect/s
1.2	• Received from the sun at noon in summer
2.1	• Minimum to cause pain after 1 minute
4.7	• Will cause pain in 15-20 seconds and injury after 30 seconds exposure (at least second-degree burns will occur)
12.6	• Significant chance of fatality for extended exposure. High chance of injury • 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	• Likely fatality for extended exposure and chance of fatality for 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	• Cellulosic material will pilot ignite within one minute's exposure • Significant chance of fatality for people exposed instantaneously

2.6.2 Explosion Overpressure

The potential for injury or property damage from an explosion is principally determined by the explosion overpressure. However, projectiles are also a possibility in an explosion. An overpressure wave is generated when the acceleration of the flame front is increased due to the turbulence produced by obstacles in the pathway of the combusting vapour cloud.

The impact of explosion overpressure on humans takes two forms and can lead to serious injury or even fatality:

- Direct exposure could lead to organ damage (e.g. ear drum rupture or lung rupture), and/or knock a person over/into a hard object (e.g. ground or a wall).
- The person could be hit by a projectile, caused by the explosion, or from the collapse of buildings.

The effects of exposure to explosion overpressure outlined in HIPAP No. 4 are presented in Table 2.

Table 2 Effects of Vapour Cloud Explosions [4]

Overpressure [kPa]	Effect/s
3.5	• 90% glass breakage • No fatality and very low probability of injury
7.0	• Damage to internal partitions and joinery but can be repaired • Probability of injury is 10%. No fatality
14.0	• House uninhabitable and badly cracked.
21.0	• Reinforced structures distort • Storage tanks fail • 20% chance of fatality to a person in a building
35.0	• House uninhabitable • Wagons and plants items overturned • Threshold of eardrum damage • 50% chance of fatality for a person in a building and 15% chance of fatality for a person in the open
70.0	• Threshold of lung damage • 100% chance of fatality for a person in a building or in the open • Complete demolition of houses

2.6.3 Toxic Exposure

As there are no uniform specific criteria to cover all toxic effects, the vulnerability criteria selection for toxic exposure requires a literature review of the available toxicity data.

2.7 Frequency and Likelihood Analysis

Once the consequences of the various hazardous 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 frequency data for which a parts count of the failure items within an isolatable section may need to be conducted. Moreover, for fire and explosion scenarios ignition probabilities are taken into consideration when determining the likelihood. This is only possible because data on such incidents and failures has been collected by various organisations over several 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 considered. 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.

2.8 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 hazardous scenarios to generate a complete picture of the risk. The risk assessment step involves comparing the risk results against risk criteria.

Location-specific risk contours are usually used to represent off-site risk for a 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: 0.1×10^{-6} per year, 0.5×10^{-6} per year, 1×10^{-6} per year, 5×10^{-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 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).

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.

2.9 Quantitative Risk Criteria

The risk criteria considered for this assessment are the DPHI risk criteria outlined in HIPAP No. 10 which have been described below.

2.9.1 Location Specific Individual Fatality Risk

The maximum acceptable individual risk of fatality for off-site population types are presented in Table 3. These are location specific risk criteria and assumes 100% occupancy and no escape.

Table 3 Location Specific Individual Fatality Risk Criteria

Maximum Individual Risk of Fatality (fatalities per year)	Limit of Exposure at the Following Locations
5E-07	Hospitals, child-care facilities, old age housing developments.
1E-06	Residential developments, places of continuous public occupancy.
5E-06	Commercial developments (offices, shops etc.)
1E-05	Sporting complexes and active open space areas.
5E-05	Limit of risk exposure for adjacent industrial land use. Preferably contained within facility boundary.

2.9.2 Injury Risk

Heat radiation of 4.7 kW/m^2 may cause pain in 20 seconds and injury after 30 seconds of exposure. The 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/m^2 at a frequency of more than 50 chances in a million per year.*

Explosion overpressure of 7 kPa has a probability of 10% to cause injury. The injury 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 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.*

2.9.3 Risk of Property Damage and Accident Propagation

Heat radiation of 23 kW/m^2 may cause unprotected steel to suffer thermal stress that may cause structural damage. The property damage risk criterion for heat radiation is as follows:

> *Incident heat flux radiation at neighbouring potentially hazardous installations or at land zoned to accommodate such installations should not exceed a risk of 50 in a million per year for the 23 kW/m^2 heat flux level.*

Explosion overpressure of 14 kPa may cause significant damage to buildings making it unhabitable. The property damage risk criterion for explosion overpressure is as follows:

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

2.9.4 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

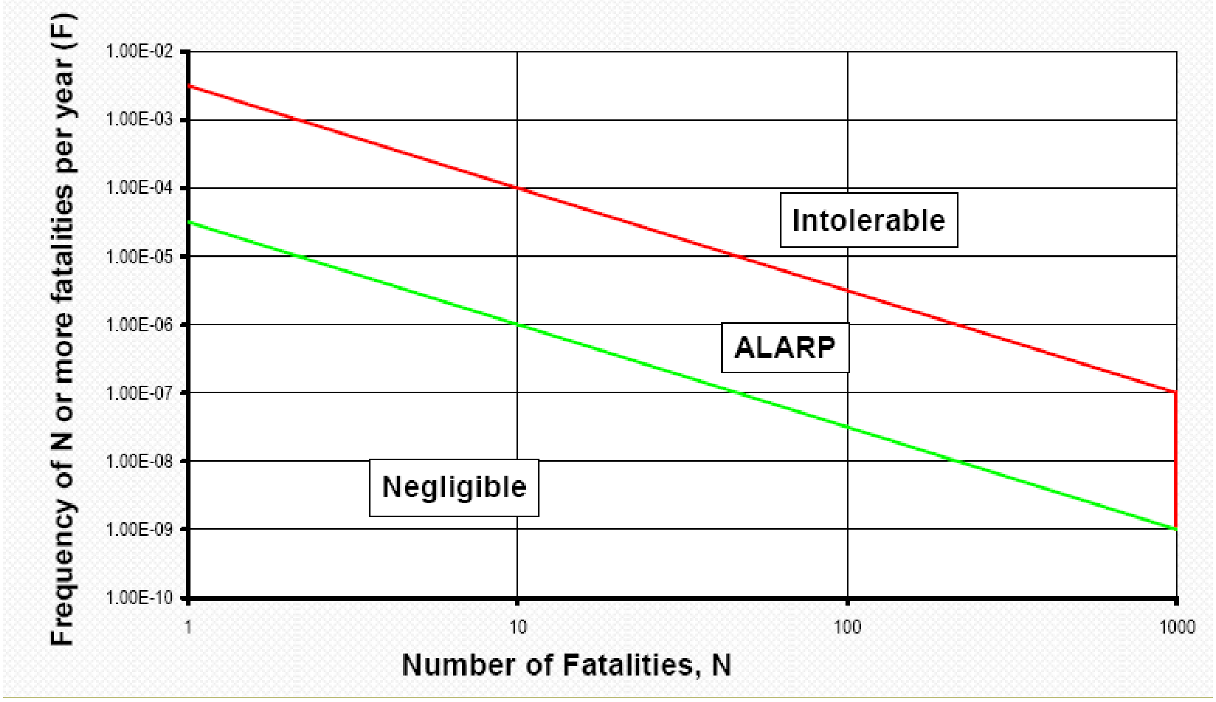
b) the frequency (likelihood) of occurrence of the incident.

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 societal risk criteria incorporate an ALARP (As Low As Reasonably Possible) approach. This is reflected as three societal risk bands: negligible, ALARP and intolerable, as shown in Figure 2.

Figure 2 DPHI Societal Risk Criteria (F-N Plot)



- *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 No. 4* [4] *are met, the risks from the activity would be considered tolerable in the ALARP region.*

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.

2.10 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, vulnerability criteria, etc.).

To comply with the general principles outlined in Section 2.2 of HIPAP No. 6 [2], 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*".

The key assumptions adopted for this QRA are listed in the Assumptions Register, Appendix A. Each assumption is numbered and detailed separately. The basis for each assumption is explained together with its potential impact on the results of the QRA and the MAE/s potentially affected. Key references are also listed for each assumption, where relevant.

3 SITE DESCRIPTION

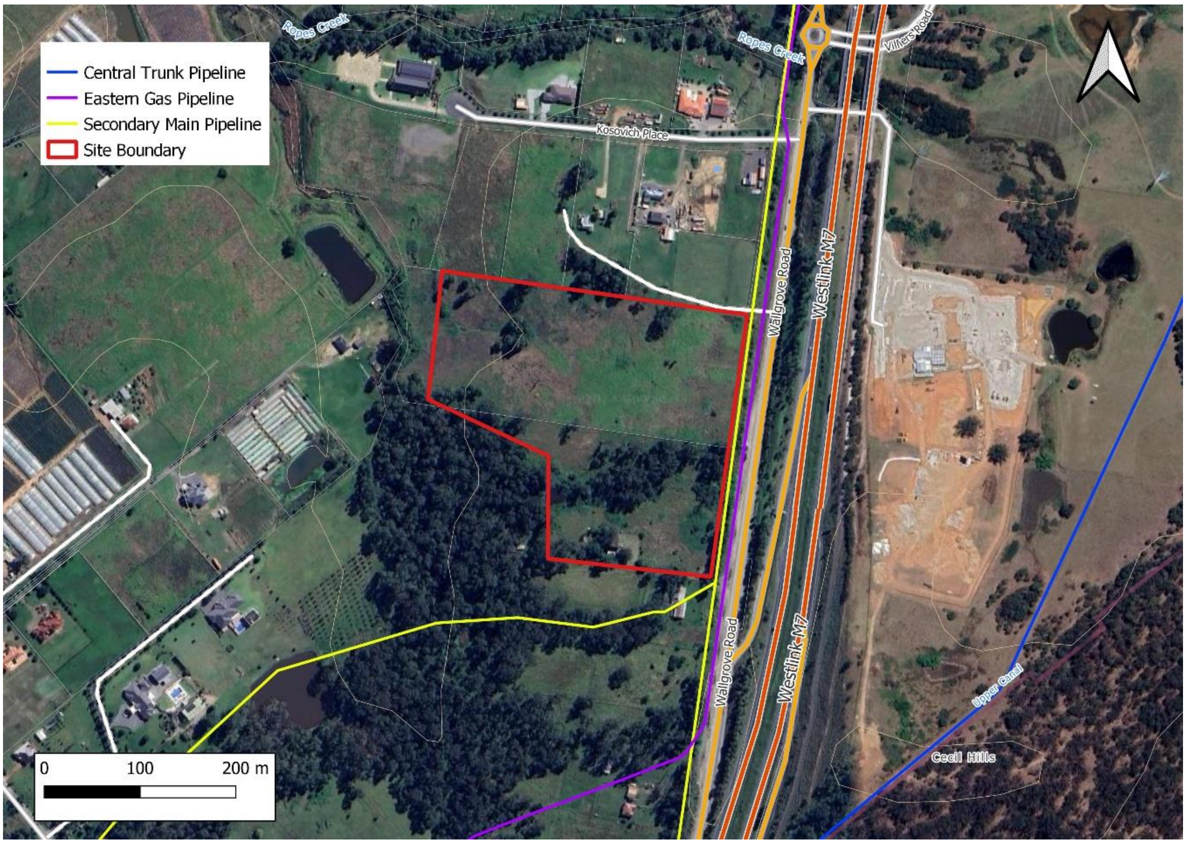
3.1 Site Location

The proposed industrial business hub is located at the following lots in the Fairfield Local Government Area (LGA):

- Part Lot 25 Sec 4 DP 2954 of 97 – 123 Wallgrove Road, Cecil Park (Southern Lot); and
- Part Lot 24 DP 1152887 of 125-151 Wallgrove Road, Cecil Park (Northern Lot).

The location of the site and the three high pressure pipelines are shown in Figure 3. The site is adjacent to Wallgrove Road and Westlink (M7) motorway with a total area of approximately 7.2 hectares.

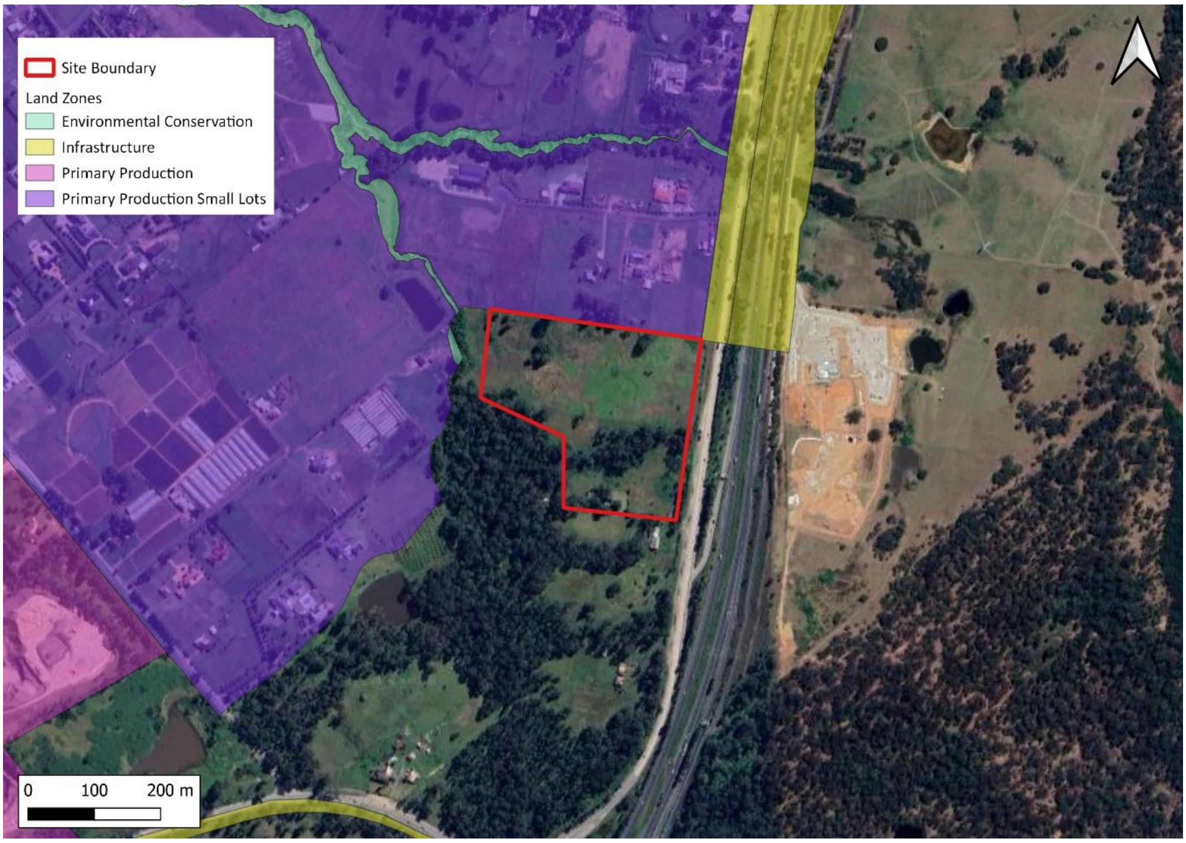
Figure 3 Site Location



3.2 Land Zoning

Under the provisions of the State Environmental Planning Policy (Precincts – Western Parkland City) 2021 (WPC Precincts SEPP), the entire area of the Western Sydney Parklands which includes the proposed development site is not zoned. The site is within the southern part of the Fairfield LGA, approximately 0.7 kilometres north of the Fairfield LGA boundary. The surrounding land use zones are shown in the Figure 4.

Figure 4 Land Zoning



3.3 Existing Facilities and Surrounding Land Uses

The site is predominantly underdeveloped with large areas of cleared land and scattered vegetation. The Southern lot (97-123 Wallgrove Road, Cecil Park) includes a dwelling on the southern boundary with access from Wallgrove Road. The site is surrounded by a variety of land use activities as summarised below:

- North: The land North of the site contains a few rural residential dwellings with open fields. The immediate land to the north-west has received development consent for the new Saints Peter and Paul Assyrian primary school, intended to cater for up to 630 students (SSD-9210) [5]. Further north-west is the Saints Peter and Paul parish church.
- East: Wallgrove Road and Westlink (M7) motorway are located East of the site with an access ramp to the M7 South-East of the site. The land East of the M7 is part of the Western Syndey Parklands, where part of it is currently being used as an ancillary facility for the M7-M12 integration project (SSI-9364 and SSI-663).

- South: The land South of the site is part of the Western Syndey Parklands, which is predominantly vegetation and open land with a few scattered dwellings.
- West: The land West of the site is predominantly open land used for farming and horticulture purposes with a few residential dwellings.

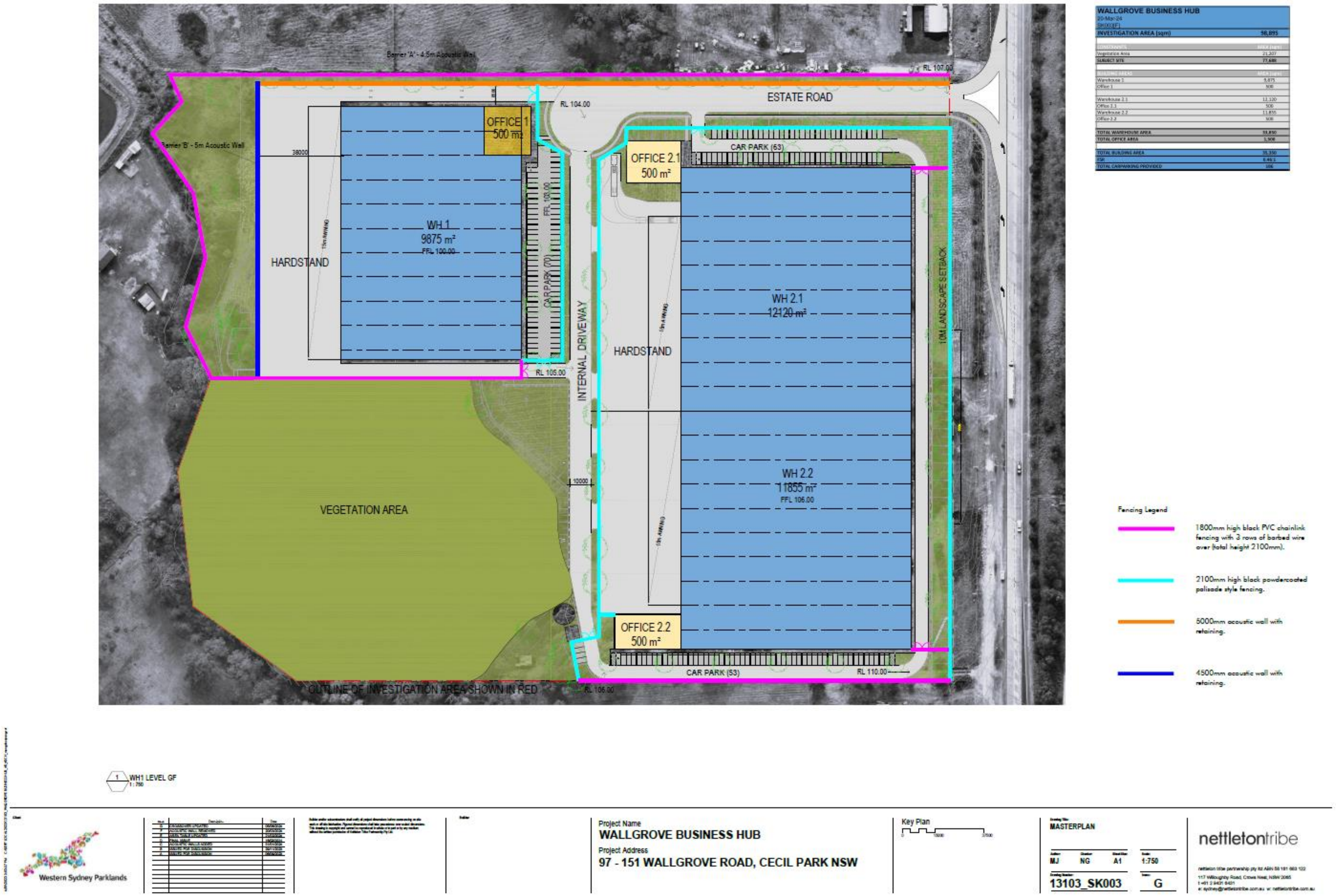
3.4 Proposed Development

The key features of the concept proposal are summarised below:

- Two industrial, warehouse and distribution building footprints to accommodate a range of land uses including light industrial, warehouse and distribution facilities and ancillary office facilities.
- Approximately 34,000 m^2 of floorspace across different buildings / tenancies.
- Concept architectural design for the future built form, and landscape concept design.
- Access road to the proposed business hub off Wallgrove Road.
- Stormwater management works to manage the quality and quantity of water flows across the site and avoid adverse impacts to adjoining properties.
- Delivery of utility services required to service the proposed development, including necessary upgrades and siting and design of the proposed industrial subdivision.

The conceptual layout of the facilities is shown in Figure 5.

Figure 5 Conceptual Masterplan



WALLGROVE BUSINESS HUB 20-Mar-24 SK003[F]	
INVESTIGATION AREA (sqm)	**98,895**
CONSTRAINTS	AREA (sqm)
Vegetation Area	21,207
SUBJECT SITE	**77,688**
BUILDING AREAS	AREA (sqm)
Warehouse 1	9,875
Office 1	500
Warehouse 2.1	12,120
Office 2.1	500
Warehouse 2.2	11,855
Office 2.2	500
TOTAL WAREHOUSE AREA	**33,850**
TOTAL OFFICE AREA	**1,500**
TOTAL BUILDING AREA	**35,350**
FSR	**0.46:1**
TOTAL CARPARKING PROVIDED	**106**

Fencing Legend

🟪	1800mm high black PVC chainlink fencing with 3 rows of barbed wire over (total height 2100mm).
🟦	2100mm high black powdercoated palisade style fencing.
🟧	5000mm acoustic wall with retaining.
🟦	4500mm acoustic wall with retaining.

3.5 Meteorology

The meteorological conditions such windspeed, wind direction, stability class, temperature, solar radiation, and humidity are important in determining the extent of hazardous consequences. Meteorological data for the site is based upon 25 years of observations at Paramatta North (Bureau of Meteorology Station ID 066124) which is one of the closest weather stations to the proposed development site.

Pasquil's stability classification scheme defines six wind stability classes (A to F). Class A refers to more turbulent, unstable conditions and Class F refers to more stable (inversion) conditions. Although the probability distribution of the 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 weather categories and their distribution considered in this analysis are presented in Table 4 - Table 7. Night-time is considered the period from one hour before sunset, to one hour after sunrise; this approximates to 14 hours night-time (58%) and 10 hours daytime (42%).

Table 4 Weather Categories Used for Daytime Analysis

Weather Category	Windspeed (m/s)	Stability Class	Temperature (°C)	Relative Humidity	Solar Radiation (kW/m^2)
1.8B	1.8	B	21.57	0.58	0.61
7.5D	7.5	D	21.76	0.53	0.47
4.1D	4.1	D	19.80	0.61	0.38
1.6D	1.6	D	17.06	0.76	0.26

Table 5 Weather Category Distribution for Daytime Analysis

Direction	1.8B	7.5D	4.1D	1.6D	Total
N	2.41%	0.54%	2.44%	0.76%	6.15%
NNE	1.21%	0.10%	1.09%	0.30%	2.69%
NE	1.17%	0.79%	2.01%	0.30%	4.26%
ENE	1.06%	1.97%	3.22%	0.21%	6.46%
E	1.32%	1.76%	3.84%	0.27%	7.20%
ESE	0.83%	2.93%	3.27%	0.26%	7.29%
SE	0.71%	3.79%	2.90%	0.33%	7.74%
SSE	0.59%	3.47%	2.31%	0.26%	6.63%
S	0.92%	2.71%	2.96%	0.58%	7.17%
SSW	0.82%	0.49%	1.43%	0.54%	3.28%
SW	1.17%	0.74%	2.75%	0.80%	5.46%
WSW	1.33%	1.50%	2.78%	0.83%	6.43%
W	2.27%	2.23%	3.16%	1.39%	9.05%

Direction	1.8B	7.5D	4.1D	1.6D	Total
WNW	2.25%	1.51%	2.57%	1.43%	7.76%
NW	2.20%	0.67%	2.77%	1.37%	7.00%
NNW	1.93%	0.56%	2.16%	0.77%	5.43%
TOTAL	22.19%	25.76%	41.66%	10.39%	100.00%

Table 6 Weather Categories Used for Night-Time Analysis

Weather Category	Windspeed (m/s)	Stability Class	Temperature (°C)	Relative Humidity	Solar Radiation (kW/m^2)
7.3D	7.3	D	17.47	0.65	0.02
3.8D	3.8	D	16.39	0.74	0.01
1D	1	D	13.56	0.89	0.01
2.6E	2.6	E	15.03	0.77	0.00
1F	1	F	13.12	0.90	0.00

Table 7 Weather Category Distribution for Night-Time Analysis

Direction	7.3D	3.8D	1D	2.6E	1F	Total
N	0.12%	1.96%	3.92%	0.11%	0.93%	7.03%
NNE	0.03%	1.03%	1.77%	0.07%	0.31%	3.21%
NE	0.14%	2.50%	2.16%	0.15%	0.47%	5.41%
ENE	0.07%	1.75%	1.92%	0.14%	0.45%	4.33%
E	0.08%	1.87%	2.09%	0.16%	0.48%	4.68%
ESE	0.29%	2.07%	1.59%	0.12%	0.43%	4.49%
SE	0.66%	2.32%	1.56%	0.09%	0.32%	4.95%
SSE	0.98%	2.20%	1.47%	0.05%	0.30%	5.01%
S	0.72%	3.14%	3.26%	0.09%	0.66%	7.87%
SSW	0.23%	1.73%	2.93%	0.09%	0.51%	5.48%
SW	0.22%	2.65%	3.94%	0.14%	0.78%	7.72%
WSW	0.41%	2.58%	4.02%	0.14%	0.84%	7.99%
W	0.61%	2.61%	5.00%	0.14%	1.24%	9.59%
WNW	0.36%	1.63%	3.63%	0.10%	0.77%	6.49%
NW	0.19%	1.73%	4.45%	0.12%	1.11%	7.59%
NNW	0.14%	2.18%	4.37%	0.17%	1.28%	8.15%
TOTAL	5.24%	33.93%	48.08%	1.87%	10.87%	100.00%

3.6 Populations

The populations considered in this analysis are described below. The assumption regarding the location and distribution of the populations are presented in Appendix A.2.

3.6.1 Surrounding Population

The residential, school and employment populations considered for this analysis are presented in Figure 6 and Figure 7. The proposed development of the new Saints Peter and Paul Assyrian primary school, intended to cater for up to 630 students (SSD-9210) [5] has been included in this analysis.

Figure 6 Surrounding Residential and School Population

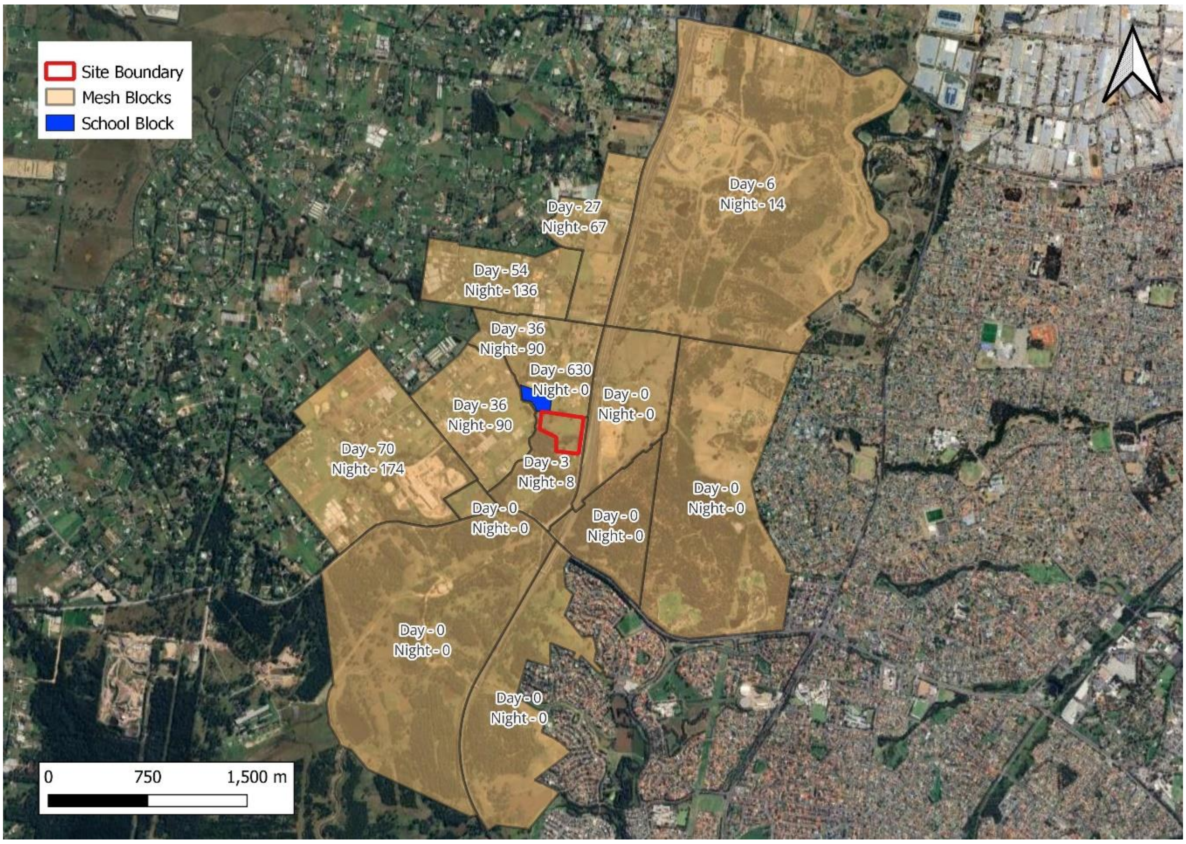


Figure 7 Surrounding Employment Population

3.6.2 Site Population

The site population was based on a similar development project (Light Horse Interchange Business Hub - SSD 9667) in which the estimated population varied from approximately 30 to 50 persons per hectare.

Based on the above data; a base population density of 50 persons per hectare (1 person per 200 m^2) was considered appropriate for the site. For the purposes of a sensitivity analysis of the societal risk, population densities of 75 and 100 persons per hectare were also considered. The estimated site populations are presented in Table 8.

Table 8 Site Population

Total Site Area (hectare)	Population Density of Total Site Area (persons per hectare)	Estimated Site Population
7.17	50	359
	75	538
	100	717

4 IDENTIFICATION OF POTENTIALLY HAZARDOUS FACILITIES & OPERATIONS

The specific use at each lot is anticipated to include industrial warehousing and distribution facilities, and ancillary offices; however, the specific details (including types and quantities of Dangerous Goods, if present) are not known at this stage and will be addressed separately in later development applications. Consequently, it was not possible to undertake a preliminary risk screening in accordance with the State Environmental Planning Policy No. 33 (Applying SEPP 33) for the proposed industrial business hub facilities or to undertake a PHA for these facilities in accordance with HIPAP No. 6.

It is noted in the SEARs that there are two high pressure pipelines near the proposed industrial business hub. These pipelines are the Central Trunk Pipeline (CTP) and the Eastern Gas Pipeline (EGP). Furthermore, the Secondary Main Pipeline which is not mentioned in the SEARs is also in the vicinity of the proposed development. All three pipelines are owned and operated by Jemena.

The location of each pipeline (Refer to Figure 3) was identified using the Australian Pipeline and Gas Association's (APGA) Australian Pipeline Database (APD), and information sourced from Before You Dig Australia (BYDA). Consultation with Jemena was undertaken during the preparation of the risk assessment, in which the relevant data for each pipeline presented in Table 9 were provided.

Table 9 Details of Pipelines

	Central Trunk Pipeline (CTP)	Eastern Gas Pipeline (EGP)	Secondary Main Pipeline
Pipeline Owner	Jemena	Jemena	Jemena
Pipeline Name	Central trunk: Wilton to Horsley Park	Eastern Gas Pipeline	150 ST 1050 (Note: Section of pipeline abandoned near Elizabeth Drive) – New connection is being laid.
Material/Product Transferred	Natural Gas	Natural Gas	Natural Gas
Licence No.	Licence 1	PL232 & PL 26	NA (Secondary mains are not licensed pipelines)
MAOP	6.895 MPag	14.895 MPag	1050 kPag
Normal Operating Pressure	4.5 – 5 MPag	14.895 MPag	Secondary mains typically operate at > 545 kPag to 1050 kPag
Kilometre Point	KP 46 to KP 47	KP 791 to KP792	-
Operating Temperature	15°C	15°C	15°C
Measurement Length	766 m	558 m	-
Flowrate	-	-	-
Pipeline Material	API 5LX65	Carbon Steel API 5LX70	Steel (Typically Carbon Steel, API 5L Grade B or Grade X42)
Nominal Pipeline Diameter	DN850	DN450	DN150
Internal Pipeline Diameter	831.4 mm	428.8 mm	158.7 mm

	Central Trunk Pipeline (CTP)	Eastern Gas Pipeline (EGP)	Secondary Main Pipeline
Wall Thickness	13.3 mm	14.1 mm	4.78 mm Typical
Depth of Cover	1200 mm	900 mm	550 mm to 1100 mm
Cathodic Protection	Impressed Current	Impressed Current	Impressed Current
External Coating	Coal Tar Enamel	Fusion Bonded Epoxy	High-Density Polyethylene (HDPE) or Tri-laminate
Leak Detection	N/A	N/A	Yes
Locations of Nearest Isolation Valves	Cecil Park ALBV KP 40.9(off Seoul Ave) and Horsley Park KP 51.08	Austral KP786 Horsley Park MS KP796.7	-
Patrols (Ground and Aerial)	Weekly Ground & Aerial	Weekly Ground, Six Weekly Aerial, Annually (foot patrol)	Weekly Ground & Aerial
Control Measures for 3rd Party Interference	DOC, Wall Thickness, Warning Signage, BYDA, Pipeline Patrols	DOC, Wall Thickness, Warning Signage, BYDA, Pipeline Patrols	BYDA, Pipeline Patrols and Surveillance
Pigging	Pigging every 10 years Last Inspected in 2014	Pigging every 10 years Last inspected in 2022	N/A - Secondary mains are not piggable

5 HAZARD IDENTIFICATION

5.1 Introduction

The hazard identification was based on a review of the: information on the pipelines (Refer to Section 4); properties of Natural Gas; and potential failure modes and consequences if a leak were to occur from the pipelines. These findings are presented as follows:

Section 5.2 – Properties of Natural Gas.

Section 5.3 – Pipeline Failure Modes.

Section 5.4 – Potential Consequences.

Section 5.5 – Control Measures.

The representative MAE/s carried forward to the consequence and analysis are listed in Section 5.6.

5.2 Properties of 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 this QRA. Methane is:

- A gas at ambient conditions;
- Flammable;
- Lighter than air at ambient temperatures; and
- Colourless, odourless and non-toxic.

Physical properties of Methane are listed in Table 10.

Table 10 Physical Properties of Methane

Boiling Point (at 760 mmHg)	-162 °C
Flash Point	-188 °C
Autoignition Temperature	540 °C
Relative Density (Air =1)	0.55
Lower Flammability Limit (vol. %)	5%
Upper Flammability (vol. %)	15%

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:

- **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 described in Appendix C.1.

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 all three pipelines.

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 all three pipelines.

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 all three pipelines.

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. it may only weaken the pipeline such that it fails at a later time).

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

This failure mode is credible for all pipelines.

5.4 Potential Consequences

If a release of Natural Gas ignites it could result in the following consequences as described in Section 2.5:

- **Jet Fire** – The potential for fatality due to exposure to heat radiation from a jet fire (including direct exposure to the jet) has been included in this analysis.
- **Flash Fire** – The potential for fatality due to direct exposure to a flash fire has been included in this analysis.

Other potential consequences that have been considered but were deemed unlikely to occur are described below.

5.4.1 Asphyxiation

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

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

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

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

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

Oxygen deficiency from exposure to Natural Gas should not be a major issue because the fire hazards are usually the dominant effects in most locations (the LFL for Methane is approximately one-tenth, or 10%, 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 this QRA.

5.4.2 Vapour Cloud Explosion

A high degree of confinement and congestion is required to produce a VCE as described in Section 2.5. The configuration of the future structures / buildings is not known at this stage and considering the relatively open area surrounding the three pipelines (Refer to Figure 3), an explosion is less likely to occur than a flash fire. This may change once the future structures / buildings are constructed.

Therefore, the potential for fatality from explosion overpressure was not carried forward to the consequence, likelihood and risk estimation steps of this QRA. All delayed ignition events were modelled as flash fires and conservative assumptions (Refer to Appendix A) were adopted in the risk assessment for the flash fire modelling (e.g. flash fire extent based on distance to 50% of the Lower Flammable Limit concentration, release pressure based on MAOP rather than lower normal operating pressure, etc.).

5.4.3 Toxic Smoke

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

5.4.4 Explosion in a Confined Space

If a leak of flammable gas or vapour enters a confined space (e.g. a building), then a confined explosion may occur if it is ignited. The type and configuration of the buildings at the proposed industrial business hub have not been defined at this stage; therefore, an explosion in a confined space was not carried forward to the consequence, likelihood and risk estimation steps of this QRA.

A leak of flammable gas or liquid from an underground pipeline also has the potential to enter underground services (e.g. sewer pipes) if there is inadequate segregation. This was the cause of major explosions in Mexico and Taiwan; however, these incidents occurred due to very specific circumstances (e.g. For the incident in Taiwan, a gas pipeline had been routed through a sewer and subsequently leaked inside the sewer due to corrosion. For the incident in Mexico, a fuel pipeline was in direct contact with a water pipe and a leak occurred between the two due to corrosion). This is not applicable in Australia, where separate easements are used or the high pressure pipelines are buried at a greater depth.

5.5 Control Measures

Under the NSW Pipelines Act 1967 and Pipelines Regulation 2013, a pipeline operator must ensure the design, construction, operation, and maintenance of a licensed pipeline is in accordance with the relevant provisions of the series of Australian and New Zealand Standards AS(/NZS) 2885 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 the AS(/NZS) 2885 series.

5.5.1 Prevention of Mechanical Failure and Corrosion

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 2885.3:2022 [6] as part of the pipeline management system.

Continual monitoring is required while the pipeline is in operation to ensure the structural integrity of the pipelines are maintained. They shall not be operated above the maximum allowable operating pressure (MAOP).

Pipelines are generally inspected via pigging to observe any mechanical defects; and cathodic protection systems and external pipe coatings are implemented to minimise the likelihood of failure due to corrosion (Refer to Section 4).

5.5.2 Prevention of Damage due to Ground Movement and Other Failures

Normal loads (e.g. due to the internal and external pressure, weight of soil, traffic loads, etc.) and occasional loads (e.g. due to flood, earthquake, transient pressures in liquid lines and land movement due to other causes) are considered during design of a pipeline as per AS/NZS 2885.1:2018 [7].

To comply with AS/NZS 2885.1:2018 [7], 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). The depth of cover of each pipeline is reported in Section 4.

5.5.3 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.

Two key control measures are typically implemented by pipeline operators to minimise the likelihood of impact from TPA: BYDA process and daily / weekly patrols.

The pipeline wall thickness affects the probability of a leak if impact occurs. For example, the average frequency of TPA contact without a leak in NSW is 1.19 per 1000 km per year (average frequency from NSW Performance Report (2022) for the 5-year period from 2017/18 to 2021/22), which is approximately 10 times higher than the average leak frequency in NSW from all causes (viz. 0.124 per 1000 km per year) and approximately 200 times higher than the average leak frequencies reported by the UK HSE for TPA (Refer to Appendix C.1).

Furthermore, the depth of cover may also reduce the likelihood of impact.

5.5.4 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 ruptures; fires; and, natural events.

Leaks may be detected during visual inspections, incident notifications and/or by instrumented monitoring systems. If a leak is detected, then the pipelines can be isolated by shutting down compressors and closing isolation valves (Refer to Section 4 for locations of upstream and downstream isolation valves).

5.6 Representative MAEs

Only one MAE was identified: a release of Natural Gas from the pipelines. The potential outcomes from such a release include a jet fire or flash fire.

6 CONSEQUENCE ANALYSIS

The consequence analysis was conducted using the Safeti version 8.9 software package at a height of interest of 0 m (ground level). The consequences of the MAE identified were modelled to estimate the potential impacts with respect to heat radiation. The impacts of explosion overpressure and toxic effects were not carried forward to the consequence analysis (refer to Section 5.4).

6.1 Release of Flammable Gas

6.1.1 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.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 B.1) than for the other failure modes (i.e. typically less than c. 10 mm). This is also consistent with the predicted hole sizes in this size category reported in Table E3 of AS 2885.1 – 2018, which are based on excavator weight and tooth dimensions (i.e. 15 mm for a 5 tonne excavator, 20 mm for 10-15 tonne excavators and 25 mm for 20-25 tonne excavators). Therefore, two representative hole diameters were selected in this category: 25 mm for TPA and 10 mm for all other failure modes.

Table 11 Representative Hole Diameters

Pipeline/s	Internal Diameter (mm)	Representative Hole Diameter (mm)			
		Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	FBR (> 110 mm)
CTP	831.4	10 or 25*	75	110	1175.7
EGP	428.8	10 or 25*	75	110	606.4
SMP	158.7	10 or 25*	75	-	224.4

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

6.1.2 Rate of Release

The rate of release from a pipeline leak is dependent on the pressure. A release of Natural Gas from the three pipelines was modelled at the MAOP of each pipeline, which is a conservative assumption (Refer to Section 4 and Appendix A.3). The peak release rates for the representative hole diameters of each pipeline are shown in Table 12.

Table 12 Peak Release Rates for Representative Hole Diameters

Representative Hole Diameter (mm)	Release Rate (kg/s)		
	CTP	EGP	SMP
10	0.902	2.11	0.137
25	5.64	13.2	0.856
75	50.7	118.8	13.2
110	109.1	255.5	-
FBR	19886.6	12339.5	117.8

For the CTP and EGP, ten different release rates over the first 5 minutes of the release are used for full bore ruptures. The release rates are selected by Safeti so that the same mass is released in each segment. For smaller holes, the pipelines maintain a constant pressure at the release point. This also implies in a constant release rate at the point of release.

For the SMP, ten different release rates over the first 5 minutes of release are used for hole sizes 75 mm and above. The release rates are selected by Safeti so that the same mass is released in each segment. For hole sizes less than 75 mm, the pipeline maintains a constant pressure at the release point. This also implies in a constant release rate at the point of release.

6.1.3 Location and Direction Release

The direction of release from a pipeline is dependent on the failure mode and representative hole size. All three pipelines were placed underground in Safeti according to their respective burial depths. Two locations of failure were considered for the release hole sizes greater than 25 mm:

- Top of the pipe (unobstructed releases); or
- Middle of the pipe (on the side - obstructed releases)

The release frequencies were distributed between the two locations; 37% for middle of the pipe and 63% for top of the pipe. All hole sizes less than or equal to 25mm were modelled as 100% from the middle of the pipe (Refer to Appendix A.3).

6.1.4 Duration of Release

Natural Gas is flammable, and any adverse impact will occur quickly; therefore, the duration of exposure is not as critical as it would be if there were a toxic material in the pipeline (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 Appendix A.3 and A.6) and the time required for each representative release case to reach steady state.

7 FREQUENCY AND LIKELIHOOD ANALYSIS

7.1 Likelihood of Release

The likelihood of a release (i.e. leak) from the three pipelines are presented 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, *2021-22 Licensed Pipelines Performance Report*. This includes data for all licensed pipelines in NSW for the 5-year period: 2017/18 to 2021/22; 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 - Reported Data for Underground Natural Gas Steel Pipelines (January 2010 to September 2017).

7.2 Likelihood of Representative Release Scenarios

The likelihood of each representative release scenario included in the risk analysis is presented in Table 13 and Table 14.

Table 13 Release Frequencies for CTP and EGP

Release 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	0.411
10mm (Top)		0.00E+00	0.00E+00	0.000
25mm (Mid)	2.20E-05		2.20E-05	0.435
25mm (Top)	0.00E+00		0.00E+00	0.000
75mm (Mid)	2.40E-06	9.32E-07	3.33E-06	0.066
75mm (Top)	0.00E+00	1.59E-06	1.59E-06	0.031
110mm (Mid)	1.00E-07	6.29E-08	1.63E-07	0.003
110mm (Top)	0.00E+00	1.07E-07	1.07E-07	0.002
FBR	1.00E-07	2.52E-06	2.62E-06	0.052
Total	2.46E-05	2.60E-05	**5.06E-05**	1

Table 14 Release Frequencies for SMP

Release Scenario	Release Frequency (per km per year)			Probability of Scenario Compared to Total
	TPA	All Other Failure Modes	Total Release Frequency	
10mm (Mid)		4.72E-04	4.72E-04	0.941
10mm (Top)		0.00E+00	0.00E+00	0.000
25mm (Mid)	2.20E-05		2.20E-05	0.044
25mm (Top)	0.00E+00		0.00E+00	0.000
75mm (Mid)	2.40E-06	9.32E-07	3.33E-06	0.007
75mm (Top)	0.00E+00	1.59E-06	1.59E-06	0.003
FBR	1.00E-07	2.52E-06	2.62E-06	0.005
Total	2.45E-05	4.77E-04	**5.02E-04**	1.000

7.3 Probability of Ignition

The ignition probabilities adopted in the risk analysis are as follows:

- The total ignition probability was based on the International Association of Oil & Gas Producers (IOGP) Scenario 3 – Pipe Gas LPG Industrial [8], which is release rate dependent.
- The total ignition probability was split 50:50 for immediate ignition and delayed ignition.

This was based on a review of relevant ignition probability data and ignition probability correlations (Refer to Appendix C.2).

Table 15 Ignition Probabilities

Pipeline	Representative Hole Diameter (mm)	Release Rate (kg/s)	Total Ignition Probability	Immediate Ignition Probability	Delayed Ignition Probability
CTP	10	0.902	0.006	0.003	0.003
	25	5.64	0.022	0.011	0.011
	75	50.7	0.110	0.055	0.055
	110	109.1	0.194	0.097	0.097
	1175.7	19886.6	1	0.5	0.5
EGP	10	2.11	0.011	0.005	0.005
	25	13.2	0.041	0.020	0.020
	75	118.8	0.207	0.103	0.103
	110	255.5	0.365	0.182	0.182
	606.4	12339.5	1	0.5	0.5
SMP	10	0.137	0.001	0.001	0.001
	25	0.856	0.005	0.003	0.003
	75	13.2	0.041	0.020	0.020
	224.4	117.8	0.206	0.103	0.103

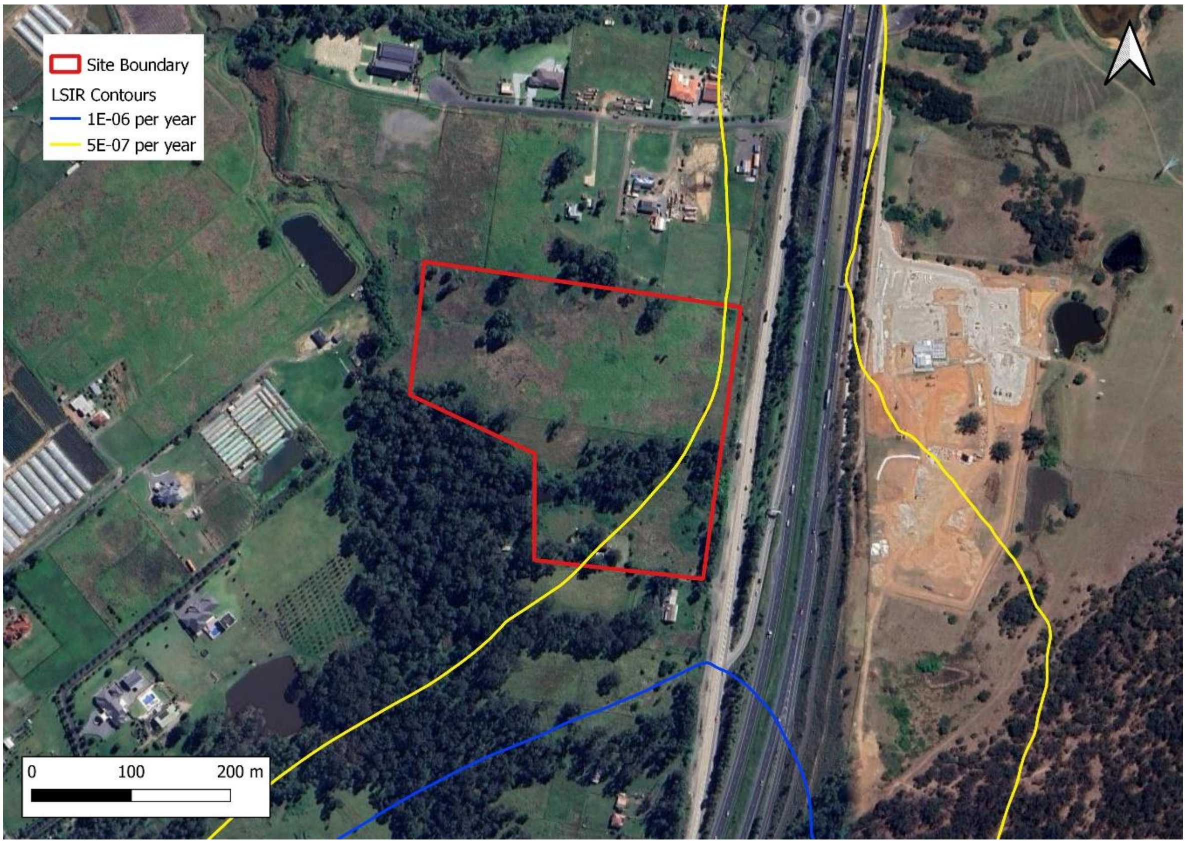
8 RISK ANALYSIS AND ASSESSMENT

The risk analysis was conducted using the Safeti version 8.9 software package.

8.1 Location Specific Individual Fatality Risk

The Location Specific Individual Risk (LSIR) contours are presented in Figure 8. The maximum LSIR at the proposed industrial business hub is 0.5 in a million per year (5E-07 per year), which is significantly lower than the DPHI's risk criterion of 50 in a million per year (5E-05 per year) for the development of industrial land in the vicinity of potentially hazardous facilities.

Figure 8 LSIR of Fatality Contours



8.2 Injury Risk

The DPHI's injury risk criteria (Refer to Section 2.9.2) are only applicable for residential or sensitive use developments; therefore, it is not applicable for the proposed industrial business hub. Nevertheless, the injury risk due to heat radiation greater than 4.7 kW/m^2 was evaluated to be less than the DPHI's criterion of 50 in million per year (5E-05 per year).

The injury risk due to explosion overpressure was not evaluated since all delayed ignition events were modelled as flash fires (Refer to Section 5.4.2). Furthermore, no events with the potential to cause acute toxic injury or irritation were identified for inclusion in the risk analysis (Refer to Section 5.4.1).

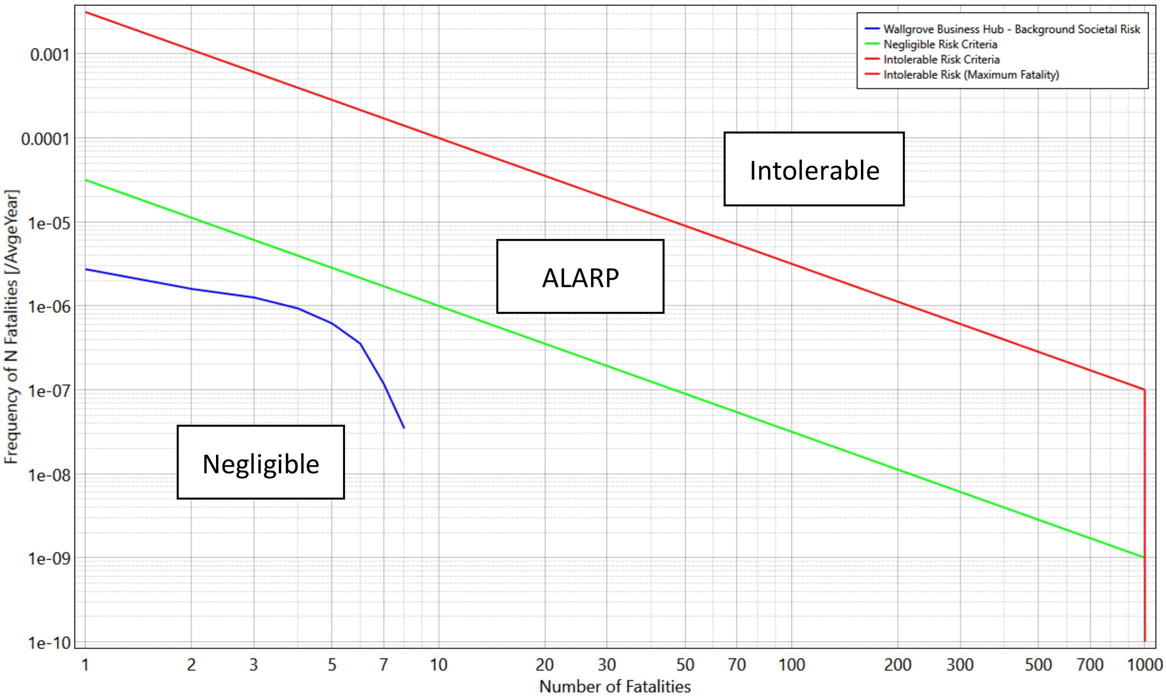
8.3 Risk of Property Damage and Accident Propagation

The property damage and accident propagation risk (Refer to Section 2.9.3) due to heat radiation greater than 23 kW/m^2 was evaluated to be less than the DPHI's criterion of 50 in million per year (5E-05 per year). The property damage and accident propagation risk due to explosion overpressure was not evaluated since all delayed ignition events were modelled as flash fires (Refer to Section 5.4.2).

8.4 Societal Risk

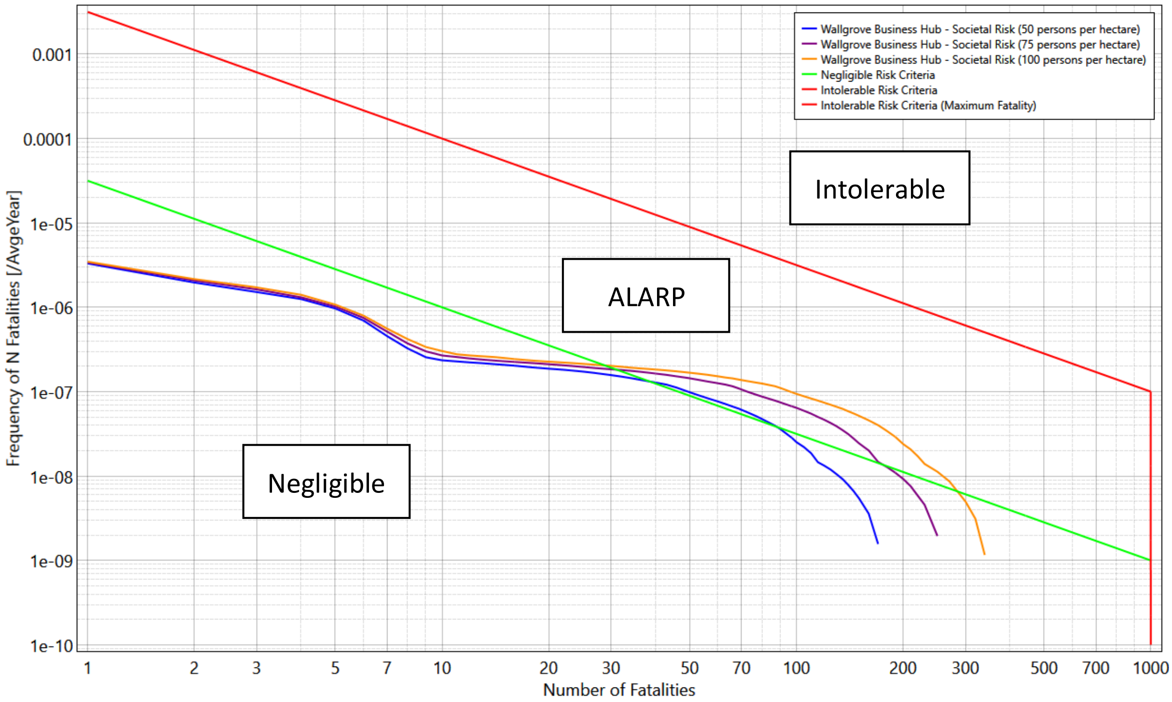
The societal risk due to the pipelines and only the existing surrounding population is presented in Figure 9 as an F-N plot.

Figure 9 Background Societal Risk (F-N Plot)



The societal risk considering the estimated populations (Refer to Section 3.6.2) at the proposed hub is presented in Figure 10. The societal risk enters the 'ALARP' zone but is well below the 'intolerable' risk zone for all population densities considered in this analysis.

Figure 10 Societal Risk with Site Populations



8.5 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 industrial business hub is considered to generally comply with the qualitative risk criteria outlined in HIPAP No. 4, as follows:

- Avoidance of all 'avoidable' risks – The three pipelines are existing facilities (i.e. it cannot be relocated to avoid the risk exposure). The proposed industrial business hub is not existing; however, it is a use that is more appropriate from a land use safety perspective than residential, sensitive or commercial uses (i.e. it avoids a potentially more significant land use safety conflict). The proposal is an important component of the Western Sydney Parklands Plan of Management.

- Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low – The pipeline owner should review the existing control measures in accordance with AS 2885 (Refer to Section 5.5).

- 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 – In this case, the risk exposure at the proposed industrial business hub is lower than the relevant quantitative individual and societal risk criteria.

9 FINDINGS AND RECOMMENDATIONS

9.1 Findings

The following findings were made from the risk assessment (Refer to Section 8):

- The individual risk of fatality at the proposed development site is extremely low and complies with the relevant DPHI risk criteria.
- The injury, property damage and accident propagation risks do not reach and complies with the relevant DPHI risk criteria.
- The societal risk is within the 'ALARP' region but is well below the 'intolerable' risk region for all population estimates. Note that the population densities of 50 or more persons per hectare is expected to be conservative for the proposed development.

9.2 Recommendations

The following recommendations should be considered by WSPT to reduce risk levels:

1. Future DAs relating to the specific use of each lot (including construction of structures or buildings) in the proposed industrial business hub should consider the risks imposed from the three pipelines (particularly societal risk). If the development will result in significant changes to any key parameters used in this risk assessment (e.g. population estimates, etc.) then this should be addressed accordingly in the future DA.
2. Future occupied buildings in the proposed industrial business hub should be constructed with due regard of the fire and explosion hazards posed by the pipelines. In future detailed DAs, the proponent should demonstrate how reasonably practicable measures to protect the building occupants has been incorporated into the building design (e.g. through use of appropriate non-combustible materials (cladding etc.), fire-rated walls or other barriers, sizing and location of windows and balconies, measures to minimise smoke ingress, measures to prevent ingress of gas into underground basements / car parks / utilities, etc.).
3. Emergency refuge and/or egress arrangements should be provided for all future occupied areas in the proposed industrial business hub. This is to ensure the safety of the occupants in the event of an incident involving the pipelines. For future development applications, the proponent should demonstrate how this has been incorporated into the design (e.g. emergency egress stairwells, egress to a safe location on the far side of the building away from the pipeline, shelter-in-place facilities, etc.) and the occupier should prepare appropriate emergency response plan/s.

10 REFERENCES

[1] NSW Department of Planning and Environment, “Planning Secretary’s Environmental Assessment Requirements, Wallgrove Business Hub (SSD-50972718),” 2022.

[2] NSW Department of Planning and Environment, “Hazardous Industry Planning Advisory Paper No. 6 - Hazard Analysis,” ISBN 978-0-73475-862-0, 2011.

[3] NSW Department of Planning and Environment, “Hazardous Industry Planning Advisory Paper No. 10 - Land Use Safety Planning,” ISBN 978-1-74263-028-1, 2011.

[4] NSW Department of Planning and Environment, “Hazardous Industry Planning Advisory Paper No. 4 - Risk Criteria for Land Use Safety Planning,” ISBN 978-0-73475-923-8, 2011.

[5] Western Sydney Parklands Trust, “Wallgrove Business Hub Scoping Report,” 2022.

[6] Standards Australia, “AS 2885.3:2022, Pipelines - Gas and Liquid Petroleum, Part 3: Operations and Maintenance,” 2022.

[7] Standards Australia & Standards New Zealand, “AS/NZS 2885.1:2018, Pipelines - Gas and Liquid Petroleum, Part 1: Design and Construction,” 2018.

[8] International Association of Oil & Gas Producers, “Ignition Probabilities (Report 434-06),” 2019.

Appendices

Appendix A Assumptions

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

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

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

It is important that the assumptions be supported by:

- Experimental data in the literature, where available;
- Actual operating experience, where available;
- Similar assumptions made by experts in the field and a general consensus among risk analysts; and
- Engineering judgement of the analyst.

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

Table 16 List of Assumptions by Subject

Subject	No.	Assumption
Operational Data	1	Operating Conditions
	2	Utilisation of Pipelines
Locational Data	3	Representative Meteorological Conditions
	4	Surface Roughness Length
	5	Location of the High-Pressure Gas Pipelines
	6	Total Site Population (Day and Night)
	7	Total Surrounding Population (Day and Night)
	8	Locational Distribution of People
Consequence Analysis	9	Representative Materials
	10	Pressure for Release Modelling
	11	Representative Hole Diameters for Release Modelling
	12	Location and Direction of Release
	13	Maximum Extent of Flash Fire
	14	Isolation Time and Duration of Release
	15	Shielding by Intervening Structures
Likelihood Analysis	16	Likelihood of Release (Loss of Containment)
	17	Ignition Probability
	18	Probability of VCE or Flash Fire
Risk Analysis	19	Event Spacing for Releases from Pipelines
Vulnerability Parameters	20	Exposure to Heat Radiation (Indoor or Outdoor)
	21	Exposure to Flash Fire (Indoor or Outdoor)

A.1 Operational Data

Assumption No. 1: Operating Conditions

Subject: Operational Data

Assumption/s:

- Operating conditions of all three pipelines (pressure, temperature, etc.) are as reported in Section 4.

Justification and Impact/s of Assumption/s:

- All operational data for the pipelines were provided by the pipeline owner (Jemena).
- Operating conditions (particularly operating pressure) are required to undertake the release and dispersion modelling.

MAE/s Affected:

- All.

Reference/s:

- Data provided by Jemena (25 January 2024).

Assumption No. 2: Utilisation of Pipelines

Subject: Operational Data

Assumption/s:

- The pipelines are utilised 100% of the time.

Justification and Impact/s of Assumption/s:

- Utilisation data is required to estimate the likelihood of a release (viz. leak frequency).
- Utilisation data was not provided by Jemena (Refer to Section 4); therefore, it was conservatively assumed to be 100% for the QRA.

MAE/s Affected:

- All.

Reference/s:

- Data provided by Jemena (25 January 2024).

A.2 Locational Data

Assumption No. 3: Representative Meteorological Conditions

Subject: Locational Data

Assumption/s:

- Representative meteorological conditions are based upon 25 years of observations at the Paramatta North weather station (Bureau of Meteorology Station ID 066124).
- The average ambient conditions (temperature, solar radiation and relative humidity), and the probabilistic distribution of wind speed and wind direction for the representative stability classes are provided in Section 3.5.
- The data was split into daytime and night-time conditions.
- Night-time is considered the period from one hour before sunset, to one hour after sunrise. This approximates to 14 hours night-time (58%) and 10 hours daytime (42%).

Justification and Impact/s of Assumption/s:

- Meteorological data is required to undertake the dispersion and consequence analysis.
- Meteorological data (mean cloud cover, temperature, wind speeds, etc.) is collected by the Bureau of Meteorology (BoM). Paramatta North is one of the closest BoM weather stations to the proposed development site.
- Raw data from observations at Paramatta North have been rationalised into a set of wind speed and weather stability classes.
- 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 Safeti for pool fires and vertical jet fires. Safeti assumes horizontal jet fires are directed in the same direction as the wind.
- The downwind gas concentrations, and hence the hazard ranges for dispersion of flammable gas or vapour, vary with wind speed and weather stability class. Therefore, multiple representative wind speed and stability class categories are included in accordance with standard practice for undertaking a quantitative risk assessment (QRA).
- The day/night split of the weather data is required to allow for the fact that residential, commercial, and industrial occupancies change over a 24-hour period.

MAE/s Affected:

- All.

Reference/s:

- BoM meteorological data for Parramatta North weather station.

Assumption No. 4: Surface Roughness Length

Subject: Locational Data

Assumption/s:

- A roughness length of 1 m is applicable for the area surrounding the pipelines.

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 faster 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.
- The roughness length for different surface types, as listed in the Safeti user manual is shown in Table 17.

Table 17 Surface Roughness Lengths

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

- It is not possible to define different surface roughness lengths for different locations within a single Safeti model. Only a single representative value can be defined for the entire study area.

MAE/s Affected:

- Dispersion modelling for all relevant MAEs.

Reference/s:

- Safeti software documentation.
- Aerial photographs of study area.

Assumption No. 5: Location of the High-Pressure Gas Pipelines

Subject: Locational Data

Assumption/s:

- The location of each pipeline was identified using the Australian Pipeline and Gas Association's (APGA) Australian Pipeline Database (APD), and information sourced from Before You Dig Australia (BYDA).
- All three pipelines are located underground. Respective burial depths are presented in Section 4.

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 series of Australian and New Zealand Standards AS(/NZS) 2885 for gas and liquid petroleum pipelines.
- 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.
- Before You Dig Australia.
- Data provided by Jemena (25 January 2024).

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

Assumption/s:
• The population at the proposed industrial business hub is as described in Section 3.6.1.
• The population is evenly distributed across the total area of the site.
• The % of the total population that is present at the proposed industrial business hub during the day and night is:
  • **Day**: 100%.
  • **Night**: 100%.

Justification and Impact/s of Assumption/s: • The total population, population density, and the % of the total population present during the day and night are required for estimation of the societal risk. • The assumed base population density is marginally less than a typical residential population density of 1 person per 182 m^2 (55 persons per hectare) and is therefore considered to be conservative for an industrial business hub.
MAE/s Affected: • All (Note: This assumption is only applicable to the calculation of societal risk).
Reference/s:

Assumption No. 7: Total Surrounding Population (Day and Night)

Subject: Locational Data

Assumption/s:

- The population surrounding the proposed industrial business hub is as described in Section 3.6.1.
- The population is evenly distributed across the total area of each respective block or zone.
- The residential and employment population is based upon the Census of Population and Housing, 2021, obtained from the Australian Bureau of Statistics (ABS) TableBuilder service.
- The residential population is evaluated at the mesh block level while the employment population is evaluated based on the destination zones.
- The % of the residential population that is present in the mesh blocks during the day and night is:
    - **Day**: 40%.
    - **Night**: 100%.
- The % of the school population that is present in the school block during the day and night is:
    - **Day**: 100%.
    - **Night**: 0%.
- The % of the employment population that is present in the destination zones during the day and night is:
    - **Day**: 100%.
    - **Night**: 0%.

Justification and Impact/s of Assumption/s:

- The total population, population density, and the % of the total population present during the day and night are required for estimation of the societal risk.
- The 2021 Census data is the most recent, and most conservative population data available.

MAE/s Affected:

- All (Note: This assumption is only applicable to the calculation of societal risk).

Reference/s:

- Census of Population and Housing, 2021, TableBuilder.

Assumption No. 8: Locational Distribution of People

Subject: Locational Data

Assumption/s:

- The % of people located indoors and outdoors for all populations (site and surrounding) during the day and night is as follows:
  - **Day**: 90% indoors.
    10% outdoors.
  - **Night**: 90% indoors.
    10% outdoors.
- All populations are located at ground level

Justification and Impact/s of Assumption/s:

- The proportion of people located indoors and outdoors will affect the societal risk analysis, as the vulnerability to fires, explosion, etc. varies depending on location.
- The default values recommended by the Netherlands Organization for Applied Scientific Research (TNO) in the 'Purple Book' for residential and industrial areas are tabulated.

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

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

- The % of the total population located indoors and outdoors was estimated from similar risk analyses (Including some data provided by NSW DPHI). It is reported in these analyses that the % of people indoors and outdoors is 90% indoors and 10% outdoors during the day, which differs slightly from the TNO data, but is typically justified as being more applicable for Australian environmental conditions. Similarly, it is reported in these analyses that the % of people indoors and outdoors is 95 to 99% indoors and 1 to 5% outdoors during the night.
- The height of the future structures / buildings is not known at this stage. Locating the entire population at ground level is conservative.

MAE/s Affected:

- All (Note: This assumption is only applicable to the calculation of societal risk).

Reference/s:

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

A.3 Consequence Analysis

Assumption No. 9: Representative Materials
Subject: Consequence Analysis
Assumption/s: • 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
MAE/s Affected: • All.
Reference/s: • Data provided by Jemena (25 January 2024).

Assumption No. 10: Pressure for Release Modelling

Subject: Consequence Analysis

Assumption/s:

- A release of Natural Gas from each pipeline is modelled at their respective MAOP (Refer to Section 4.)
- For the CTP and EGP, ten different release rates over the first 5 minutes of the release are used for full bore ruptures. The release rates are selected by Safeti so that the same mass is released in each segment. For smaller holes, the pipelines maintain a constant pressure at the release point. This also implies in a constant release rate at the point of release.
- For the SMP, ten different release rates over the first 5 minutes of release are used for hole sizes 75 mm and above. The release rates are selected by Safeti so that the same mass is released in each segment. For hole sizes less than 75 mm, the pipeline maintains a constant pressure at the release point. This also implies in a constant release rate at the point of release.
- The release rates used for consequence modelling are dependent upon the type of consequence modelled:
  - The release rate for jet fires is the average rate over the first 30 seconds of the release; being equal to the assumed exposure to a jet fire (and hence worst case assuming immediate ignition).
  - Dispersion calculations are based on 10 different observer rates, equivalent to the ten release rates and intervals where applicable as discussed above.

Justification and Impact/s of Assumption/s:

- All operational data for the pipelines were provided by the pipeline owner (Jemena).
- The release rate is dependent on the pressure and the MAOP is the maximum pressure permitted under an existing licence (viz. most conservative pressure)
- The long pipeline model assumes the input pressure is reduced by frictional losses along the pipeline length until the breach point. This results in a lower pressure at the release point that the operating pressure and hence also a lower release rate.
- HIPAP 4 does not comment on time dependent or multiple release rates. The Netherlands Reference Manual Bevi Risk Assessments states: “In exceptional cases, it is possible to deviate from the approach set out above. In particular, this includes situations in which the duration of outflow is greater than 50 s and the outflow rate reduces significantly in the period from 0 to 1800 s. In such a situation it is possible to assume a time-dependent outflow, in which case at least five segments are defined”. The pressure in the pipeline drops rapidly for large hole sizes and the analysis uses 10 release rates, double the minimum allowed for in the Bevi Manual.

MAE/s Affected:

- All.

Reference/s:

- Data provided by Jemena (25 January 2024).

Assumption No. 11: Representative Hole Diameters for Release Modelling

Subject: Consequence Analysis

Assumption/s:

- Consequence modelling is based on representative hole diameters as described in Section 6.1.1.

Justification and Impact/s of Assumption/s:

- The representative hole diameters 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 B.1) than for the other failure modes (i.e. typically less than c. 10 mm). This is also consistent with the predicted hole sizes in this size category reported in Table E5 of AS/NZS 2885.1:2018, which are based on excavator weight and tooth dimensions (i.e. 15 mm for a 5 tonne excavator, 20 mm for 10-15 tonne excavators and 25 mm for 20-25 tonne excavators). Therefore, two representative hole diameters were selected in this category: 25 mm for TPA and 10 mm for all other failure modes.

MAE/s Affected:

- All.

Reference/s:

- Refer to Appendix B.1 and C.1

Assumption No. 12: Location and Direction of Release

Subject: Consequence Analysis

Assumption/s:

- High pressure gas releases would create a crater on the ground as the pipelines are buried underground. The direction of release for underground pipeline failures from the crater is always vertical.
- The location of failure on the pipe for hole sizes greater than 25 mm can be taken as:
  - Top of the pipe; or
  - Middle of the pipe (on the side)
- The release frequencies were distributed between the two locations; 37% for middle of the pipe and 63% for top of the pipe.
- All hole sizes less than or equal to 25mm were modelled as 100% from the middle of the pipe.

Justification and Impact/s of Assumption/s:

- The crater size depends on the location of the hole.
- Top releases are taken as non-obstructed releases and middle/bottom releases are taken as obstructed releases.
- Impingement (viz. obstructions) 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. 19° from horizontal) 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, Review of the Event Tree Structure and Ignition Probabilities used in HSE’s Pipeline Risk Assessment Code MISHAP, Research Report (RR) 1034, 2015.

Assumption No. 13: 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 50% of the lower flammability limit (LFL).
- The concentration is 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 a 10-minute averaging time to another (Hanna et al., 1993):

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

      where time is in seconds. Ct denotes time averaged concentration at the new averaging time of t seconds.
    - Hanna claims that experimentally:

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

      where C_{max} is the maximum peak concentration in the plume.
    - Substituting C_{max} from (2) with C_600 (600/t)^0.2 from (1) and solving for t, it yields,

      t = 18.75 s.
- This time should be adopted to carry out worst case predictions for the extent of 50% 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.

Assumption No. 14: 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 and the time required for each representative release scenario to reach steady state.
Justification and Impact/s of Assumption/s: • Natural Gas is flammable, and any adverse impact will occur quickly (fire or explosion); therefore, the duration of exposure is not as critical as it would be if there were toxic materials in the pipeline (i.e. where the adverse impact can significantly increase for longer exposure durations). • The assumption is justified from the consequence calculations of the Long Pipeline Model, using a 30 second 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. 15: Shielding by Intervening Structures
Subject: Consequence Analysis
Assumption/s: • The presence of intervening structures (e.g. buildings) does not shield other receptors from heat radiation.
Justification and Impact/s of Assumption/s: • It is not possible to take account of the potential protection provided by intervening structures in Safeti.
MAE/s Affected: • All MAEs with a jet fire as a potential outcome.
Reference/s: • Safeti software documentation.

A.4 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.
- The UK HSE pipeline failure rate data is the primary data used for the risk assessment.

Justification and Impact/s of Assumption/s:

- The estimated likelihood of release (or loss of containment) is a critical and significant input for the risk analysis. The risk results are directly proportional to this input.
- Generic failure rate data for cross-country pipelines from the UK, USA and Europe were reviewed. The UK data incorporates the European data. There are two sources of data from the UK: (a) HSE recommended data for land use safety planning (RR 1035); and (b) British Standards Institute PD 8010-3:2009+A1:2013. The HSE data is primarily used in this study, which is consistent with the NSW performance data.
- The HSE data identifies four contributors to pipeline failure: (a) mechanical failure; (b) corrosion; (c) ground movement/other; and (d) Third Party Activity (TPA). Of these, mechanical, corrosion and TPA are similar to conditions in Australia and hence no frequency adjustments due to local conditions are justified.
- The justification for the data used in this risk analysis is provided in Appendix C.1.

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 provided in Appendix C.2.

Justification and Impact/s of Assumption/s:

- The estimated probability of ignition is a critical and significant input for the risk analysis. The risk results are directly proportional to this input.
- The justification for the data used in this risk analysis is provided in Appendix C.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:

- Delayed Ignition of a free gas or vapour cloud would result in only a flash fire.

Justification and Impact/s of Assumption/s:

- Ignition of a free gas cloud may demonstrate characteristics of a flash fire and/or an explosion. This is typically modelled as two separate events: a flash fire or an explosion.
- Since the configuration of the future structures / buildings is not known at this stage, all delayed ignition events were modelled as flash fires and conservative assumptions were adopted in the risk assessment for the flash fire modelling (e.g. flash fire extent based on distance to 50% of the LFL concentration, release pressure based on MAOP rather than lower normal operating pressure, etc.).

MAE/s Affected:

- All MAEs with a VCE or flash fire as potential outcomes.

Reference/s:

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

A.5 Risk Analysis

Assumption No. 19: Event Spacing for Releases from Pipelines
Subject: Risk Analysis
Assumption/s: - Release scenarios (i.e. events) are distributed along the pipeline at set intervals.
Justification and Impact/s of Assumption/s: - The interval at which representative release scenarios are distributed along the pipeline is selected automatically by the Safeti based on the consequences of the event.
MAE/s Affected: - All.
Reference/s: - Safeti software documentation.

A.6 Vulnerability Parameters

Assumption No. 20: Exposure to Heat Radiation (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.
- A jet fire averaging time of 30 seconds has been adopted to align with the maximum exposure duration.
- The probability of fatality for an individual located outdoors (30 seconds exposure), as calculated using the above probit equation, is as follows:

Table 19 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/m2 and above, regardless of the exposure duration.
- For the calculation of societal risk:
  - The probability of fatality for individuals located outdoors is factored by 0.14 (Safeti default) to allow for the protection provided by clothing and the possibility of seeking shelter behind obstacles.
  - The probability of fatality for an individual located indoors is 0 at less than 35 kW/m^2, and 1 at 35 kW/m^2 or greater.

Assumption No. 20: Exposure to Heat Radiation (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 20 Effects of Thermal Radiation

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

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

MAE/s Affected:

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

Reference/s:

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

Assumption No. 21: 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 50% LFL concentration).
- For calculation of societal risk, the probability for fatality for any individual located within the flammable cloud (distance to 50% 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.

Appendix B Consequence Analysis – 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.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 following available historical data.

B.1.1 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 21 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

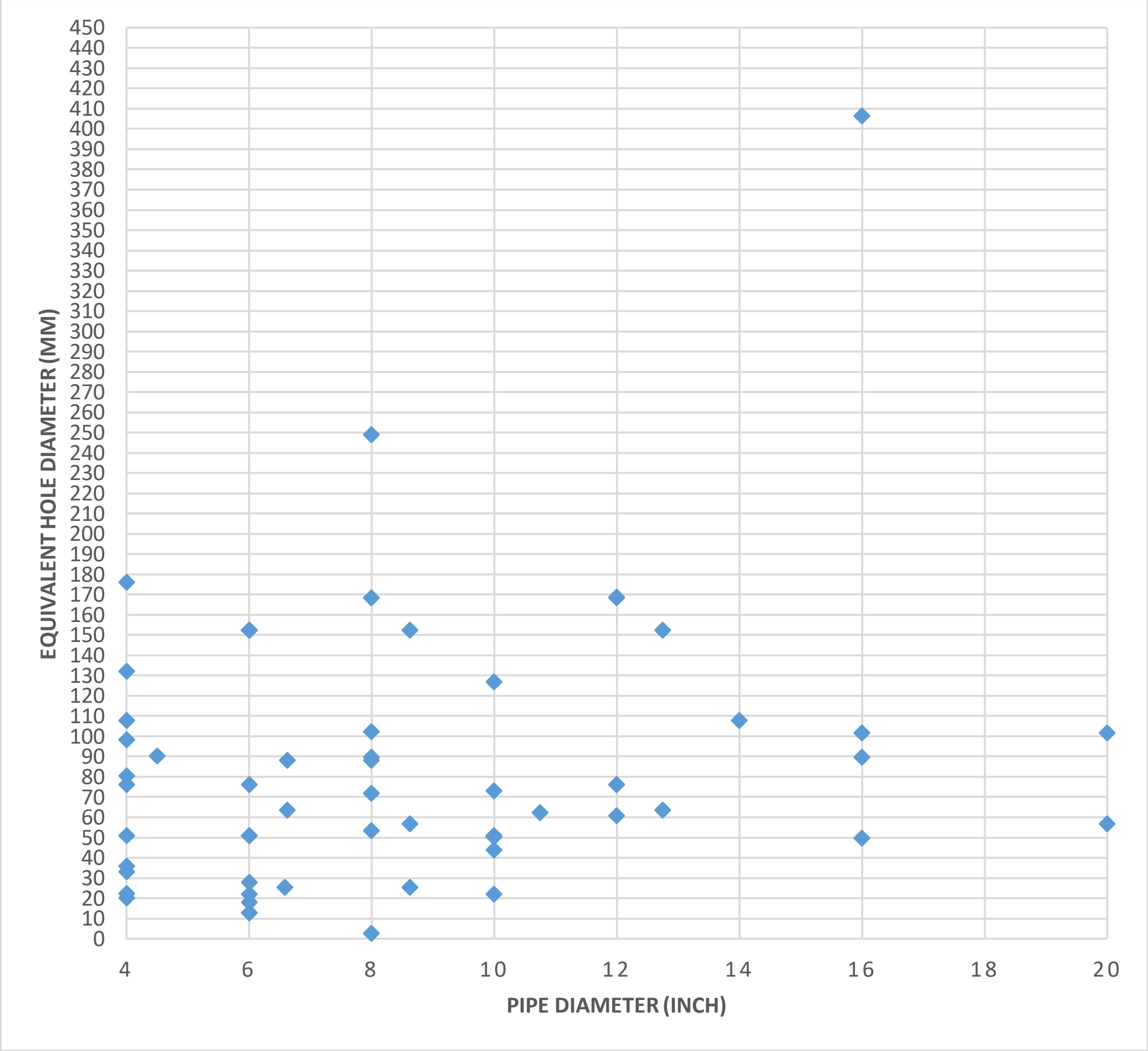
Table 22 Dimensions of Puncture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)

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

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	1.25	1.5	0.7	0.8	67.2	26.0	Excavation Damage
4	129	2	2	1	1.6	50.0	35.9	Excavation Damage
9.5	167	2	1	3	2.4	75.0	44.0	Excavation Damage
25	274	2	3.5	0.7	1.9	61.3	39.8	Incorrect Operation
52	460	2	0.5	0.5	0.2	6.3	12.7	Other Outside Force - Electrical arcing
60	515	2	1	0.5	0.4	12.5	18.0	Excavation Damage
60	515	2	0.5	0.5	0.2	6.3	12.7	Excavation Damage
60	515	2	1.5	0.7	0.8	26.3	26.0	Other Outside Force - Not Specified
35	343	2.375	1	1	0.8	17.7	25.4	Excavation Damage
440	3135	2.375	2.5	0.5	1.0	22.2	28.4	Excavation Damage
60	515	3	3	9.4	22.1	313.3	134.9	Excavation Damage
17	219	4	1.3	1.3	1.3	10.6	33.0	Excavation Damage
30	308	4	6	3	14.1	112.5	107.8	Excavation Damage
35	343	4	2	2	3.1	25.0	50.8	Excavation Damage
35	343	4	3	3	7.1	56.3	76.2	Excavation Damage
57	494	4	5	2	7.9	62.5	80.3	Excavation Damage
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

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)							
870	6100	8	25.1	25.1	494.8	984.4	637.5	Excavation Damage
0.43	104	8.625	6	6	28.3	48.4	152.4	Excavation Damage
60	515	8.625	1	1	0.8	1.3	25.4	Other Outside Force - Not Specified
250	1825	8.625	1	5	3.9	6.7	56.8	Excavation Damage
15	205	10	5	5	19.6	25.0	127.0	Excavation Damage
50	446	10	1.5	0.5	0.6	0.8	22.0	Excavation Damage
60	515	10	0.3	13	3.1	3.9	50.2	Excavation Damage
60	515	10	1	3	2.4	3.0	44.0	Excavation Damage
150	1136	10	7.5	1.1	6.5	8.3	73.0	Excavation Damage
240	1756	10	2	2	3.1	4.0	50.8	Excavation Damage
82	667	10.75	3	2	4.7	5.2	62.2	Excavation Damage
33	329	12	11	4	34.6	30.6	168.5	Excavation Damage
60	515	12	3	3	7.1	6.3	76.2	Excavation Damage
100	791	12	2.3	2.5	4.5	4.0	60.9	Excavation Damage
100	791	12	3	3	7.1	6.3	76.2	Excavation Damage
225	1653	12	7	6.3	34.6	30.6	168.7	Excavation Damage
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

Figure 11 Equivalent Hole Diameter for Leaks from Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)



B.1.2 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.

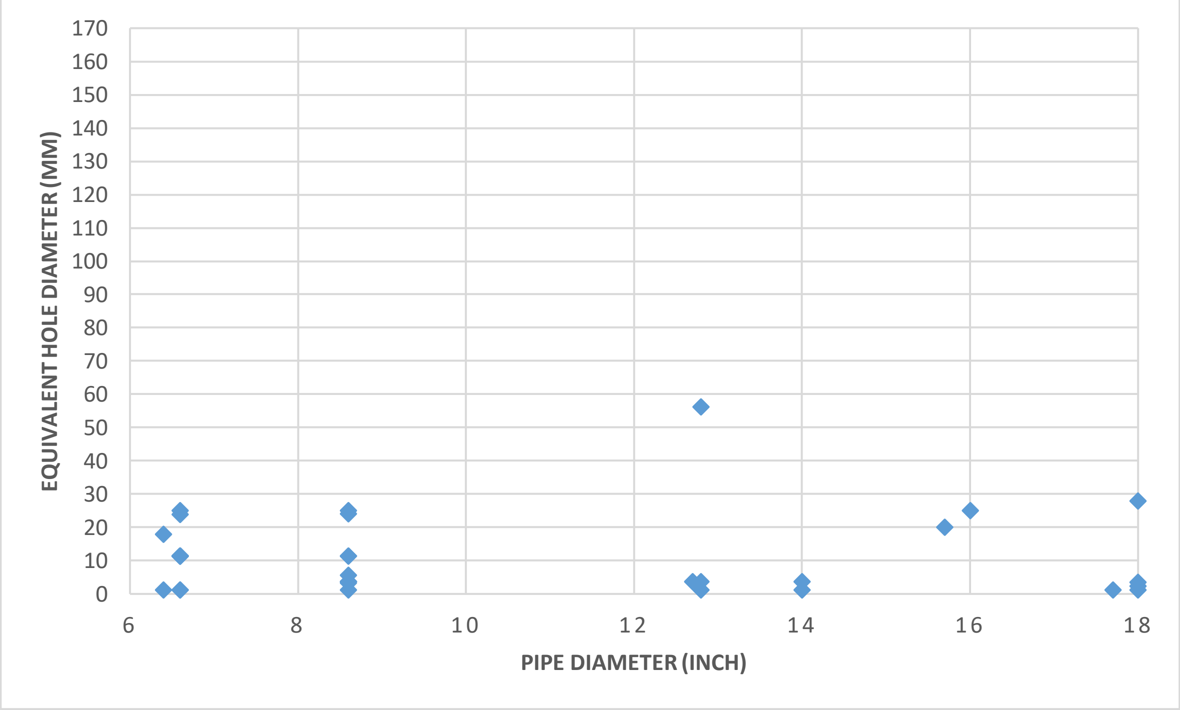
The following table includes the recorded incidents where the hole size was reported (Cited by HSE in RR1035). This data is almost exclusively for Natural Gas (NG) leaks, with only one leak from another material (Propylene).

Table 23 Dimensions of Leaks for Above Ground or Underground Cross-Country Natural Gas or Propylene Pipelines (UKOPA - Reported Values Only)

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

Fault ID	Discovery Date	Product	Wall Thickness (mm)	Diameter (in)	Diameter (mm)	Equivalent Hole Diameter (mm)	Cause
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

Figure 12 Equivalent Hole Diameter for Leaks from Above Ground or Underground Cross-Country Natural Gas or Propylene Pipelines (UKOPA - Reported Values Only)



B.2 Consequence Analysis Results for Representative Release Scenarios

The hazard ranges for the release cases modelled are presented in Table 24 and Table 25.

Table 24 Jet Fire Consequence Analysis Results

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
Central Trunk Pipeline	10 mm (Mid)	0	1.8B	15.6	14	1.97	Not reached at height of interest	Not reached at height of interest
			7.5D	10.9	19.4	13.4	11	9.38
			4.1D	12.4	17	11.3	Not reached at height of interest	Not reached at height of interest
			1.6D	15.9	13.1	1.61	Not reached at height of interest	Not reached at height of interest
			7.3D	10.8	19.3	13.2	10.9	9.18
			3.8D	12.6	16.9	10.8	2.53	Not reached at height of interest
			1D	17.3	8.79	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	14	16.2	6.74	Not reached at height of interest	Not reached at height of interest
			1F	17.3	8.82	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
	25 mm (Mid)	0	1.8B	33.5	34	8.8	Not reached at height of interest	Not reached at height of interest
			7.5D	23.4	43.3	28.4	23.2	18.3
			4.1D	26.7	39.2	25.3	13.2	3.64
			1.6D	34.3	32.4	6.98	Not reached at height of interest	Not reached at height of interest
			7.3D	23.4	43.2	28.3	23	18
			3.8D	27.1	39	24.5	11.1	1.37
			1D	37.4	25.5	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	30.2	37.8	18.5	3.52	Not reached at height of interest
			1F	37.3	25.6	0.08	Not reached at height of interest	Not reached at height of interest
	75 mm (Mid)	0	1.8B	81.4	91.6	31.2	10.3	Not reached at height of interest
			7.5D	56.8	112	72.3	56.6	43
			4.1D	64.7	104	65.3	39.3	19.4

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			1.6D	83.1	88.7	28	3.37	Not reached at height of interest
			7.3D	56.7	111	72.2	56.3	42.6
			3.8D	65.8	104	63.8	36.8	17.3
			1D	90.6	76.9	20.6	Not reached at height of interest	Not reached at height of interest
			2.6E	73.2	100	51	17.9	8.34
			1F	90.6	77	20.7	Not reached at height of interest	Not reached at height of interest
	75 mm (Top)	0	1.8B	68.3	65.7	15	Not reached at height of interest	Not reached at height of interest
			7.5D	47.7	84.8	52.3	32.6	13.5
			4.1D	54.3	80.3	38.8	13.5	Not reached at height of interest
			1.6D	69.7	63.6	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	47.6	84.8	52	32.3	12.5
			3.8D	55.2	79.4	36.6	12.2	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			1D	76	56.4	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	61.4	73.8	25.7	Not reached at height of interest	Not reached at height of interest
			1F	76	56.6	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	110 mm (Mid)	0	1.8B	109	125	44.5	13.1	Not reached at height of interest
			7.5D	75.8	151	98.2	75	55.6
			4.1D	86.4	143	86.7	51.8	26.1
			1.6D	111	121	41.9	Not reached at height of interest	Not reached at height of interest
			7.3D	75.6	151	98	74.6	55
			3.8D	87.8	143	84	47.6	Not reached at height of interest
			1D	121	108	31.1	Not reached at height of interest	Not reached at height of interest
			2.6E	97.6	136	66.7	24.8	9.02

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			1F	121	108	31.3	Not reached at height of interest	Not reached at height of interest
	110 mm (Top)	0	1.8B	91.7	90	22.9	Not reached at height of interest	Not reached at height of interest
			7.5D	64	115	68.7	41	15.6
			4.1D	73	109	51.4	19.1	Not reached at height of interest
			1.6D	93.7	87.3	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	63.9	115	68.5	40.7	15.7
			3.8D	74.2	107	48.7	17.4	Not reached at height of interest
			1D	102	78.8	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	82.5	100	36.3	Not reached at height of interest	Not reached at height of interest
			1F	102	78.9	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	FBR	0	1.8B	508	705	338	173	84.7

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			7.5D	355	714	465	335	242
			4.1D	404	753	448	284	169
			1.6D	519	695	327	164	55.3
			7.3D	354	715	465	334	241
			3.8D	411	753	442	274	158
			1D	566	657	287	117	Not reached at height of interest
			2.6E	457	748	402	218	132
			1F	565	658	287	117	Not reached at height of interest
Eastern Gas Pipeline	10 mm (Mid)	0	1.8B	22.4	21.5	3.97	Not reached at height of interest	Not reached at height of interest
			7.5D	15.6	28.3	18.7	15.6	12.8
			4.1D	17.8	25.2	16.5	7.68	0.564
			1.6D	22.9	20.4	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	15.6	28.2	18.6	15.5	12.5

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			3.8D	18.1	25.1	16	5.93	Not reached at height of interest
			1D	24.9	15	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	20.1	24.2	11.1	1.33	Not reached at height of interest
			1F	24.9	15	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	25 mm (Mid)	0	1.8B	47.6	50.6	15.9	2.78	Not reached at height of interest
			7.5D	33.3	62.8	41	32.9	25.6
			4.1D	37.9	57.6	36.9	20.6	7.29
			1.6D	48.7	48.6	12.3	0.506	Not reached at height of interest
			7.3D	33.2	62.7	40.8	32.7	25.2
			3.8D	38.5	57.3	35.8	18.4	5.96
			1D	53.1	40	8.15	Not reached at height of interest	Not reached at height of interest
			2.6E	42.8	55.9	28.5	9.78	3.11

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			1F	53	40.1	8.2	Not reached at height of interest	Not reached at height of interest
	75 mm (Mid)	0	1.8B	109	122	42.9	Not reached at height of interest	Not reached at height of interest
			7.5D	75.9	149	97	72.3	51.8
			4.1D	86.5	142	81.4	43.8	17.6
			1.6D	111	119	40	Not reached at height of interest	Not reached at height of interest
			7.3D	75.7	149	96.8	71.8	51.3
			3.8D	87.9	141	78.7	39.2	16.6
			1D	121	106	27.1	Not reached at height of interest	Not reached at height of interest
			2.6E	97.7	134	60.3	23	Not reached at height of interest
			1F	121	106	27.3	Not reached at height of interest	Not reached at height of interest
	75 mm (Top)	0	1.8B	95.4	94.3	25.1	Not reached at height of interest	Not reached at height of interest
			7.5D	66.6	120	71.9	43.1	16.7

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			4.1D	75.9	113	54.1	19.9	Not reached at height of interest
			1.6D	97.4	91.5	17.8	Not reached at height of interest	Not reached at height of interest
			7.3D	66.4	120	71.7	42.9	16.7
			3.8D	77.1	112	51.4	18.8	Not reached at height of interest
			1D	106	82.7	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	85.7	105	38.5	Not reached at height of interest	Not reached at height of interest
			1F	106	82.9	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	110 mm (Mid)	0	1.8B	145	166	61.1	Not reached at height of interest	Not reached at height of interest
			7.5D	101	198	128	91.2	62.5
			4.1D	115	191	106	52.9	25.2
			1.6D	148	162	57.2	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			7.3D	101	198	128	90.5	61.7
			3.8D	117	190	103	47.4	22.8
			1D	161	148	40.4	Not reached at height of interest	Not reached at height of interest
			2.6E	130	180	80.1	32.5	Not reached at height of interest
			1F	161	148	40.7	Not reached at height of interest	Not reached at height of interest
	110 mm (Top)	0	1.8B	132	137	41.2	Not reached at height of interest	Not reached at height of interest
			7.5D	92.2	171	102	62.4	26.9
			4.1D	105	162	79.3	33.7	Not reached at height of interest
			1.6D	135	133	38.3	Not reached at height of interest	Not reached at height of interest
			7.3D	91.9	171	102	62	27
			3.8D	107	160	75.9	31.3	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			1D	147	122	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	119	151	59.4	Not reached at height of interest	Not reached at height of interest
			1F	147	122	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	FBR	0	1.8B	380	518	241	121	59.1
			7.5D	265	543	358	265	195
			4.1D	302	571	349	230	147
			1.6D	388	509	232	114	33.2
			7.3D	265	544	358	264	194
			3.8D	307	569	343	220	135
			1D	423	477	201	78.4	Not reached at height of interest
			2.6E	342	551	299	155	91.6
			1F	423	478	202	79	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
Secondary Main Pipeline	10 mm (Mid)	0	1.8B	7.02	5.59	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	4.9	8.53	6.43	5.2	4.86
			4.1D	5.58	7.49	5.12	Not reached at height of interest	Not reached at height of interest
			1.6D	7.17	5.05	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	4.89	8.5	6.37	5.11	4.8
			3.8D	5.67	7.25	4.88	Not reached at height of interest	Not reached at height of interest
			1D	7.81	2.21	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	6.31	6.86	1.75	Not reached at height of interest	Not reached at height of interest
			1F	7.81	2.22	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	25 mm (Mid)	0	1.8B	15.2	13.6	1.89	Not reached at height of interest	Not reached at height of interest
			7.5D	10.6	18.9	13.1	10.7	9.21

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			4.1D	12.1	16.6	11	3.89	Not reached at height of interest
			1.6D	15.5	12.8	1.49	Not reached at height of interest	Not reached at height of interest
			7.3D	10.6	18.9	12.9	10.7	9.01
			3.8D	12.3	16.5	10.6	1.5	Not reached at height of interest
			1D	16.9	8.49	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	13.7	15.8	6.53	Not reached at height of interest	Not reached at height of interest
			1F	16.9	8.52	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	75 mm (Mid)	0	1.8B	37.9	36.9	8.76	Not reached at height of interest	Not reached at height of interest
			7.5D	26.5	49.5	32.1	25.5	18.9
			4.1D	30.2	44.8	27.4	13.9	2.91
			1.6D	38.7	35.4	7.68	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			7.3D	26.4	49.4	32	25.2	18.5
			3.8D	30.7	44.6	26.1	11.9	2.8
			1D	42.2	28.5	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	34.1	41.9	17.4	3.9	Not reached at height of interest
			1F	42.2	28.6	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	75 mm (Top)	0	1.8B	31.5	26.1	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	22	36.5	22.4	12.8	Not reached at height of interest
			4.1D	25.1	34.1	14.5	Not reached at height of interest	Not reached at height of interest
			1.6D	32.2	24.8	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	22	36.5	22.2	12.6	2.33
			3.8D	25.5	33.7	13.1	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Flame Length (m)	Distance Downwind to Intensity Level 1 (4.7 kW/m2) (m)	Distance Downwind to Intensity Level 2 (12.6 kW/m2) (m)	Distance Downwind to Intensity Level 3 (23 kW/m2) (m)	Distance Downwind to Intensity Level 4 (35 kW/m2) (m)
			1D	35.1	20.9	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	28.3	30.5	7.62	Not reached at height of interest	Not reached at height of interest
			1F	35.1	21	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	FBR	0	1.8B	51.1	56.4	21.8	6.14	1.01
			7.5D	35.7	67.3	44	35.6	28
			4.1D	40.7	61.8	40.2	24	11.3
			1.6D	52.2	54.6	18.5	5.67	Not reached at height of interest
			7.3D	35.6	67.2	43.9	35.3	27.6
			3.8D	41.4	61.6	39.3	21.9	9.86
			1D	57	45.3	10.9	Not reached at height of interest	Not reached at height of interest
			2.6E	46	60.4	31.7	11.4	3.23
			1F	56.9	45.4	10.9	Not reached at height of interest	Not reached at height of interest

Table 25 Flash Fire Consequence Results

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
Central Trunk Pipeline	10 mm (Mid)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
	25 mm (Mid)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	75 mm (Mid)	0	1.8B	1.37	1.2	0.858	1.97

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			7.5D	1.35	1.19	Not reached at height of interest	1.65
			4.1D	1.35	1.19	0.847	2.1
			1.6D	1.35	1.19	0.846	2.13
			7.3D	1.35	1.19	0.844	1.93
			3.8D	1.35	1.19	Not reached at height of interest	1.58
			1D	1.34	1.18	Not reached at height of interest	1.64
			2.6E	1.35	1.17	Not reached at height of interest	1.21
			1F	1.44	1.15	Not reached at height of interest	1.73
	75 mm (Top)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	110 mm (Mid)	0	1.8B	1.63	1.42	1.07	2.48
			7.5D	1.6	1.4	Not reached at height of interest	1.57
			4.1D	1.6	1.4	1.06	2.37
			1.6D	1.59	1.39	1.05	2.46
			7.3D	1.59	1.39	Not reached at height of interest	1.82

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			3.8D	1.59	1.39	1.05	2.77
			1D	1.59	1.39	1.05	2.78
			2.6E	1.56	1.38	1	2.53
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	110 mm (Top)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	FBR	0	1.8B	15.3	13.3	9.71	24.9
			7.5D	13.9	12.2	9.22	19.7
			4.1D	13.9	12.2	9.22	21
			1.6D	13.9	12.2	Not reached at height of interest	18.8
			7.3D	13.8	12.2	9.2	21
			3.8D	13.8	12.2	9.2	24.8
			1D	13.9	12.2	9.21	20.4
			2.6E	14.1	12.3	9.09	24.3
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
Eastern Gas Pipeline	10 mm (Mid)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	25 mm (Mid)	0	1.8B	0.706	Not reached at height of interest	Not reached at height of interest	0.501
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	0.689	0.609	Not reached at height of interest	0.761
			1D	0.687	Not reached at height of interest	Not reached at height of interest	0.535
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	75 mm (Mid)	0	1.8B	1.22	1.08	Not reached at height of interest	1.29
			7.5D	1.22	1.08	Not reached at height of interest	1.55
			4.1D	1.22	1.08	Not reached at height of interest	1.08
			1.6D	1.22	1.08	0.773	1.61
			7.3D	1.22	1.07	0.771	1.69

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			3.8D	1.22	1.07	0.772	1.77
			1D	1.21	1.07	0.769	1.78
			2.6E	1.21	1.04	Not reached at height of interest	1.18
			1F	1.26	0.909	Not reached at height of interest	1.21
	75 mm (Top)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	110 mm (Mid)	0	1.8B	1.43	1.27	0.945	1.96
			7.5D	1.41	1.26	Not reached at height of interest	1.74
			4.1D	1.41	1.26	Not reached at height of interest	1.26
			1.6D	1.41	1.26	0.929	1.86
			7.3D	1.41	1.25	0.928	1.87
			3.8D	1.41	1.25	0.929	2.05
			1D	1.4	1.25	0.927	2.09
			2.6E	1.41	Not reached at height of interest	Not reached at height of interest	1.1
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	110 mm (Top)	0	1.8B	0.725	Not reached at height of interest	Not reached at height of interest	0.461

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	0.713	0.644	Not reached at height of interest	0.7
			1.6D	0.715	Not reached at height of interest	Not reached at height of interest	0.612
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	0.667	Not reached at height of interest	Not reached at height of interest	0.488
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	FBR	0	1.8B	12.2	10.6	7.72	19.7
			7.5D	11.1	9.78	7.37	15.1
			4.1D	11.1	9.77	7.36	19.7

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			1.6D	11.1	9.76	7.35	19.5
			7.3D	11.1	9.75	7.34	16.1
			3.8D	11.1	9.75	7.35	18.6
			1D	11.1	9.73	7.33	20.2
			2.6E	11.1	9.69	7.21	18.8
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
Secondary Main Pipeline	10 mm (Mid)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	25 mm (Mid)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	75 mm (Mid)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
	75 mm (Top)	0	1.8B	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.5D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			4.1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1.6D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			7.3D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			3.8D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1D	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			2.6E	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest
			1F	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest	Not reached at height of interest

Pipeline	Scenario	Height of Interest (m)	Weather Category	Distance to ½ LFL (m)	Distance to LFL (m)	Distance to UFL (m)	Maximum Width (at Height of Interest) to LFL fraction (m)
	FBR	0	1.8B	2.8	2.42	1.72	4.88
			7.5D	6.68	3.64	1.36	4.68
			4.1D	3.92	2.31	1.68	4.27
			1.6D	2.7	2.33	1.68	5.06
			7.3D	6.45	3.5	1.41	4.76
			3.8D	3.64	2.33	1.68	4.68
			1D	2.68	2.32	1.67	5.01
			2.6E	2.63	2.27	1.63	5.1
			1F	2.74	2.32	1.63	4.42

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, *2021-22 Licensed Pipelines Performance Report*. This includes data for all licensed pipelines in NSW for the 5-year period: 2017/18 to 2021/22; 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 - Reported Data for Underground Natural Gas Steel Pipelines (January 2010 to September 2017).

The leak frequency data reported in RR1035 (Refer to Section C.1.2) was adopted for the QRA as it is most 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 (Refer to Section C.1.3) was not used since the leak rates (other than ruptures) are not clearly defined for all failure modes. Furthermore, the rupture frequency due to ‘TPA’ estimated for the pipelines using the approach in Annex B of PD 8010-3:2009+A1:2013 is clearly not consistent with NSW performance data.

The leak frequency data derived from the US DoT data (Refer to Section C.1.4) was not used since the total leak frequency is lower than reported in RR1035 and the NSW performance data.

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 NSW Performance Report

The average leak frequency from the 2022 NSW Performance Report for all licensed pipelines in NSW for the 5-year period 2017/18 to 2021/22 is 1.24E-04 per km per year.

C.1.2 UK HSE (RR1035)

The total leak frequency data reported in Section 7.1 of RR1035 for underground natural gas pipelines is comparable to the average leak frequency from the 2022 NSW Performance Report (e.g. 5.06E-05 per km per year for a pipeline with a diameter ≥ 305 mm and wall thickness ≥ 10 mm.)

Table 26 Leak Frequencies for Underground Natural 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 =	127 to < 273	5 to < 10	4.94E-04	4.92E-06	2.70E-07	2.62E-06	**5.02E-04**
	≥ 305	≥ 10	4.28E-05	4.92E-06	2.70E-07	2.62E-06	**5.06E-05**
% =	127 to < 273	5 to < 10	84.6	9.7	0.5	5.2	
	≥ 305	≥ 10	98.4	1.0	0.1	0.5	

C.1.3 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 pipelines (Refer to Table 27). The data applicable for a pipeline with a wall thickness of 8.5 mm.

Leak frequency data is not reported for internal corrosion.

For leaks (other than ruptures) due to 'Ground Movement / Other' or 'TPA', 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).

The rupture frequency due to 'TPA' was derived from the generic pipeline failure frequency, which was modified in accordance with the relevant parameters for each pipeline (i.e. location, design factor, wall thickness and depth of cover).

Table 27 Approx. Leak Frequencies for Underground Natural Gas Pipeline

Failure Mode	Approx. Leak Frequency (per km per yr)					Comments (Refer to Annex B of PD 8010-3:2009+A1:2013)
	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	4.0E-05	1.6E-05	0.0E+00	0.0E+00	5.6E-05	
Corrosion	3.2E-05	1.1E-05	3.0E-06	0.0E+00	4.6E-05	No data reported for internal corrosion.
Ground Movement / Other	2.0E-06	2.0E-06	2.0E-06	6.0E-07	6.6E-06	Based on average incident rate (0.02 per 1000 km.yr) and survival values of 0.03 (Rupture) and 0.3 (Leaks).
TPA	1.7E-05	1.7E-05	1.7E-05	8.8E-05	1.4E-04	Proportion of ruptures = 0.63.
Total Leak Freq. =	9.1E-05	4.6E-05	2.2E-05	8.8E-05	**2.48E-04**	
% =	36.8	18.6	8.9	35.6		

C.1.4 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 28.

Period of Recorded Incident Data = 7.75 yrs (Jan 2010 to Sept 2018)
Total Length of Natural Gas Pipelines = 479980 km Note: Average for 2010 to 2017

Table 28 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	**3.66E-05**
% =	52.2	23.5	12.5	11.8	

C.2 Ignition Probability

A review of relevant ignition probability data and ignition probability correlations was conducted (Refer to Sections C.2.1 - C.2.2). For this QRA:

- The total ignition probability was based on IOGP Scenario 3, which is release rate dependent.
- The total ignition probability was split 50:50 for immediate ignition and delayed ignition.

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 29 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

Hole Size Class #	Total Number of Incidents	Number of Incidents with Ignition	Total Ignition Probability	Total Ignition Probability
0 – 6mm	118	4	0.03	
Unknown	2	0	0.0	0.0
Total =	192	9	0.047	0.047

IOGP, 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 (Refer to Table 30).

The IOGP 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 30 Ignition Probability – IOGP Scenario 3

Release Rate (kg/s)	Total Ignition Probability
0.1	0.0011
0.2	0.0018
0.5	0.0036
1	0.0060
2	0.0101
5	0.0199
10	0.0332
20	0.0554
50	0.1091
100	0.1821
200	0.3041
500	0.5989
1000	1.0000

C.2.2 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:

Pign = 0.0555 + 0.0137 pd^2; 0 ≤ pd^2 ≤ 57

Pign = 0.81; pd^2 > 57

Pign = probability of ignition

p = pipeline operating pressure (bar)

d = pipeline diameter for ruptures (m)

The probability of ignition Pign, 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 31 Ignition Probability – Acton & Baldwin

Pipeline	Pipeline Diameter (mm)	Operating Pressure (bar)	Equivalent Hole Diameter (mm)	pd^2	Probability of Immediate Ignition	Probability of Delayed Ignition	Total Ignition Probability
CTP	831.4	68.95	10	0.01	0.028	0.028	0.056
			25	0.04	0.028	0.028	0.056
			75	0.39	0.029	0.029	0.058
			110	0.83	0.031	0.031	0.061
			FBR	47.66	0.15	0.15	0.708

Pipeline	Pipeline Diameter (mm)	Operating Pressure (bar)	Equivalent Hole Diameter (mm)	pd^2	Probability of Immediate Ignition	Probability of Delayed Ignition	Total Ignition Probability
EGP	428.8	148.95	10	0.01	0.028	0.028	0.056
			25	0.04	0.028	0.028	0.056
			75	0.39	0.029	0.029	0.058
			110	0.83	0.031	0.031	0.061
			FBR	12.68	0.15	0.15	0.229
SMP	158.7	10.5	10	0.01	0.028	0.028	0.056
			25	0.04	0.028	0.028	0.056
			75	0.39	0.029	0.029	0.058
			110	0.83	0.031	0.031	0.061
			FBR	1.74	0.15	0.15	0.079

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 32 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 33 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 34 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