Beverly Hills Master Plan

Ethane Pipeline Preliminary Hazard Analysis

For Georges River Council

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Summary

This report is a Preliminary Hazard Analysis (PHA) to determine if proposed zoning changes associated with the Beverly Hills Masterplan can be accommodated while satisfying the NSW Department of Planning, Industry and Environment's risk criteria as described in HIPAP 10.

Arriscar Pty Limited (Arriscar) has been requested by Georges River Council (GRC) to prepare a PHA for the Beverly Hills Masterplan (the Plan). The Plan is located within the Notification Zone of the Moomba to Sydney Ethane (MSE) Pipeline that runs through the northern portion of the Georges River Local Government Area.

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

Based on generic failure rates for natural gas and liquefied flammable gas pipelines in the literature, the most appropriate data was used for the risk assessment. The 'long pipeline model' in DNVGL's SAFETI 8.4 software was used. The resulting risk values were compared with the risk criteria in HIPAP No.10 [1].

The following results were obtained from the risk assessment:

- Location Specific Individual Risk of fatality exceeds 1.0 x 10^{-6} p.a. in some areas planned for residential intensification, but does not exceed 1.0 x 10^{-5} p.a. NSW Department of Planning, Industry & Environment (DPI&E) criteria for development in the vicinity of potentially hazardous facilities allows for residential intensification in such areas, but only if it can be demonstrated mitigating measures are put in place to reduce the risk to less than 1.0 x 10^{-6} p.a.
- The individual risk of fatality within some properties exceeds the DPI&E criterion for sensitive use development (0.5 x 10-6 p.a.). There should be no intensification of sensitive use development in these properties.
- No events with the potential to cause acute toxic injury or irritation were identified for inclusion in the risk analysis (Also refer to Section 4.4.6); therefore the proposed rezoning complies with the relevant DPI&E risk criteria (Refer to Section 3.4.2).
- The cumulative risk of property damage and accident propagation (Overpressure exceeding 14 kPa) does not reach 50 x 10^{-6} per annum. DPI&E criteria relating to accident damage due to overpressure will not impact proposals in the Study Area masterplan.
- The cumulative risk of property damage and accident propagation (Heat radiation exceeding 23 kW/m^2) does not reach 50 x 10^{-6} per annum. DPI&E criteria relating to accident damage due to overpressure will not impact proposals in the Study Area masterplan.
- The cumulative risk of injury (Overpressure exceeding 7 kPa) does not reach 50 x 10^{-6} per annum; therefore the proposed rezoning complies with the relevant DPI&E risk criteria (Refer to Section 3.4.2).
- The cumulative risk of injury (Heat radiation exceeding 4.7 kW/m^2) does not reach 50 x 10^{-6} per annum; therefore the proposed rezoning complies with the relevant DPI&E risk criteria (Refer to Section 3.4.2).

- The individual risk of fatality never exceeds 5.0 x 10-6 p.a. and therefore intensification of other land uses (business use) as proposed within the Study Area is consistent with DPI&E criteria
- The societal risk, represented as an F-N curve, is within the ALARP region and below the upper limit of the risk tolerability band. This level of societal risk does not preclude the changes envisaged in the masterplan, provided that options to relocate people from affected areas are explored and implemented where practicable. If there is still a need to locate people in affected areas, the benefits must be demonstrated to clearly outweigh the risks.

Conclusions and Recommendations

Rezoning of the Study Area as described is compatible with the NSW DPIE risk criteria providing the following recommendations are incorporated into the rezoning:

Recommendation 1: Ensure sensitive use developments such as aged care facilities, childcare centres or schools are not approved for properties listed in Table 14.

Recommendation 2: Review if it is feasible for the masterplan to change so that residential intensification is minimised where fatality risk levels are greater than 1 x 10-6 p.a.

Recommendation 3: Properties listed in Table 13 be either excluded from any rezoning that would enable residential intensification. Alternatively specific requirements be placed for developments involving those properties to demonstrate that the design of the development effectively reduces the individual fatality risk to less than 1 per million per year.

Recommendation 4: As the future societal risk lies within the ALARP region, GRC should consider, if possible, using Development Control Plans to encourage developers and designers to consider the implications of development in the proximity of the MSE and incorporate features in the design, construction, and operation of buildings to reduce societal risk to ALARP.

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Notation

Abbreviation	Description
APD	Australian Pipeline Database
APGA	Australian Pipeline and Gas Association
Arriscar	Arriscar Pty Limited
BoM	Bureau of Meteorology
CIA	Chemical Industries Association
Council	Georges River Council
DBYD	Dial Before You Dig
DoT	United States Department of Transport
DPI&E	Department of Planning Industry and Environment
FBR	Full Bore Rupture
HAZID	Hazard Identification
HDD	Horizontal Directional Drilling
km	Kilometre
kPa	Kilo Pascals
kW/m^2	kiloWatts per square metre
LEP	Local Environmental Plan
LFL	Lower Flammable Limit
LGA	Local Government Area
LSIR	Location Specific Individual Risk
m	Metre
m/s	Metres per second
MAE	Major Accident Event
MAOP	Maximum Allowable Operating Pressure
mg/m^3	Milligrams per cubic metre
mm	millimetres
MPa	Mega Pascals
MSE	Moomba-Sydney Ethane pipeline
NSW	New South Wales
OGP	Oil and Gas Producers Association
p.a.	Per annum
QRA	Quantitative Risk Assessment

Abbreviation	Description
The Study Area	Area considered under the Beverly Hills Town Centre Master Plan
TPA	Third Party Activity
UK HSE	United Kingdom health and Safety Executive
VCE	Vapour Cloud Explosion

1 INTRODUCTION

Beverly Hills is a suburb at the northern tip of the Georges River Council (Council) Local Government Area (LGA). The Beverly Hills Town Centre is under development pressure, traffic impacts from the implementation of clearways, and is characterised by fragmented urban fabric, poor public domain and lack of activation especially during daylight hours [2]. Council has initiated a study to explore options to revitalise the town centre.

Arriscar Pty Limited (Arriscar) has been requested by Council to prepare a Preliminary Hazard Analysis (PHA) for the Beverly Hills Masterplan Study Area (the Study Area) with respect to risks associated with the Moomba-Sydney Ethane Pipeline (MSE) that intersects the Study Area. The Study Area is located within the Notification Zone of the MSE.

2 SITE DESCRIPTION

2.1 Beverly Hills Town Centre Master Plan Study Area

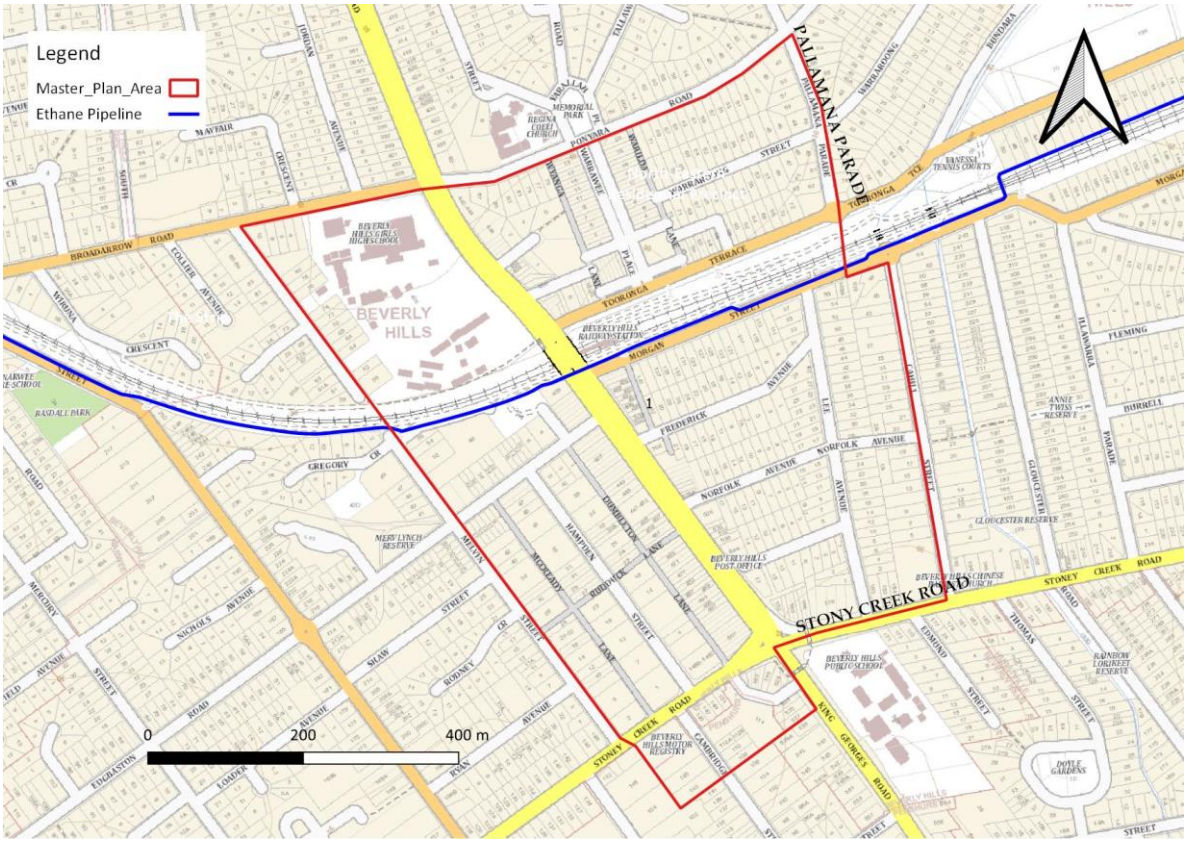
2.1.1 Overview

The Study Area (Figure 1) is bounded by:

- Broadarrow and Ponyara Roads to the north;
- Pallamana Parade, Morgan Street, and Cahill Street to the east;
- Melvin Street to the west; and
- Stoney Creek Road to the south, but with some key sites south of Stoney Creek Road and west of King Georges Road included.

Two major transport routes intersect the Study Area – the East Hills railway line in an east-west direction, and King Georges Road in a north-south direction. The MSE also transverses the Study Area in along an east-west axis.

Figure 1 The Study Area (map courtesy NSW Government)



The Study Area is characterised by five precincts (Figure 2):

1. The North-Western Educational Precinct. This precinct consists of the Beverly Hills Girls High School and the adjoining co-educational Beverly Hills Intensive English Centre. Melvin Street

forms the western boundary of the Study Area at this point and consists of single family housing.

2. The South-Western Residential Precinct. The South-Western Residential Precinct comprises mainly three storey residential flat buildings (RFB) interspersed with some as yet undeveloped earlier housing. There are two main streets and rear lanes, one of which services properties fronting King Georges Road.
3. The North-Eastern Residential Precinct. Consists of mostly red-brick bungalows with some "village shop" character commercial use along Tooronga Terrace just north of the railway line.
4. The Eastern Residential Precinct. The Eastern Residential Precinct is mainly single family housing with some spread of commercial uses into side streets from King Georges Rd. Relatively quiet streets with clusters of post war red brick bungalows interspersed with more recent family housing.
5. The Strip. Focused on King Georges Road, the Strip comprises a near continuous row of one and two storey restaurants, retail shops, some commercial spaces and limited shop-top housing. The west side is more dominant with the Cinema and Hotel uses.

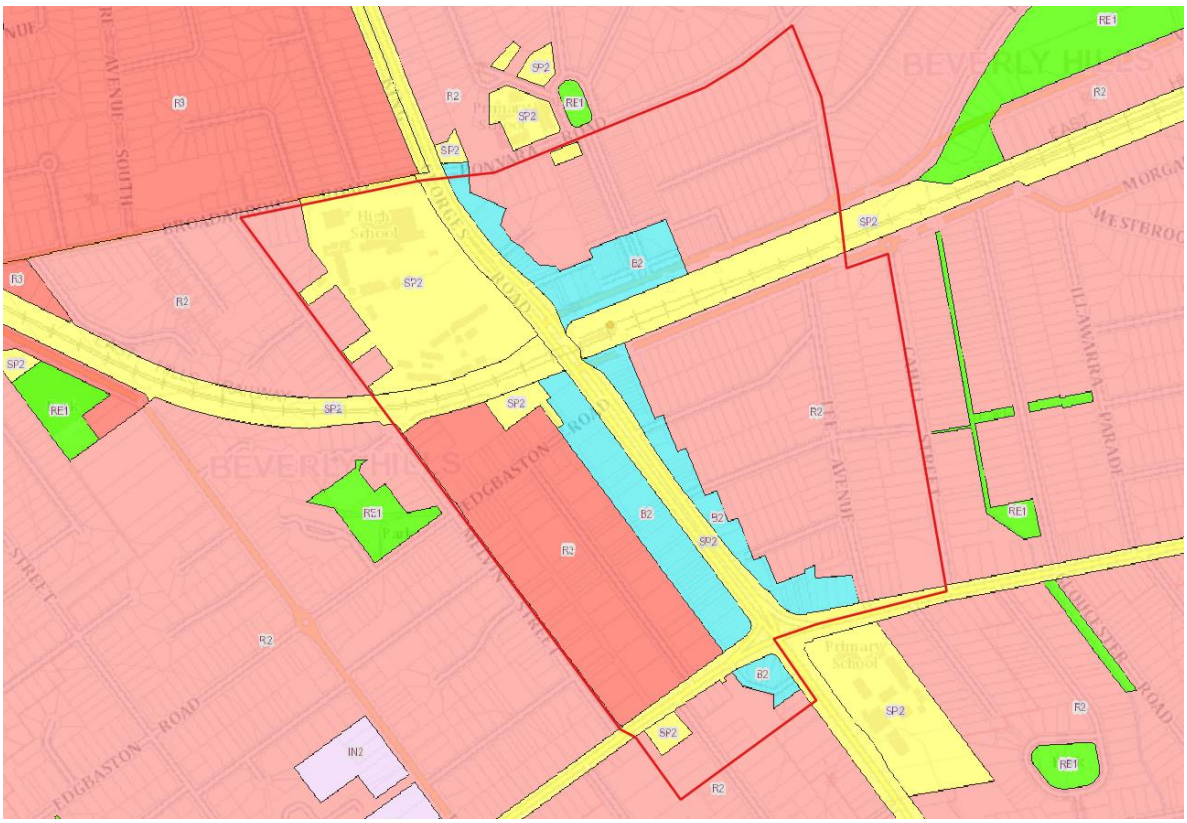
Figure 2 Study Area Precincts (Aerial Imagery Courtesy Google Earth)

2.1.2 Current Land Use

The current land zoning for the Study Area is shown in Figure 3, and shows the following:

- Land zoning in the North-Western Educational Precinct is majority special purpose infrastructure (SP2) with some low density residential (R2).
- Eastern Residential Precinct consists a majority low density residential (R2) with some Town Centre (B2) areas on the west of King George Road and the north of Tooronga Terrace.
- The South-Western Residential Precinct is almost exclusively medium density residential (R3) with the Town Centre (B2) zoning of The Strip to the East.
- The Eastern Residential Precinct is almost exclusively low density residential (R2) with the Town Centre (B2) zoning of the Strip to the West.

Figure 3 Current Land Zoning of the Study Area



2.1.3 Meteorology

The weather conditions such windspeed, wind direction, stability class, temperature, solar radiation, and humidity are important in determining the extent of hazardous consequences. Weather conditions have been derived from observations taken at the Bankstown Airport. Table 1 and Table 2 show the distribution of weather categories used in the study. Day-time weather is the period from one hour after sunrise to one hour before sunset and accounts for approximately 42% of the time, while night-time is the balance.

Table 1 Day-time Weather Categories and Distribution

Weather Category	1.9B	7.5D	4.1D	1.5D	Total
Stab. Class	B	D	D	D	
Wind Speed (m/s)	1.9	7.5	4.1	1.5	
N	0.0247	0.0055	0.0258	0.0076	0.0635
NNE	0.0120	0.0009	0.0108	0.0029	0.0265
NE	0.0113	0.0079	0.0201	0.0022	0.0416
ENE	0.0106	0.0198	0.0315	0.0021	0.0640
E	0.0141	0.0181	0.0382	0.0029	0.0733
ESE	0.0094	0.0289	0.0313	0.0024	0.0720
SE	0.0078	0.0381	0.0276	0.0028	0.0763
SSE	0.0062	0.0356	0.0223	0.0025	0.0667
S	0.0103	0.0274	0.0296	0.0059	0.0732
SSW	0.0081	0.0048	0.0140	0.0057	0.0327
SW	0.0106	0.0071	0.0274	0.0082	0.0533
WSW	0.0129	0.0153	0.0280	0.0089	0.0651
W	0.0228	0.0224	0.0325	0.0144	0.0921
WNW	0.0216	0.0147	0.0253	0.0148	0.0764
NW	0.0204	0.0064	0.0271	0.0137	0.0676
NNW	0.0197	0.0057	0.0220	0.0083	0.0557
Total	0.2223	0.2587	0.4137	0.1053	1.0000

Table 2 Night-time Weather Categories and Distribution

Stab. Class	D	D	D	E	F	Total
Wind Speed (m/s)	7.3	4	1	2.6	1	
N	0.0012	0.0161	0.0083	0.0052	0.0429	0.0736
NNE	0.0003	0.0081	0.0027	0.0031	0.0178	0.0320
NE	0.0013	0.0218	0.0024	0.0049	0.0227	0.0530
ENE	0.0005	0.0151	0.0021	0.0033	0.0221	0.0432
E	0.0008	0.0162	0.0024	0.0044	0.0245	0.0483
ESE	0.0026	0.0181	0.0020	0.0035	0.0178	0.0440
SE	0.0065	0.0208	0.0021	0.0033	0.0148	0.0475
SSE	0.0097	0.0203	0.0022	0.0026	0.0150	0.0498
S	0.0071	0.0272	0.0062	0.0056	0.0354	0.0814
SSW	0.0021	0.0137	0.0056	0.0046	0.0294	0.0555
SW	0.0021	0.0210	0.0073	0.0070	0.0393	0.0766
WSW	0.0038	0.0203	0.0072	0.0071	0.0422	0.0806
W	0.0061	0.0214	0.0086	0.0064	0.0559	0.0984
WNW	0.0032	0.0124	0.0063	0.0045	0.0366	0.0630
NW	0.0019	0.0132	0.0075	0.0050	0.0427	0.0703

Stab. Class	D	D	D	E	F	Total
Wind Speed (m/s)	7.3	4	1	2.6	1	
NNW	0.0014	0.0175	0.0091	0.0060	0.0487	0.0828
Total	0.0505	0.2833	0.0820	0.0765	0.5078	1.0000

2.1.4 Future Development

The Beverly Hills Town Centre Master Plan [3] proposes to achieve the desired revitalisation of the Study Area through changes to the Local Environmental Plan (LEP) and Development Control Plan (DCP) Provisions with respect to land use zoning, Height of Building (HOB), and Floor Space Ratio (FSR).

Through land acquisition, it is proposed to develop a shared use “New East Street” running south from Morgan Street to Beresford Avenue

Proposed changes include:

- Extend the Town Centre zoning east from King George Road into the existing Eastern Residential Precinct, to the “New East Street”.
- Changing the residential zoning of the Eastern Residential Precinct between the “New East Street” and Lee Avenue, change from Low Density Residential (R2) to High Density Residential (R4).
- Providing “pocket parks”, zoned RE1 for public recreation
- Changing the residential zoning of the South-Western Residential Precinct between Edgbaston Road and the railway line from Medium Density Residential R3 to High Density Residential R4.
- Change the zoning of a current car park west of King George Road and immediately south of the railway line from SP2 to Town Centre B2.

These changes are presented graphically in Figure 4, Figure 5, Figure 6, and Figure 7

Figure 4 Overview of Proposed Changes

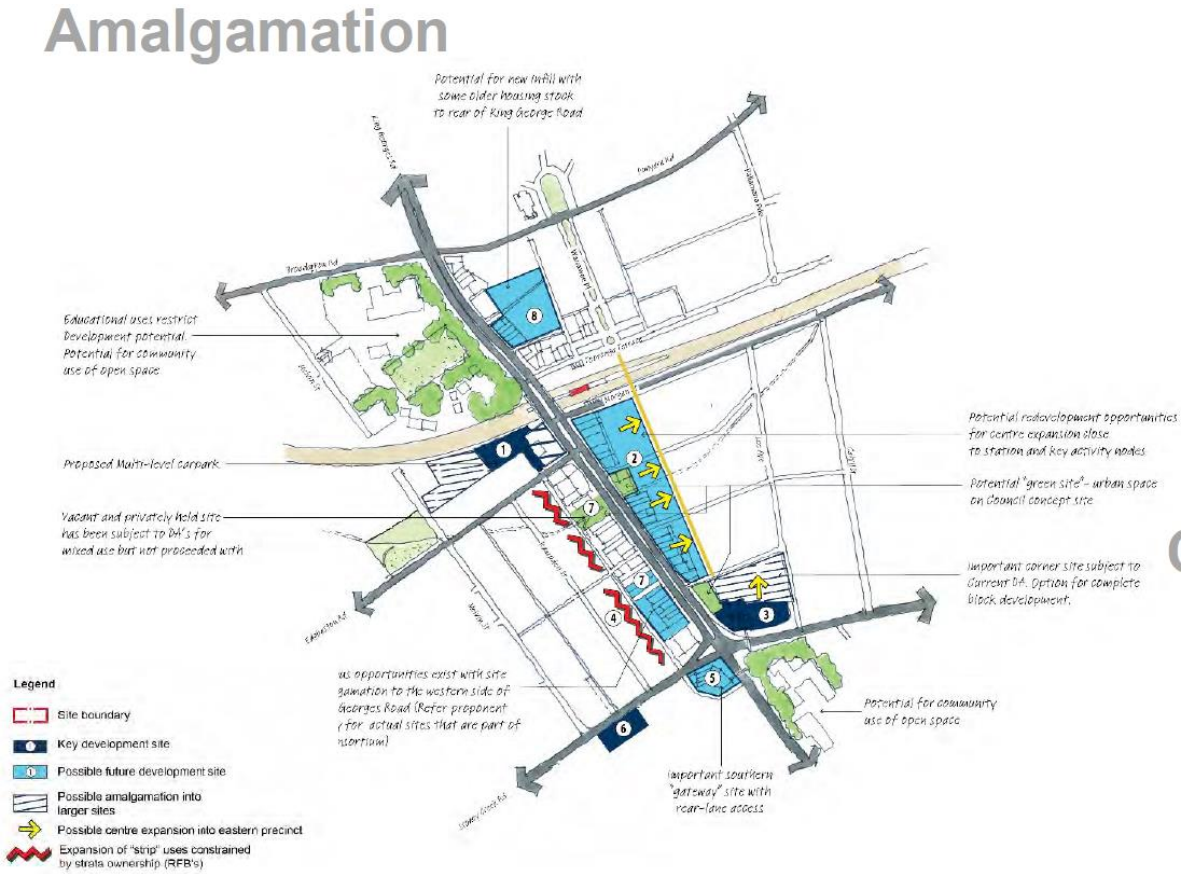
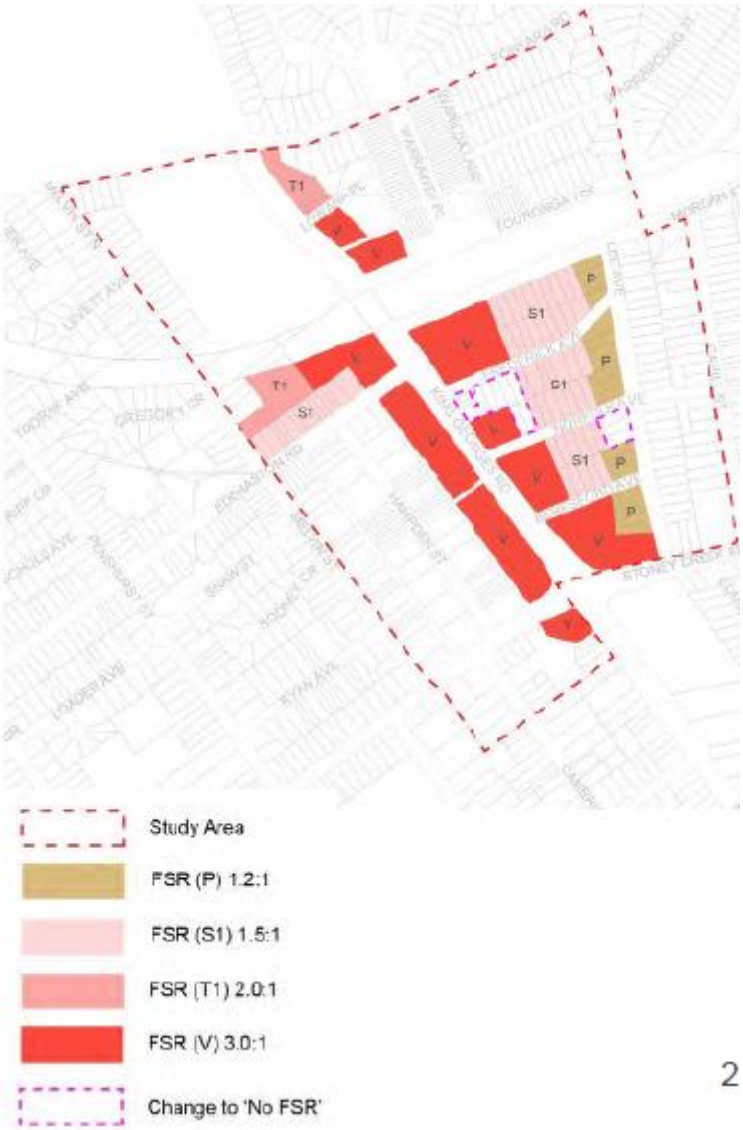


Figure 5 Proposed Land Use Changes

New proposed building height restrictions and floor space ratio restrictions are presented in Figure 6 and Figure 7

Figure 6 Proposed Building Height Restrictions

Figure 7 Proposed Floor Space Ratio Restrictions



2.2 Surrounding Suburbs and Populations

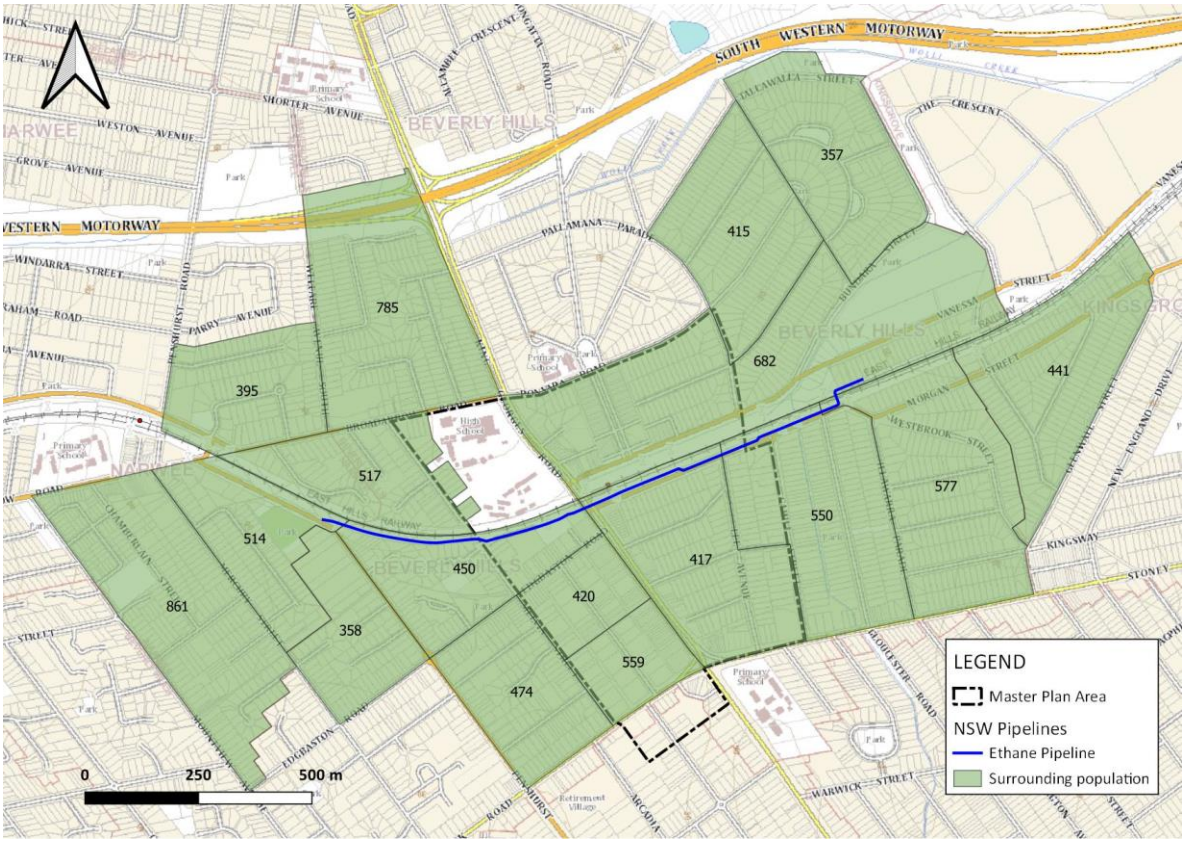
2.2.1 Residential Population

A full discussion on estimates for the residential population is presented in Appendix D.

The current residential population based on the 2016 Census of Housing and Population, adjusted upward based on projections for the 2021 population from the DPI&E. The estimated 2021 population used for the study is shown in Figure 8. This has been assumed to be the population present during the night.

Day time population has been adjusted for people leaving the area for work or education. Based on an analysis of Census data for the Narwee-Beverly Hills Level 2 Statistical Area (SA2), which encompasses the majority of area under consideration, the day time population in residential areas is approximately 45% of the night population. Refer Appendix D.

Figure 8 Current Population in the Surrounding Area



The future population growth for the Study area has been assumed to occur only in the areas for which proposed changes in the zoning allows for residential intensification. This includes the commercial areas that are proposed to be mixed use. The areas of residential intensification, and the estimated additional population is shown in Figure 9.

Figure 9 Future Residential Intensification

2.2.2 School Population

The Beverly Hills Girls High School and associated intensive English language centre in the North Western Education Precinct represent a significant concentration of people near within the Study Area and close to the MSE.

The student population has been extracted from the 2020 Beverly Hills Girls High School Annual Report [4]. The staff population has been based on Australian Bureau of Statistics data [5] for student-teacher ratios, and also teaching staff as a percentage of all school staff. The estimated population in the school is presented in Table 3.

Table 3 Nearby School Populations

School	Student Population	Staff	Total
BHGHS & Intensive Language Centre	1160	126	1286

No increase in school population has been considered in the study.

2.2.3 Commercial Population

The number of people employed within the study area currently is estimated as 1,169, and are located within the areas designated for business use. The area where the employed population is expected to be during the day is shown in Figure 10.

The forecast for employment in the expanded commercial precinct (the Strip) is estimated to be 3,255 and the area where the employed population is expected to be during the day is shown in Figure 11.

For the purposes of the analysis, the future population has been overlaid on current population, so the future population in the model is the incremental increase in population.

Figure 10 Location of Existing Commercial Population

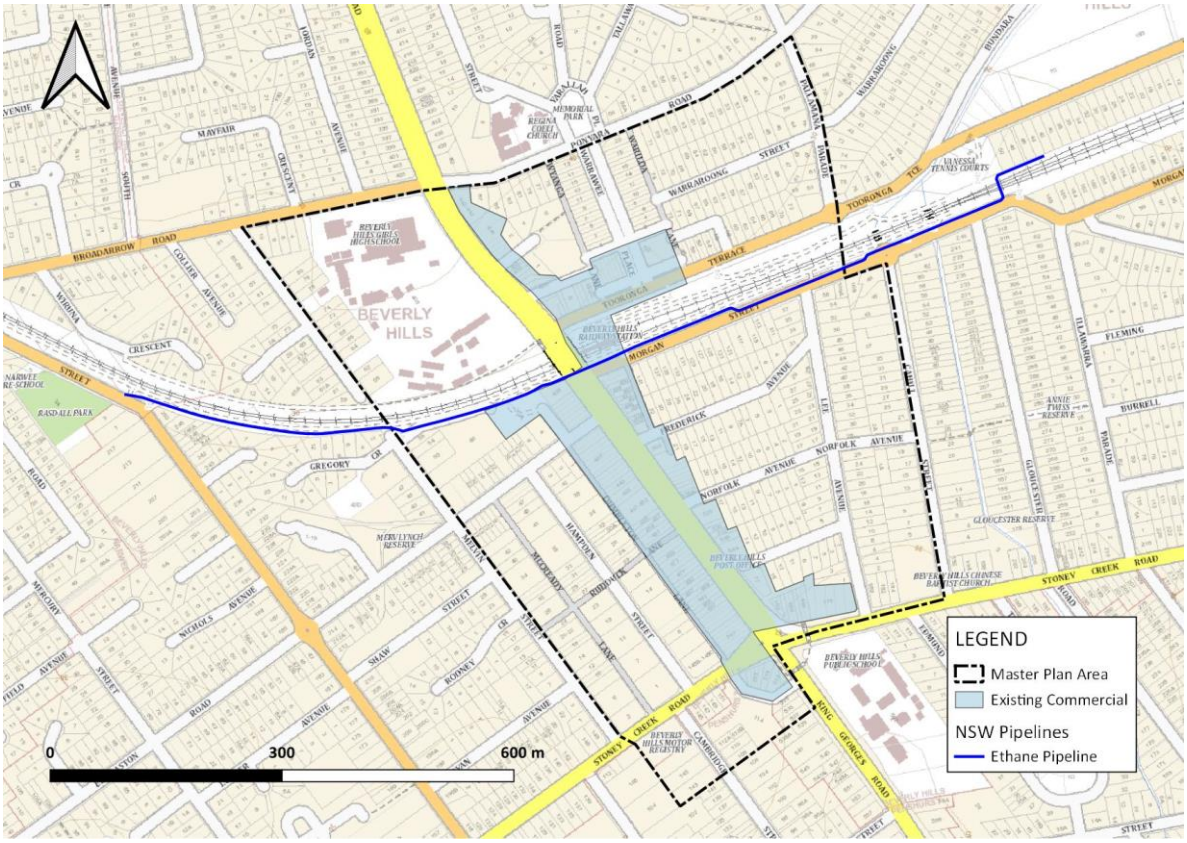
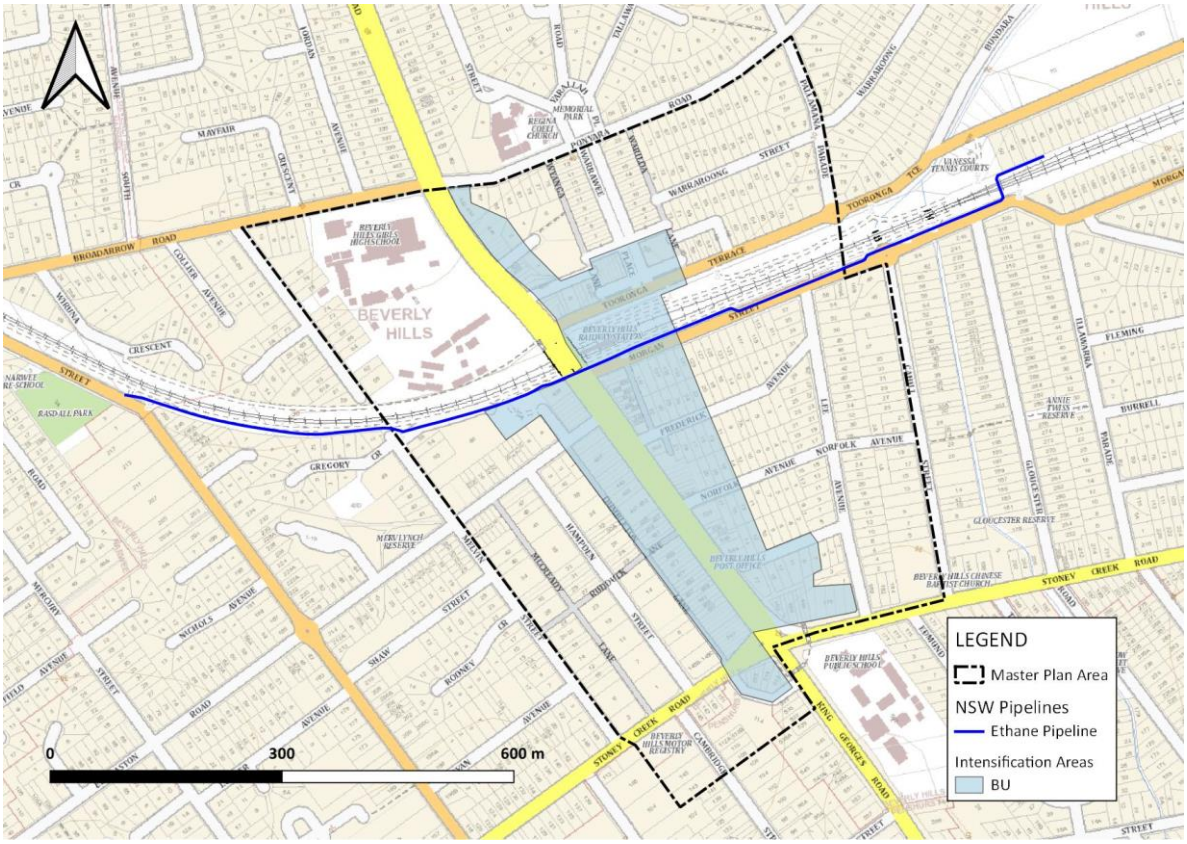


Figure 11 Area for Commercial Intensification



2.3 Ethane Pipeline

The Moomba Sydney Ethane pipeline (MSE) runs parallel to the Eastern Hills railway. The location of the MSE in relation to the Study Area is shown in blue in Figure 1 and Figure 2. The pipeline is owned by APA Group. Information obtained from APA about the MSE in this location is presented in Table 4.

Table 4 Data for the MSE Pipeline in Proximity to the Study Area

Description	MSE Pipeline
Pipeline Owner	Gorodok Pty Ltd (part of APA Group)
Pipeline Name	Moomba to Sydney Ethane Pipeline
Product in pipeline	Ethane
Pipeline Licence (NSW)	New South Wales Licence No 15
MAOP (Maximum allowable operating pressure)	10,000kPa
Actual Operating Pressure	8,200kPa
Operating Temperature	Typical 20°C
Material flow rate (pumping rate)	Typical 30 Tonne per hour
Pipeline Material	API -5L grade X60
Pipeline Diameter	200mm NB

Description	MSE Pipeline
Pipeline Wall Thickness	11.9mm in area of concern
Design factor	
Critical defect length	332mm
Minimum depth of cover	>1200mm – Varies between 1200 and 2500mm
Cathodic Protection for pipeline	Impressed Current Cathodic Protection applied.
External Coating on pipeline	HDPE (Yellowjacket) Joint Coating is 2 layer Tape Wrap system
Location of ALBVs from first ALBV upstream of HIA to first ALBV downstream of HIA	Upstream LV - Moorebank Ave kp1344 Downstream LV - Marsh Street kp1368
Pressure set points for ALBVs and approximate closure time.	4500kPa
Frequency of inspections and patrols undertaken	Ground Patrol Daily (Monday to Friday) Aerial Patrol Fortnightly
Control measures for third party activity near pipeline	11.9mm pipe wall thickness >1.2m depth of cover 25mm Concrete Coating of pipeline (Rockjacket) Either Top slabbing or top and side slabbing in all areas of concern apart from Rail Easements Marker Posts DBYD Patrols Aerial patrol fortnightly. Daily ground patrol Liaison with Councils, telecommunications companies, Electricity companies,
Pigging done for pipeline? If so, how often?	Metal Loss intelligent pigging carried out on a risk basis program but is undertaken at 5 yearly presently.
Was intelligent pigging carried out to determine rate of loss of wall thickness?	Yes – no wall thickness loss has been found in this section of pipeline.
Location of nearest upstream pump / compressor station and pressure at this point.	Bulla Park
Are there non-return valves located in the pipeline downstream of and where?	Downstream NRV - Bexley Rd kp1363

APA have also made a submission to Council on the Draft Beverly Hills Town Centre Masterplan [6].

3 RISK ASSESSMENT METHODOLOGY

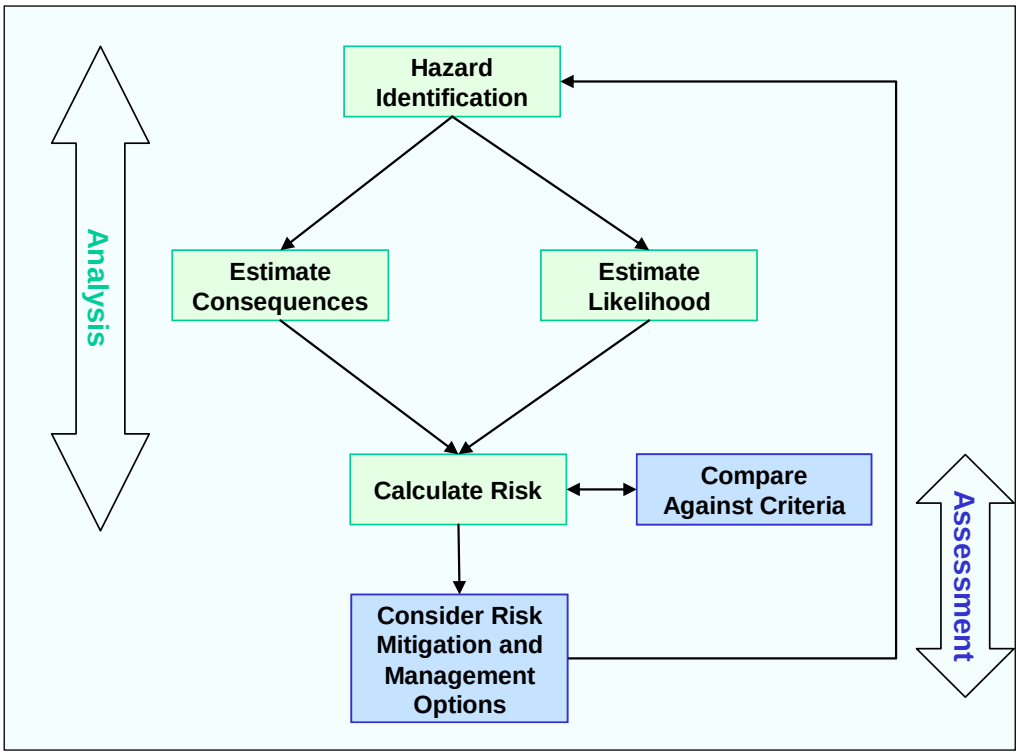
3.1 Introduction

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

In developing the estimates for use in a QRA, it is important to ensure that any estimates fall on the side of conservatism, particularly where there is uncertainty in the underlying data and assumptions. This precautionary approach uses 'cautious best estimate' values, which, whilst conservative, are still realistic. This approach is consistent with the DPI&E's guidelines for undertaking this type of assessment [7].

Diagrammatically, the QRA process is as follows:

Figure 12 Overview of QRA Process [7]



3.2 Methodology Overview

3.2.1 Hazard Identification and Register of Major Accident Events

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

For example, the Hazard identification (or HAZID) step for a QRA of a potentially hazardous pipeline would identify representative events that could result in a release of the material from the pipeline with the potential to cause harm (e.g. due to a subsequent ignition and fire/explosion). The representative potentially hazardous events are commonly described as 'Major Accident Events' (or MAEs). In the context of the QRA, an MAE is an event with the potential to cause: off-site fatality

or injury; off-site property damage; or, long-term damage to the biophysical environment (i.e. any outcome for which DPI&E has defined an acceptable risk criterion – Refer to Section 3.4).

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

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

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

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

3.2.2 Hazard Consequence Analysis

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

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

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

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

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

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

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

3.2.3 Impairment Criteria

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

Explosion

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

The impact of explosion overpressure on humans takes two forms:

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

The vulnerability to explosion overpressure used in the analysis are summarised in Table 5 and Table 6

Table 5 Probability of Fatality from Exposure to Peak Side on-Overpressure (Outdoor)

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

Table 6 Probability of Fatality from Exposure to Peak Side on-Overpressure (Indoor)

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

Fire

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

For individuals located outdoors, the probability of fatality is based on the following probit equation:

$$Y = -36.38 + 2.56 \ln\left(I^{1.333} t\right)$$

Where Y is the probit value, *I* is the heat radiation intensity (W/m^2) and t is the exposure duration (seconds).

The probit value Y can be related back to a percentage of a population. Table 7 depicts the probability of fatality for various radiation intensities and a thirty second exposure.

Table 7 Probability of Fatality for 30 Second Exposure for a Given Radiation Intensity

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

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

3.2.4 Frequency and Likelihood Analysis

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

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

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

The frequency analysis data and results are summarised in Section 4.3 and Appendix C.

3.2.5 Risk Analysis and Assessment

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

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

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

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

The latest SAFETI 8.4 software package was used to generate the iso-risk contours / transects and societal risk results (Refer to Section 6).

3.3 Study Assumptions

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

To comply with the general principles outlined in Section 2.2 of HIPAP No. 6 [7], all steps taken in the risk analysis should be: "*traceable and the information gathered as part of the analysis should be well documented to permit an adequate technical review of the work to ensure reproducibility, understanding of the assumptions made and valid interpretation of the results*". Therefore, details of the key assumptions adopted for the risk analysis are provided in Appendix A.

3.4 Quantitative Risk Criteria

3.4.1 Residential and Sensitive Land Use Individual Fatality Risk Criteria for Development in the Vicinity of Potentially Hazardous Facilities

The individual fatality risk imposed by a proposed (or existing) industrial activity should be low relative to the background risk. This forms the basis for the following individual fatality risk criteria adopted by the NSW DPI&E [1] and [8].

The following criteria apply to *residential and sensitive use development* in the vicinity of existing industry [1]:

- *the half in a million per year individual fatality risk level is an appropriate criterion above which no intensification of sensitive use development should take place;*
- *the one in a million per year individual fatality risk level is an appropriate criterion above which no intensification of residential development should take place;*

- *residential intensification may be appropriate where mitigating measures can be implemented to reduce risk exposure to less than the one in a million per year individual fatality risk level, provided the pre-mitigation residual risk levels are below the 10 in a million per year individual fatality risk level; and*
- *no residential intensification should take place where pre-mitigation residual risk levels are in excess of the 10 in a million per year individual fatality risk level.*

Table 8 Individual Fatality Risk Criteria – Other Land Uses

Land Use	Risk Criterion [per million per year]
Commercial developments, including offices, retail centres, warehouses with showrooms, restaurants, and entertainment centres	5
Sporting complexes and active open space areas	10
Industrial sites	50 *

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

The DPI&E has adopted a fatality risk criterion of 1 x 10^{-6} per year (or 1 chance of fatality per million per year) for residential area exposure because this risk is very low in relation to typical background risks for individuals in NSW. For land uses such as hospitals, schools, child-care facilities, and old age housing, the criterion is one-half that for residential area, viz. 0.5 x 10^{-6} pe year. "Sensitive" is the implied term for such uses in HIPAP 4 and the term sensitive is used in this study.

3.4.2 Injury Risk

The DPI&E has adopted risk criteria for levels of effects that may cause injury to people but will not necessarily cause fatality. Criteria are included in HIPAP No. 4 [8] for potential injury caused by exposure to heat radiation, explosion overpressure and toxic gas/ smoke/dust.

The DPI&E's suggested injury risk criterion for heat radiation is as follows:

- *Incident heat flux radiation at residential and sensitive use areas should not exceed 4.7 kW/m^2 at a frequency of more than 50 chances in a million per year.*

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

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

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

- *Toxic concentrations in residential and sensitive use areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure at a maximum frequency of 10 in a million per year.*
- *Toxic concentrations in residential and sensitive use areas should not cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community over a maximum frequency of 50 in a million per year.*

3.4.3 Risk of Property Damage and Accident Propagation

Heat radiation exceeding 23 kW/m^2 may cause unprotected steel to suffer thermal stress that may cause structural damage and an explosion overpressure of 14 kPa can cause damage to piping and low-pressure equipment. The DPI&E's criteria for risk of damage to property and accident propagation are as follows [8]:

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

3.4.4 Societal Risk

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.

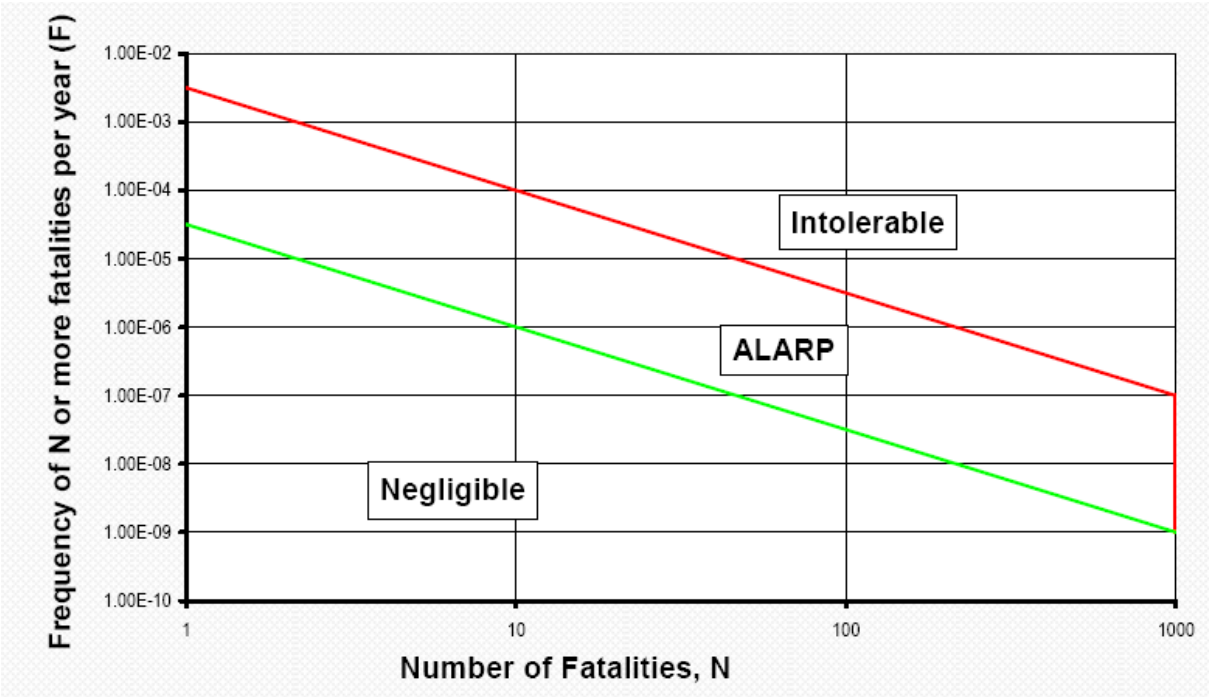
The DPI&E's suggested societal risk criteria (Refer to Figure 13), recognise that society is particularly intolerant of accidents, which though infrequent, have a potential to create multiple fatalities. Below the negligible line, provided other individual criteria are met, societal risk is not considered significant. Above the intolerable level, an activity is considered undesirable, even if individual risk criteria are met. Within the 'As Low As Reasonably Practicable' (ALARP) region, the emphasis is on reducing risks as far as possible towards the negligible line. Provided other quantitative and qualitative criteria of HIPAP 4 [8] are met, the risks from the activity would be considered tolerable in the ALARP region.

In HIPAP 10 [1], the following is reported regarding the F-N criteria:

If a development proposal involves an intensification of population in the vicinity of a potential source of risk, then the incremental change in societal risk needs to be taken into account, even if individual risk criteria are met [Ref.2, Section 5.5.4]. The incremental societal risk should be compared against the indicative societal risk criteria in Section 5.4.2 of HIPAP No. 10 [Figure 13 below]. If the incremental societal risk lies within the 'Negligible' region, then the development should not be precluded and if it lies within the 'Tolerable if ALARP' region, then options should be considered to relocate people away from the affected areas [Ref.2, Section 5.5.4]. If, after taking this step, there is still a significant portion of the societal risk plot within the 'Tolerable if ALARP'

region, the proposed development should only be approved if benefits clearly outweigh the risks [Ref.2, Section 5.5.4].

Figure 13 Indicative Societal Risk Criteria



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

HIPAP No.4 [8] also states that the criteria in Figure 13 are an indicative criteria and provisional only and do not represent a firm requirement in NSW.

3.5 Qualitative Risk Criteria

Irrespective of the numerical value of any risk criteria for risk assessment purposes, it is essential that certain qualitative principles be adopted concerning the land use safety acceptability of a proposed development or existing activity. The qualitative risk criteria outlined in HIPAP No. 4 [8] encompass the following general principles:

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

4 HAZARD IDENTIFICATION

4.1 Introduction

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

Section 4.2 - Properties of Ethane.

Section 4.3 - Pipeline Failure Modes.

Section 4.4 - Consequences.

Section 4.5 - Control Measures.

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

4.2 Properties of Ethane

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

Physical properties are listed in Table 9.

Table 9 Physical Properties of Ethane

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

Ethane is:

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

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

4.3 Pipeline Failure Modes

Pipelines may leak due to various causes. The four principal failure modes that may result in a leak from an underground pipeline include [9]:

- **Mechanical failures**, including material defects or design and construction faults;
- **Corrosion**, including both internal and external corrosion;
- **Ground movement and other failure modes**, including ground movement due to earthquakes, heavy rains/floods or operator error, and other natural hazards such as lightning, etc.; and

- **Third Party Activity (TPA)**, including damage from heavy plant and machinery, damage from drills/boring machines and hot tapping, etc.

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

4.3.1 Mechanical Failure

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

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

4.3.2 Corrosion

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

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

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

4.3.3 Ground Movement and Other Failure Modes

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

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

This failure mode is credible for the MSE.

4.3.4 Third Party Activity

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

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

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

This failure mode is credible for the MSE.

4.4 Consequences of Gas Release

4.4.1 Asphyxiation

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

Methane and Ethane are simple asphyxiants with low toxicity to humans. If a release does not ignite, then the potential exists for the gas concentration to be high enough to present an asphyxiation hazard to individuals nearby.

An atmosphere with marginally less than 21% oxygen can be breathed without noticeable effects. However, at 19.5% (which is OSHA's lower limit for confined space entry in 29 CFR 1915.12 [10]) there is a rapid onset of impairment of mental activity.

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

The potential for unconsciousness and fatality is only significant at less than 10% oxygen. However, to reduce the oxygen concentration to 10% requires a relatively high concentration (viz. approximately 52% v/v, which equates to 641,000 mg/m^3 for Ethane and 342,000 mg/m^3 for Methane).

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

4.4.2 Jet Fire

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

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

4.4.3 Flash Fire

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

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

4.4.4 Vapour Cloud Explosion

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

In the case of a gas release from the gas pipelines in the vicinity of the school, a gas cloud explosion is less likely than a flash fire due to the relatively open areas and absence of congestion surrounding the MSE.

4.4.5 Gas Ingress into Buildings

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

4.4.6 Toxic Smoke

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

4.5 Control Measures

Under the NSW Pipelines Act (1967) and Pipeline Regulations (2013), a pipeline operator must ensure the design, construction, operation and maintenance of a licensed pipeline is in accordance with the relevant provisions of Australian Standard AS 2885 [11] for gas and liquid petroleum pipelines.

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

4.5.1 Prevention of Mechanical Failure

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to develop and implement systems and processes to ensure the pipeline structural integrity for the design life of the pipeline in accordance with Section 6 of AS 2885.3:2012 [12] as part of the pipeline management system.

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

4.5.2 Corrosion Prevention

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to develop and implement systems and processes to ensure the pipeline structural integrity for the design life of the pipeline. (as per Section 6 of AS 2885.3:2012) as part of the pipeline management system. This should include corrosion protection systems.

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

The Moomba to Sydney Ethane Pipeline is inspected using ‘intelligent pigging’ (Refer to Section 2.2) and has a significant wall thickness (11.9 mm). It is equipped with a cathodic protection system and a double layered HDPE coating (Refer to Section 2.2).

4.5.3 Prevention of Damage due to Ground Movement and Other Failures

Normal loads (e.g. due to the internal and external pressure, weight of soil, traffic loads, etc.) and occasional loads (e.g. due to flood, earthquake, transient pressures in liquid lines and land movement due to other causes) are considered during design of a pipeline (as per AS2885.1:2012). To comply with AS2885.1:2012 [13], additional depth of cover may also be required where the minimum depth of cover cannot be attained because of the action of nature (e.g. soil erosion, scour).

4.5.4 Prevention of Damage due to Third Party Activity

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: the 'Dial Before You Dig' (DBYD) process and daily / weekly patrols.

Statistical data indicates that the pipelines in NSW are 100% cathodically protected with effectiveness between 95 and 100%, and that over 96% of parties contacted DBYD before any excavation work [14].

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

4.5.5 Mitigation Control Measures

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

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

Leaks may be detected during visual inspections, incident notifications and/or by instrumented monitoring systems. If a leak is detected, then the HP pipelines can be isolated by closing automated and/or manual valves (Refer to Section 2.2 for locations of upstream and downstream isolation valves).

4.6 MAEs for Risk Analysis

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

Table 10 List of MAEs

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

5 CONSEQUENCE ANALYSIS

5.1 Release of Flammable Liquid / Gas

5.1.1 Representative Hole Diameter

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

- Leaks from underground pipelines in the Pinhole size category tend to be larger for TPA incidents (i.e. typically c. 20 mm to 25 mm - Refer to Appendix D) than for the other failure modes (i.e. typically less than c. 10 mm). Therefore, two representative hole diameters were selected in this category: 25 mm for TPA and 10 mm for all other failure modes.
- There is insufficient historical incident data for Ethane to determine the representative hole diameter/s in each hole size category. Therefore, the representative hole diameters were assumed to be the same as proposed by the UK HSE for LPG.

Table 11 Representative Hole Diameters Selected for Consequence Analysis

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

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

5.1.2 Discharge Model

Release events were modelled using the 'Long Pipeline' model in SAFETI. The estimated peak release rates are tabulated below for each representative hole size. Further detail on release rates, including the time varying release rates, are contained in Appendix B.2.1.

Table 12 Representative Hole Diameters Selected for Consequence Analysis

MAE	Hole Diameter (mm)	Peak Release Rate [kg/s]
Release of High Pressure Ethane from MSE	10	3.5
	25	21.7
	75	96.7
	110	208
	FBR	656

5.1.3 Height and Orientation of Release

The release of high pressure gas or liquefied gas from a buried pipeline would result a crater and gas would be released vertically from the crater [15]. The Safeti GASPIPE module determines a crater size and air entrainment for a release from a buried pipeline originating at ground level.

5.1.4 Duration of Release

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

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

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

5.2 Fire Modelling

The latest SAFETI software package (Version 8.4) was used to model all the representative fire events included in the risk analysis.

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

5.2.1 Jet Fire

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

5.2.2 Flash Fire

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

5.3 Vapour Cloud Explosion

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

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

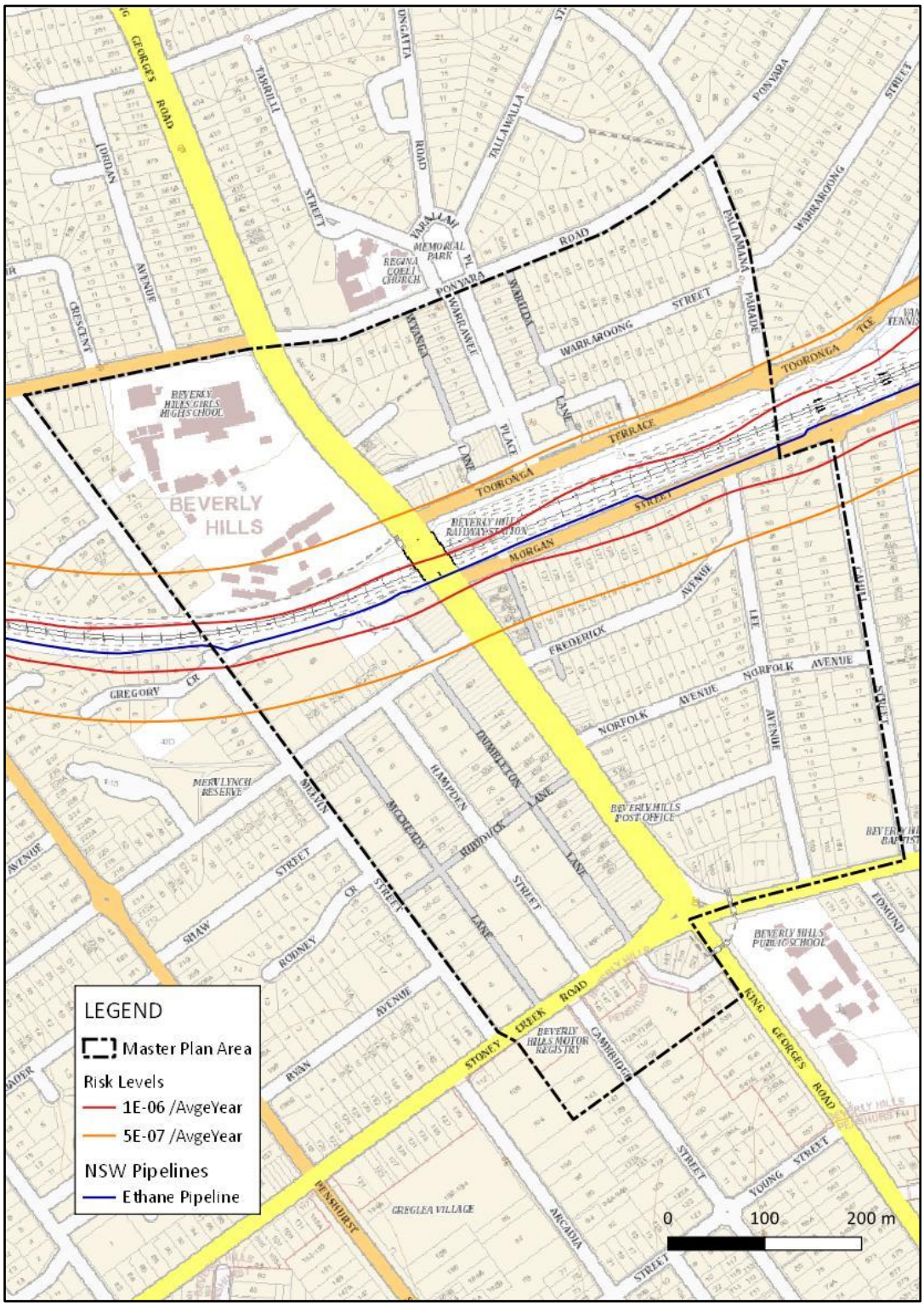
The Multi-Energy model in SAFETI was used to estimate the overpressure for a VCE. Results are provided in Appendix B.2.3.

6 RISK ANALYSIS

6.1 Individual Risk of Fatality

The risk contour for individual risk of fatality at 1.0 and 0.5 x 10^{-6} per annum (p.a.) for the MSE is shown in Figure 14.

Figure 14 Location Specific Individual Risk Contours



To provide a better understanding of how risk decays with distance from the MSE, the estimated risk along four 500 m transects perpendicular to the MSE is presented in Figure 15. In Figure 15, the pipeline is indicated by the dashed blue line, located 250 m south of the start of each transect. The location of each transect is shown in Figure 16.

The transects show there is very little difference in the decay of risk from the pipeline within the Study Area. The 1.0 x 10^{-6} p.a. LSIR is generally found between 20 m and 35 m from the MSE, and the 0.5 x 10^{-6} p.a. LSIR between 60 m and 75 m from the MSE.

Figure 15 Risk Transects at Four Points Along MSE

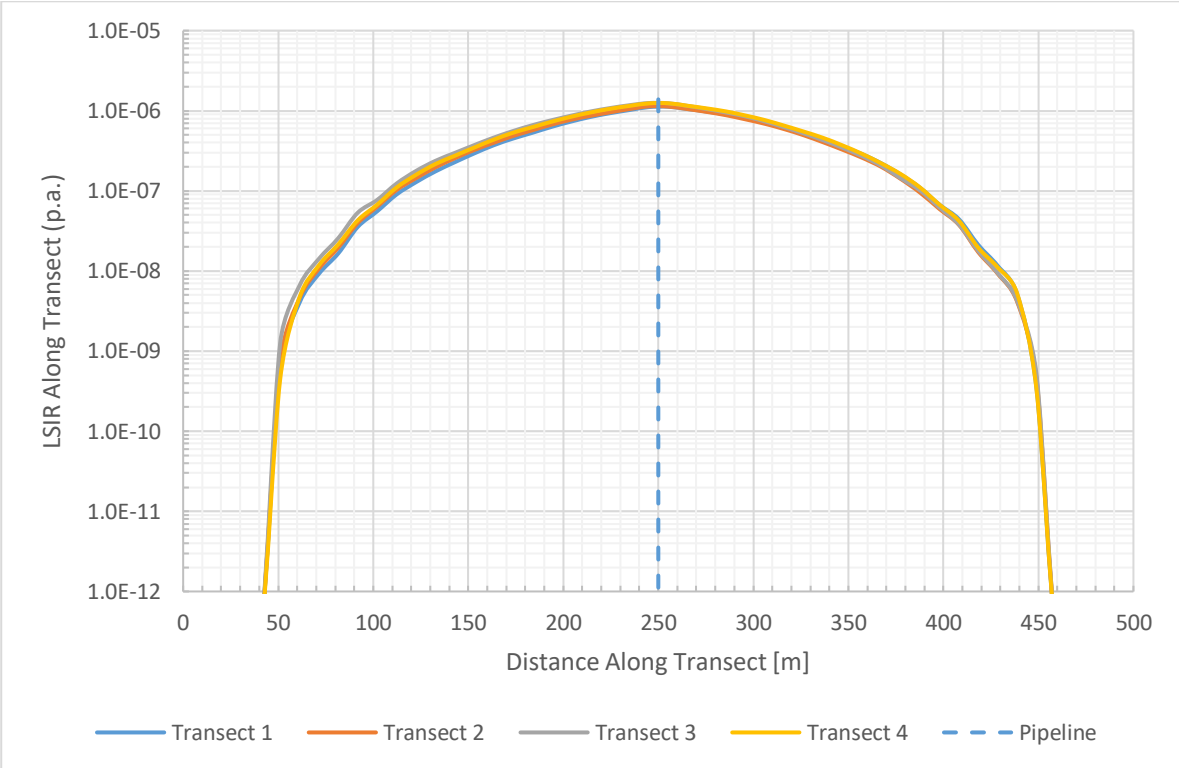
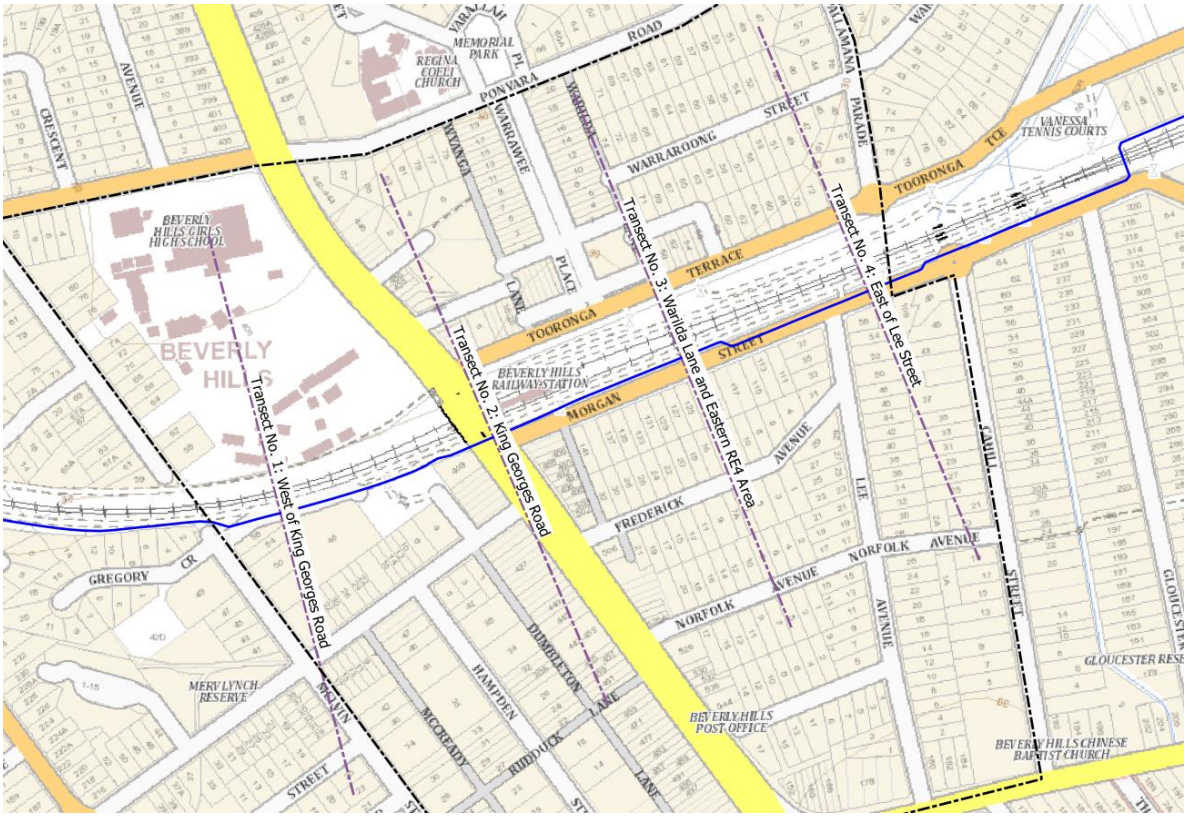


Figure 16 Location of Transects



6.2 Risk of Acute Toxic Injury or Irritation

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

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

The cumulative risk of property damage and accident propagation (Overpressure exceeding 14 kPa) does not reach 50 x 10^{-6} per annum. This criterion does not apply to the proposed residential rezoning (Refer to Section 3.4.3).

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

The cumulative risk of property damage and accident propagation (Heat radiation exceeding 23 kW/m^2) does not reach 50 x 10^{-6} per annum. This criterion does not apply to the proposed residential rezoning (Refer to Section 3.4.3).

6.5 Risk of Injury (Exceeding 7 kPa)

The cumulative risk of injury (Overpressure exceeding 7 kPa) does not reach 50 x 10^{-6} per annum; therefore the proposed rezoning complies with the relevant DPI&E risk criteria (Refer to Section 3.4.2).

6.6 Risk of Injury (Exceeding 4.7 kW/m^2)

The cumulative risk of injury (Heat radiation exceeding 4.7 kW/m^2) does not reach 50 x 10^{-6} per annum; therefore the proposed rezoning complies with the relevant DPI&E risk criteria (Refer to Section 3.4.2).

6.7 Qualitative Risk Criteria

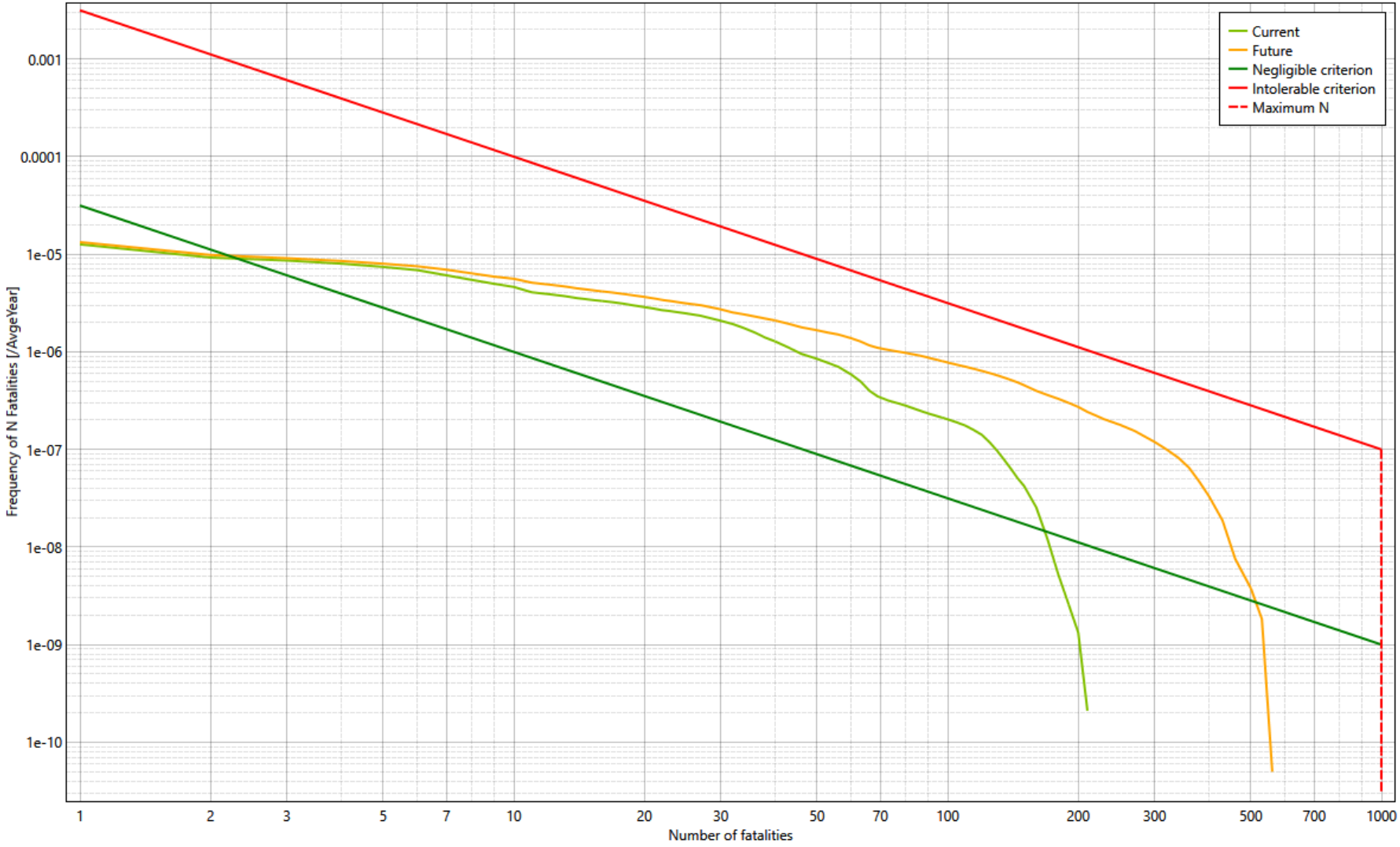
Irrespective of the numerical value of any risk criteria level for risk assessment purposes, it is essential that certain qualitative principles be adopted concerning the land use safety acceptability of a proposed development or existing activity. The proposed development is considered to comply with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

- Avoidance of all 'avoidable' risks – The pipeline is an existing facility and cannot be relocated to avoid risk exposure. While intensification of business and residential use could be avoided, there are significant adverse societal effects from avoiding such redevelopment such as loss of business income, increased costs of home ownership and further societal costs involved in accommodating population growth in areas where public infrastructure does not already exist.
- Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low. This would require a review of the proposed masterplan to determine if refinements can be made to focus residential intensification in the Study Area further from the MSE.
- Containment, wherever possible, within the site boundary of the effects (consequences) of the more likely hazardous events. There are no further reasonably practicable means of containing the effects of hazardous release from the MSE.
- Recognition that if the risk from an existing installation is already high, further development should not be permitted if it significantly increases that existing risk. The risk levels within the Study Area from the MSE are below the criteria for commercial development, sporting complexes and active open space, and industrial development. Only some parts of the study are impacted by risk levels that exceed the criteria for residential or sensitive uses.

6.8 Societal Risk

An FN curve depicting the societal risk from the MSE in the Study Area is shown in Figure 17. This shows the societal risk with the Study Area both rezoned and fully developed, and before the rezoning. There is a noticeable increase in societal risk at all points along the fN curve, but when the Study Area is fully developed, the risk is still within the ALARP region.

Figure 17 Societal Risk (Smoothed FN plot)



7 FINDINGS AND RECOMMENDATIONS

7.1 Findings

The following findings were made from the risk assessment:

- The individual risk of fatality within some properties south of the MSE exceed the DPIE criterion for residential development (1.0 x 10^{-6} p.a.). These properties are listed in Table 13 and shown graphically in Figure 18. The DPI&E criteria suggests that no residential intensification should take place at these locations unless mitigating measures can be implemented to reduce fatality risk exposure to less than the one in a million per year. The current plan is for residential intensification in these areas.
- The individual risk of fatality within some properties exceeds the DPIE criterion for sensitive use development (0.5 x 10^{-6} p.a.). These properties are listed in Table 14 and shown graphically in Figure 19. There should be no intensification of sensitive use development in these properties.
- The individual risk of fatality never exceeds 5.0 x 10^{-6} p.a. and therefore intensification of other land uses (business use) as proposed within the Study Area is consistent with DPI&E criteria.
- The societal risk, represented as an F-N curve, is within the ALARP region and below the upper limit of the risk tolerability band. This level of societal risk does not preclude the changes envisaged in the masterplan, provided that options to relocate people from affected areas are explored and implemented where practicable. If there is still a need to locate people in affected areas, the benefits must be demonstrated to clearly outweigh the risks.

Figure 18 Lots where the LSIR of Fatality exceeds 1.0 x 10^{-6} p.a.

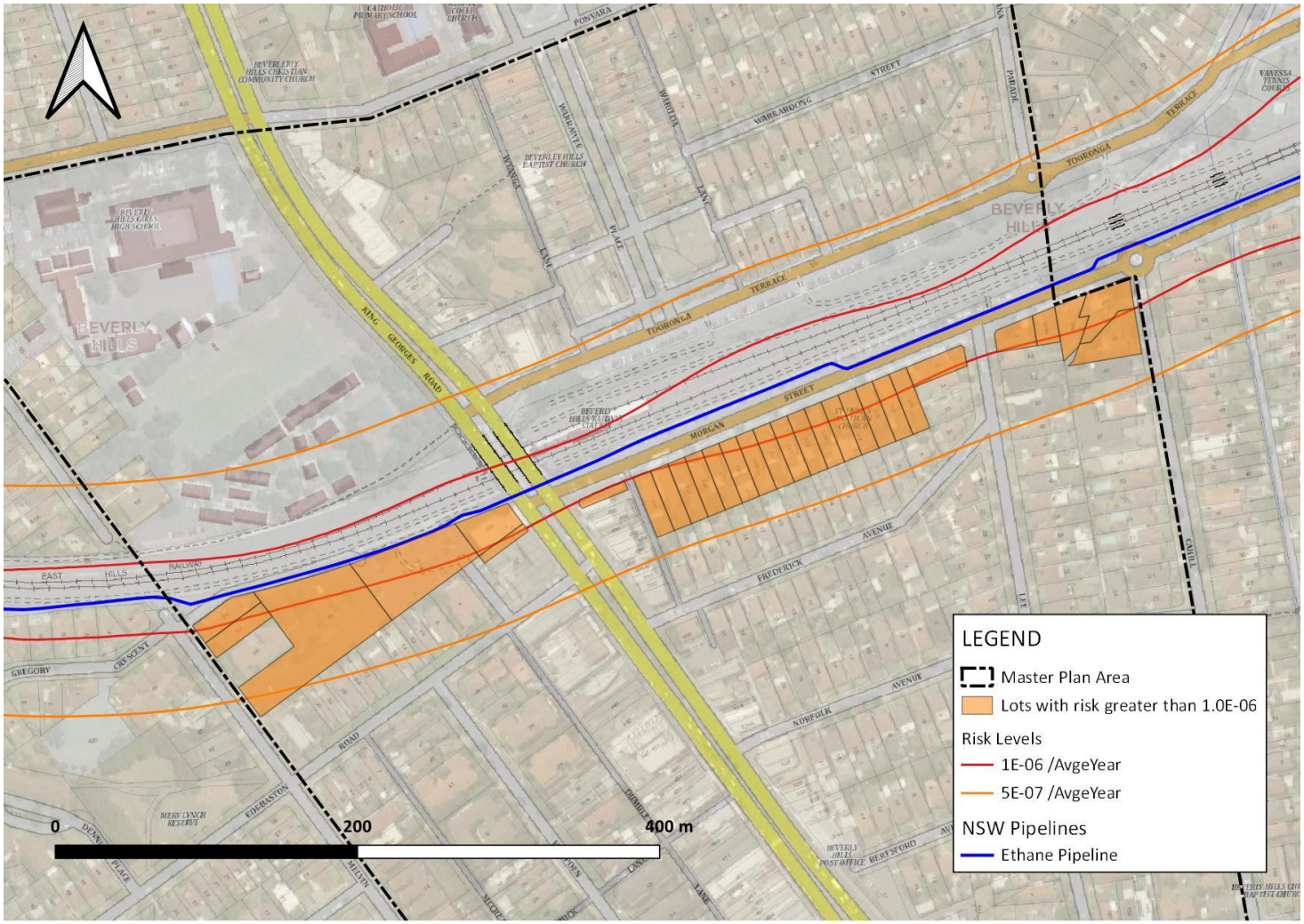


Figure 19 Lots where the LSIR of Fatality exceeds 0.5 x 10^{-6} p.a.

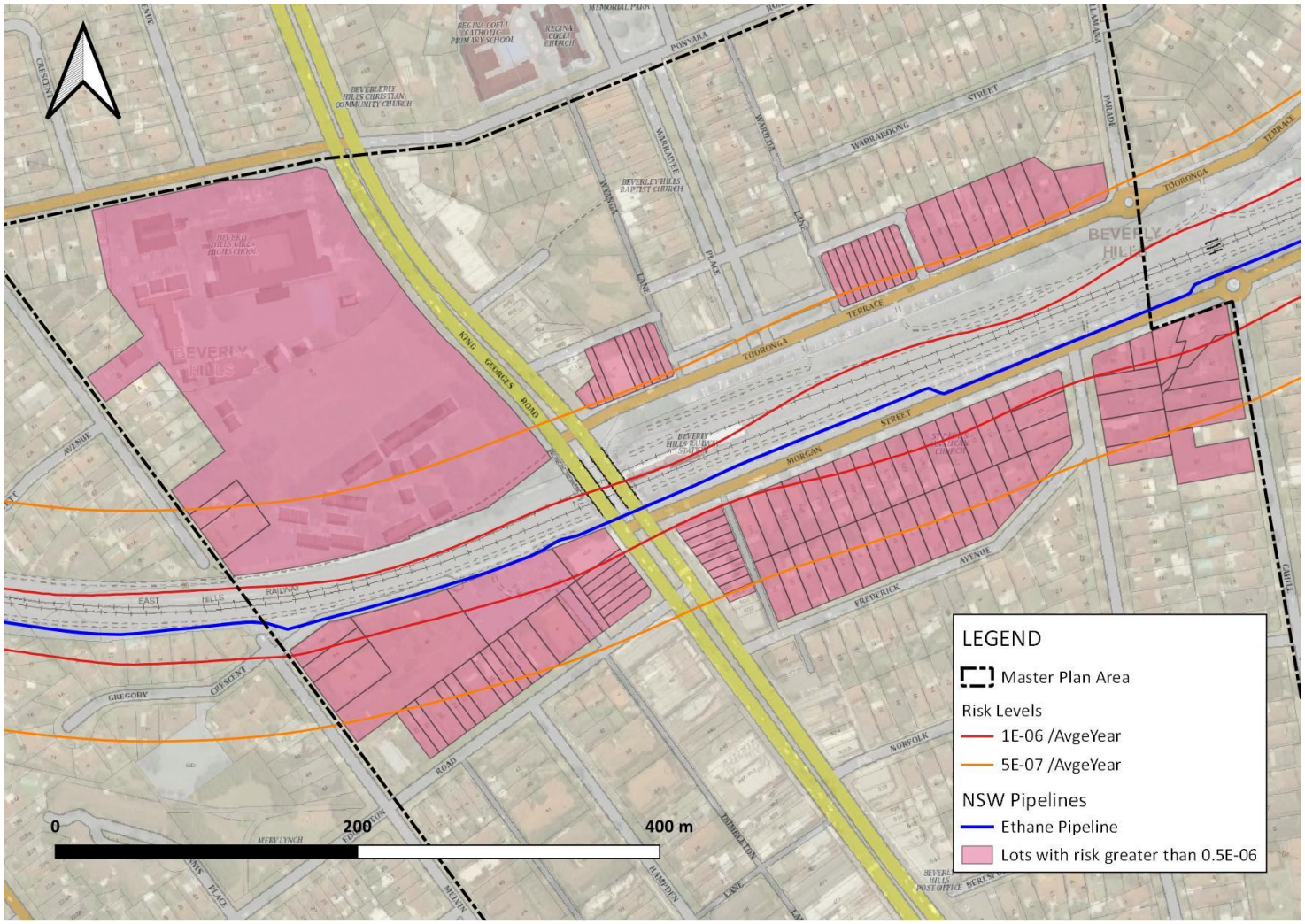


Table 13 Properties where LSIR of Fatality Exceeds 1.0 x 10^{-6} p.a.

Plan	Lots
DP12807	15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31
DP19223	1
DP21064	F
DP521347	1, 2
DP533022	1, 2
DP546842	1
DP853974	1, 2
SP67093	N/A
SP70373	N/A
SP72663	N/A

Table 14 Properties where LSIR of Fatality Exceeds 0.5 x 10^{-6} p.a.

Plan	Lots
DP1097960	10
DP1250626	100
DP12807	15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 44, 45, 46, 47, 48, 49, 161
DP13496	10, 11, 12, 13, 14, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93
DP15341	10, 11
DP15394	8
DP19223	1, 2, 3, 6, 7, 8
DP19294	2
DP20718	E, F
DP208342	1, 2
DP208878	1, 2
DP21064	B, C, D, E, F
DP227593	22, 23

Plan	Lots
DP338494	A, B, C
DP366409	A, B
DP378690	X, Y
DP385804	B
DP390258	A, B
DP392994	2
DP409292	A, B
DP455272	1
DP521347	1, 2
DP533022	1, 2
DP537815	1, 2
DP546842	1, 2
DP716517	1
DP853974	1, 2
SP2864	N/A
SP38663	N/A
SP55005	N/A
SP55006	N/A
SP55018	N/A
SP67093	N/A
SP70373	N/A
SP72663	N/A

7.2 Recommendations

The following recommendations are mode to ensure compliance with the HIPAP 10 land use criteria:

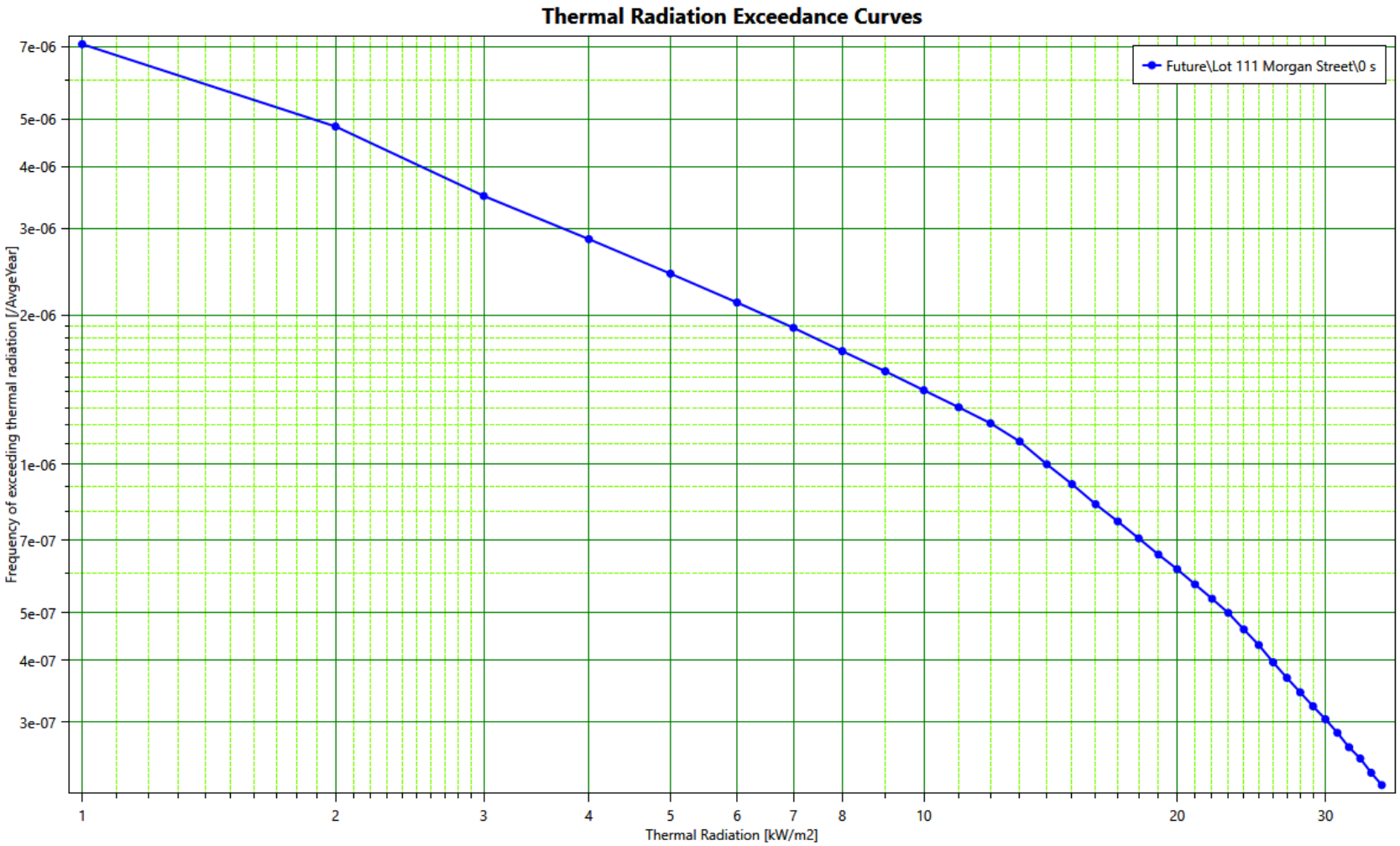
Recommendation 1: Ensure sensitive use developments such as aged care facilities, childcare centres or schools are not approved for properties listed in Table 14.

Recommendation 2: Review if it is feasible for the masterplan to change so that residential intensification is minimised where fatality risk levels are greater than 1 x 10^{-6} p.a.

Recommendation 3: Properties listed in Table 13 be either excluded from any rezoning that would enable residential intensification. Alternatively specific requirements be placed for developments involving those properties to demonstrate that the design of the development effectively reduces the individual fatality risk to less than 1 per million per year.

Recommendation 4: As the future societal risk lies within the ALARP region, GRC should consider, if possible, using Development Control Plans to encourage developers and designers to consider the implications of development in the proximity of the MSE and incorporate features in the design, construction, and operation of buildings to reduce societal risk to ALARP.

Figure 20 Thermal Radiation Exceedance Curve at Lot 111 Morgan Street



8 REFERENCES

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Appendices

Appendix A Assumptions

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

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

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

It is important that the assumptions be supported by:

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

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

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A.1 Operational Data

Assumption No. 1 Pipeline Operating Conditions
Subject: Operational Data
Assumption/s: • All pipeline operating conditions (pressure, temperature, etc.) are as reported in Section 2.2
Justification and Impact/s of Assumption/s: • All operational data for the pipelines was provided by the pipeline owner (APA Group). • Operating conditions (particularly operating pressure) are required to undertake the release and dispersion modelling.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group.

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

A.2 Locational Data

Assumption No. 3: Representative Wind Speeds, Wind Directions and Stability Classes
Subject: Locational Data
Assumption/s: • Representative weather data is based upon 25 years of observations at Bankstown Airport, BoM Station ID 066137 • The probabilistic distribution of wind speed and wind direction for the representative stability classes is provided in Section 2.1.3. • The data was split into daytime and night-time conditions. • Night-time is considered the period from 1 hour before sunset, to one hour after sunrise. This approximates to 10 hours daytime and 14 hours night-time.
Justification and Impact/s of Assumption/s: • Bankstown is approximately 9.5 km from the Study Area. It is one of the two closest BoM weather stations to the Study Area, the other being Sydney Airport (ID 066037) at approximately 8.3 km from the Study Area. • Sydney Airport is located much closer to the coast for that reason, Bankstown is considered the more representative location. • Raw data from Bankstown observations have been rationalised into a set of wind speed/weather stability classes for dispersion calculations. • Wind will cause flames to tilt downwind. The higher the wind speed, the greater the tilt. The net effect of the tilt is to increase the heat radiation in the downwind direction. This is much more pronounced for pool fires than jet fires because jet fires have much greater momentum. An allowance for flame tilt is included in the SAFETI models for pool fires and vertical jet fires. The SAFETI model assumes horizontal jet fires are directed in the same direction as the wind. • The downwind gas concentrations, and hence the hazard ranges for dispersion of flammable gas or vapour, vary with wind speed and weather stability class. Therefore, multiple representative wind speed and stability class categories are included in accordance with standard practice for undertaking a quantitative risk assessment (QRA). • The day/night split of the weather data is required to allow for the fact that residential, commercial and industrial occupancies change over a 24 hour period.
MAE/s Affected: • All.
Reference/s: • BoM meteorological data for Bankstown AWS.

Assumption No. 4: Surface Roughness Length

Subject: Locational Data

Assumption/s:

- A conservative roughness length of 1.0 m is applicable for Beverly Hills.

Justification and Impact/s of Assumption/s:

- The roughness length for different surface types, as listed in the SAFETI user manual, is shown below in Table 15. Beverly Hills is a landlocked suburb of Sydney, most associated with the terminology of "regular large obstacle coverage (suburb, forest)"

Table 15 Surface Roughness Length

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

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

MAE/s Affected:

- Dispersion modelling for all relevant MAEs.

Reference/s:

- SAFETI software documentation.

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

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

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

Assumption No. 6: Residential Population (Day and Night)
Subject: Locational Data
Assumption/s: • The current residential population is based upon the Census of Population and Housing, 2016, obtained from the Australian Bureau of Statistics TableBuilder service. The population is based upon Statistical Area Level 1. • The estimated current residential population has been increased based upon the NSW Department of Planning, Industry and Environment forecast population increases for local government areas. •
Justification and Impact/s of Assumption/s: • The 2016 Census data is five years old and at the time of the study, the 2021 Census data is unavailable. In the absence of better information, the NSW DPIE projections are the best available data to account for population changes through to 2021.
MAE/s Affected: • All societal risk calculations. Population density, along with the area of consequence distances, determines the fN points of societal risk. • Locational specific risk is not impacted by these assumptions.
Reference/s: • Census of Population and Housing, 2016, TableBuilder • https://www.planning.nsw.gov.au/Research-and-Demography/Population-projections/Projections#:~:text=NSW%20medium%20growth%20demographic%20assumptions%202016-2041%20%20,to%20%20...%20%202%20more%20rows%20

Assumption No. 7: Indoor / Outdoor distribution of people

Subject: Locational Data

Assumption/s:

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

Justification and Impact/s of Assumption/s:

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

Table 16 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 DPI&E). It is reported in these analyses that the % of people indoors and outdoors is 90% indoors and 10% outdoors during the day, which differs slightly from the TNO data, but is typically justified as being more applicable for Australian environmental conditions. Similarly, it is reported in these analyses that the % of people indoors and outdoors is 95 to 99% indoors and 1 to 5% outdoors during the night.

MAE/s Affected:

- All societal risk calculations

Reference/s:

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

A.3 Risk Analysis Methodology

Assumption No. 8: Location and Segmentation of Pipelines
Subject: Risk Analysis Methodology
Assumption/s: • Representative release events are modelled using the 'Long Pipeline' model in SAFETI, which distributes these events along the pipeline at set intervals.
Justification and Impact/s of Assumption/s: • The 'Long Pipeline' model in SAFETI is used to estimate the time-dependent release from a long pipeline. The 'Long Pipeline' model includes inputs for use in the risk calculations, such as pipeline burial depth, leak frequency, etc. • The interval at which representative incidents are distributed along the pipeline is selected automatically by the 'Long Pipeline' model based on the incident consequence.
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation.

A.4 Consequence Analysis

Assumption No. 9: Representative Materials
Subject: Consequence Analysis
Assumption/s: • Ethane is modelled as 100% Ethane.
Justification and Impact/s of Assumption/s: • The composition and materials used affect the magnitude of the consequences. Materials containing multiple components are simplified for modelling purposes by choosing a representative component to best approximate the variable composition. Modelling a representative material rather than a multi-component material reduces complexity, limits the potential for inconsistencies and ultimately has a minimal effect on the results. • The ethane pipeline carries ethane which has been processed to serve as a petrochemical feed stock.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group.

Assumption No. 10: Pressure and Flow for Release Modelling
Subject: Consequence Analysis

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

Justification and Impact/s of Assumption/s: • The release rate is dependent on the pressure and the MAOP is the maximum pressure permitted under an existing licence. • The pressure used to model the release rates was based on the pipeline pressure near the proposed development, as advised by the pipeline owner. • The long pipeline model assumes the input pressure is reduced by frictional losses along the pipeline length until the breach point. This results in a lower pressure at the release point that the operating pressure and hence also a lower release rate. • Providing a flow will slow the rate of pressure reduction calculated by the long pipeline model. • HIPAP 4 is silent 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 APA Group. •

Assumption No. 11: Representative Hole Diameters for Release Modelling

Subject: Consequence Analysis

Assumption/s:

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

Table 17 Representative Hole Diameters Selected for Consequence Analysis

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

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

Justification and Impact/s of Assumption/s:

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

MAE/s Affected:

- All.

Reference/s:

- Refer to Appendix B.1.

Assumption No. 12: Location of Release for Transmission Pipelines
Subject: Consequence Analysis
Assumption/s: • High pressure gas releases would create a crater on the ground. The direction of release for underground pipeline failures from the crater is always vertical. • The location of failure on the pipe can be taken as: - Top of the pipe (unobstructed releases); or - Middle of the pipe (on the side – obstructed releases) • The release frequency is distributed between the two locations (37% from middle of pipe and 63% from top of pipe for all release cases except non-TPA events with a hole size less than or equal to 25mm, which are modelled as 100% from middle of pipe).
Justification and Impact/s of Assumption/s: • The crater size depends on the location of the hole on the pipe and hence all three locations (top, middle and bottom) may be modelled (DNVGL, 2020). Top releases are taken as non-obstructed releases and middle/ bottom releases are taken as obstructed releases. • Impingement reduces the momentum of the release and the dispersion modelling is dominated by the representative wind conditions. • The UK HSE [RR 1034] reports that some data from UKOPA includes the 'hole circumferential position' for releases from underground pipelines. Based on the 71 recorded incidents (All pipelines and materials) and average crater dimensions, an unobstructed release (c. ±71° from vertical) was estimated to occur for 63% of the releases and an obstructed release was estimated to occur for the balance (37% of releases). The distribution is not reported for different failure modes.
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation. • UK HSE, 2015, *Review of the Event Tree Structure and Ignition Probabilities used in HSE's Pipeline Risk Assessment Code MISHAP*, Research Report (RR) 1034.

Assumption No. 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 100% of the lower flammability limit (LFL) concentration calculated using a 18.75s averaging time.

Justification and Impact/s of Assumption/s:

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

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

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

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

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

  Hanna claims that experimentally:

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

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

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

  $$t = 18.75\ s.$$

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

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

MAE/s Affected:

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

Reference/s:

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

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

Assumption No. 15: Shielding by Intervening Structures
Subject: Consequence Analysis
Assumption/s: • The presence of intervening structures (e.g. buildings) does not shield other receptors from the heat radiation from a jet fire.
Justification and Impact/s of Assumption/s: • In the SAFETI software, it is not possible to take account of the potential protection provided by intervening structures. • This analysis is taking place during the concept stage of development of a large growth area. There is insufficient information available to determine the location of large structures that could offer protection against radiant heat. • People located indoors are typically less vulnerable to fire, which is an relevant consideration for the societal risk assessment (Refer to Assumption No. 20).
MAE/s Affected: • All MAEs with a pool fire or jet fire as a potential outcome.
Reference/s: • SAFETI software documentation.

Assumption No. 16: 3D Explosion Model Parameters
Subject: Consequence Analysis
Assumption/s: • The maximum explosive mass in a flammable gas or vapour cloud is the maximum mass between the LFL and UFL concentration for that section of the cloud that overlaps a congested area. • The peak side-on overpressure resulting from an explosion is estimated using the Extended Explosion Modelling option in the SAFETI software. • The severity of the blast is based on an unconfined blast strength of 4, with no specified obstruction region. • The blast strength is estimated based on the obstructed volume (%) and potential obstructions in each congested area. The following congested areas are included in the QRA: • **Buildings** - A medium obstructed volume (60% for a residential building) and level of congestion is assumed to simulate entry of the gas or vapour into the building and the subsequent confined explosion. This equates to TNO Model curve number 4. • Only overpressure effects are included. Projectiles and whole-body displacement are not included.
Justification and Impact/s of Assumption/s: • The explosive mass and blast strength are key parameters for modelling the overpressure from a VCE. • There are no significantly congested locations in the study area; however, a confined explosion could occur if gas or vapour enters a building. • The open space between the buildings in the study area is not strictly a congested area; however, the presence of vehicles, trees etc. at ground level may contribute to flame acceleration and the formation of an overpressure if ignition occurs. Therefore, TNO Model curve number 2 was assumed to apply, which is the default value in the SAFETI software. • The 3D Obstructed Region Explosion Modelling option considers the interactions between the flammable cloud and obstructed regions that have been defined for the study area. This is more valid than simple models (e.g. TNT equivalence) which do not consider these interactions.
MAE/s Affected: • All MAEs with a VCE as a potential outcome.
Reference/s: • Centre for Chemical Process Safety, Estimating the flammable mass of vapour clouds", American Institute of Chemical Engineers, 1999. • TNO, VROM, 'Yellow Book'. • SAFETI software documentation.

A.5 Likelihood Analysis

Assumption No. 17: Likelihood of Release (Loss of Containment)
Subject: Likelihood Analysis
Assumption/s: • The likelihood of each representative release is provided in Appendix C.3. • The UK HSE pipeline failure rate data is the primary data used for the risk assessment. • The contribution to pipeline failure from ground movement has been adjusted down to allow for local conditions.
Justification and Impact/s of Assumption/s: • The estimated likelihood of release (or loss of containment) is a critical and significant input for the risk analysis. The risk results are directly proportional to this input. • Generic failure rate data for cross-country pipelines from the UK, USA and Europe were reviewed. The UK data incorporates the European data. There are two sources of data from the UK: (a) HSE recommended data for land use safety planning (RR 1035); and (b) British Standards Institute PD 8010-3:2009+A1:2013. The HSE data is primarily used in this study, which is consistent with the NSW performance data. • The HSE data identifies four contributors to pipeline failure: (a) mechanical failure; (b) corrosion; (c) ground movement/other; and (d) Third Party Activity (TPA). Of these, mechanical, corrosion and TPA are similar to conditions in Australia and hence no frequency adjustments due to local conditions are justified. • The justification for the data used in this risk analysis is provided in Appendix C.1.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.1.

Assumption No. 18: Ignition Probability
Subject: Likelihood Analysis
Assumption/s: • The probability of ignition for each representative release is provided in Appendix C.
Justification and Impact/s of Assumption/s: • The estimated probability of ignition is a critical and significant input for the risk analysis. The risk results are directly proportional to this input. • The justification for the data used in this risk analysis is provided in Appendix 0.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix 0.

Assumption No. 19: Probability of VCE or Flash Fire
Subject: Likelihood Analysis
Assumption/s: • Ignition of a free gas or vapour cloud is modelled as a flash fire in uncongested areas and as a vapour cloud explosion in congested areas. • Congested areas include buildings in the vicinity of the pipelines.
Justification and Impact/s of Assumption/s: • Ignition of a free gas cloud may demonstrate characteristics of a flash fire and/or an explosion. SAFETI uses the delayed ignition probability resulting in either of the events. • Obstructed areas in the dispersing vapour cloud are defined by the user in the layout map. As the model calculates gas dispersion, it automatically calculates the consequence as vapour cloud explosion in congested areas and flash fires in uncongested areas. • The current version of SAFETI, with the 3D obstructed area module, does not require a conditional probability of an explosion given ignition.
MAE/s Affected: • All MAEs with clouds in an obstructed region.
Reference/s: • SAFETI software documentation. • TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

A.6 Vulnerability Parameters

Assumption No. 20: Exposure to Heat Radiation from a Fire (Indoor or Outdoor)

Subject: Vulnerability Parameters

Assumption/s:

- For individuals located outdoors, the probability of fatality is based on the following probit equation [TNO 'Purple Book']:

$$Y = -36.38 + 2.56 \ln\left(I^{1.333} t\right)$$

  Where Y is the probit value, *I* is the heat radiation intensity (W/m^2) and t is the exposure duration (seconds).
- A maximum exposure duration of 30 seconds is applicable for individuals located outdoors in an urban setting. It is assumed after 30 seconds, the persons will have found shelter from heat radiation.
- The probability of fatality for an individual located outdoors (30 seconds exposure), as calculated using the above probit equation, is as follows:

Table 18 Probability of Fatality for Exposure to Heat Radiation (Outdoor)

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

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

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

Assumption No. 20: Exposure to Heat Radiation from a Fire (Indoor or Outdoor)

Justification and Impact/s of Assumption/s:

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

Table 19 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 LFL concentration). • For calculation of societal risk, the probability for fatality for any individual located within the flammable cloud (Distance to LFL concentration) is 1 (outdoor) or 0.1 (indoor).
Justification and Impact/s of Assumption/s: • The assumed probabilities differ from the guidance in the TNO 'Purple Book' and the default values in the SAFETI software. In both cases, the probability of fatality is set at 1 for all individuals (outdoor or indoor). This was considered too conservative. The probability of fatality indoors was set at 0.1 to take account of the possibility of open doors / windows and/or failure to evacuate.
MAE/s Affected: • All MAEs with a flash fire as a potential outcome.
Reference/s: • SAFETI software documentation. • TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

Assumption No. 22: Exposure to Explosion Overpressure (Indoor or Outdoor)	
Subject:	Vulnerability Parameters

Assumption/s:

- The probability of fatality from exposure to the peak side-on overpressure from an explosion is as shown in Table 20 (Person located outdoors) and Table 21 (Person located indoors).

Table 20 Probability of Fatality from Exposure to Peak Side on-Overpressure (Outdoor)

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

Table 21 Probability of Fatality from Exposure to Peak Side on-Overpressure (Indoor)

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

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

Table 22 Effects of Explosion Overpressure

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

Assumption No. 22: Exposure to Explosion Overpressure (Indoor or Outdoor)
Justification and Impact/s of Assumption/s: • When calculating location-specific individual injury or fatality risk contours (peak individual risk), all individuals must be considered to be located outdoors for 100% of the time since this is the underlying basis for the NSW DPI&E's individual risk criteria. Vulnerability parameters for individuals located indoors are only applicable for the calculation of societal risk. • The probability of fatality is higher for an individual located in a conventional building than when outdoors due to the higher chance of harm from collapse of the structure. • The NSW DPI&E's injury/damage risk criterion for explosion overpressure is as follows: "Incident explosion overpressure at residential and sensitive use areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year".
Incidents Affected: • All incidents with a VCE as a potential outcome.
Reference/s: • NSW Department of Planning and Infrastructure, Jan 2011, Hazardous Industry Planning Advisory Paper (HIPAP) No. 4, *Risk Criteria for Land Use Safety Planning*. • SAFETI software documentation. • Oil & Gas Producers Association (OGP), Risk Assessment Data Directory, Report No. 434-14.1, *Vulnerability to Humans*, March 2010. • Chemical Industries Association (CIA), 2003, *Guidance for the location and design of occupied buildings on chemical manufacturing sites*, 2nd. ed.

Appendix B Consequence Analysis – Example Data and Results

B.1 Representative Hole Diameters

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

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

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

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

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

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

Table 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

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

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

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

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

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

Table 24 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 25 Dimensions of Puncture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)

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

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

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

B.2 Consequence Analysis Results for Representative Release Scenarios

Hazard ranges for the modelled release cases are tabulated in Sections B.2.1 to B.2.3

B.2.1 Discharge Results

The discharge rate for 10mm and 25mm holes has been calculated assuming a constant pressure in the pipe. For 75mm hole sizes and larger, the pipeline depressurisation has been considered and a set of 10 different rates over the first five minutes has been used for dispersion modelling. The various release rates are presented in Table 26.

Table 26 Discharge Results

Scenario	Release time [s]	Release phase	Mass flow [kg/s]	Final velocity [m/s]	Liquid fraction [fraction]	Droplet diameter [um]
10mm	All	Two-phase	3.5	27.9	0.53	12.0
25mm	All	Two-phase	21.7	32.2	0.53	12.0
75mm	0.0	Two-phase	96.7	61.1	0.35	130.9
	28.9	Two-phase	88.3	56.0	0.36	152.8
	59.5	Two-phase	84.7	54.2	0.37	159.1
	91.2	Two-phase	81.9	53.0	0.37	163.1
	123.9	Two-phase	79.5	52.0	0.38	165.8
	157.5	Two-phase	77.5	51.2	0.38	167.9
	192.0	Two-phase	75.7	50.4	0.38	169.4
	227.2	Two-phase	74.0	49.8	0.39	170.7
	263.3	Two-phase	72.5	49.2	0.39	171.7
	300.0	Two-phase	71.1	48.7	0.39	172.4
110mm	0.0	Two-phase	208.0	84.2	0.35	130.9
	22.1	Two-phase	158.2	69.8	0.39	171.0
	48.1	Two-phase	139.3	66.0	0.40	174.8
	77.1	Two-phase	126.4	63.2	0.41	175.5
	108.7	Two-phase	116.8	61.0	0.41	175.3
	142.8	Two-phase	109.1	59.2	0.42	174.7
	179.1	Two-phase	102.9	57.5	0.42	174.1
	217.5	Two-phase	97.6	56.1	0.42	173.5
	257.8	Two-phase	93.1	54.8	0.42	172.9
	300.0	Two-phase	89.2	53.6	0.43	172.4

Scenario	Release time [s]	Release phase	Mass flow [kg/s]	Final velocity [m/s]	Liquid fraction [fraction]	Droplet diameter [um]
FBR	0.0	Two-phase	655.6	28.1	0.35	130.9
	14.0	Two-phase	240.9	18.5	0.43	170.4
	35.7	Two-phase	181.6	19.5	0.44	168.1
	62.6	Two-phase	152.2	19.9	0.44	167.7
	93.9	Two-phase	133.9	20.2	0.43	168.1
	129.0	Two-phase	121.1	20.3	0.43	168.7
	167.4	Two-phase	111.5	20.4	0.43	169.6
	208.8	Two-phase	103.9	20.5	0.43	170.5
	253.1	Two-phase	97.7	20.6	0.43	171.6
	300.0	Two-phase	92.5	20.6	0.43	172.6

In all cases, the final release temperature is -88.6 °C, the saturated vapour temperature of ethane at atmospheric pressure.

B.2.2 Jet Fire Consequence Results

Distance downwind to defined radiation levels are reported in Table 27 and Table 28.

Table 27 Night conditions downwind distance (m) to varying heat radiation levels @1.5m height

Scenario	Weather	Flame length [m]	4.7 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²
10mm MID	7.3D	15.5	36.3	25.6	20.6	17.1
	4.0D	17.7	35.1	22.8	18.3	14.7
	1.0D	24.9	30.2	12.6	3.9	2.12
	2.6E	20	33.1	22.1	15.3	8.74
	1.0F	24.9	30.2	12.6	3.91	2.12
25mm MID	7.3D	32.8	82.7	55.9	42.8	36.9
	4.0D	37.6	79.6	51.3	40.3	31.8
	1.0D	52.7	70.8	31.9	10.5	5.07
	2.6E	42.5	76.5	49.9	34.7	21.5
	1.0F	52.7	70.9	32	10.5	5.08
75mm MID	7.3D	56.8	138	89.8	70.1	59.9
	4.0D	65.1	144	93.3	71.1	54.9
	1.0D	91.3	132	60.7	18.8	7.43
	2.6E	73.5	144	91.1	61.9	38.6
	1.0F	91.3	132	60.9	18.9	7.46
75mm TOP	7.3D	52.5	120	77.3	61.1	50.2
	4.0D	60.2	118	74.6	50.4	30.5
	1.0D	84.4	120	51.6	10.4	3.27
	2.6E	68	123	70.5	38.7	15.7
	1.0F	84.4	121	51.8	10.6	3.27
110mm MID	7.3D	72	170	109	86.5	72.2
	4.0D	82.5	172	113	83.7	61.2
	1.0D	116	173	81	25.3	9.1
	2.6E	93.3	181	111	72.1	41.3
	1.0F	116	174	81.2	25.4	9.14
110mm TOP	7.3D	67.8	151	97.5	76.3	61.3
	4.0D	77.7	149	92.8	60.5	34.1
	1.0D	109	158	68.5	14.8	4.57
	2.6E	87.8	155	86.9	44.9	17.3
	1.0F	109	159	68.7	14.9	4.58
FBR	7.3D	95	217	140	112	93.7
	4.0D	109	245	159	122	96.7
	1.0D	153	238	130	66.1	34.7
	2.6E	123	246	160	115	81.4
	1.0F	153	239	131	66.4	34.9

Table 28 Day conditions downwind distance (m) to varying heat radiation levels @1.5m height

Scenario	Weather	Flame length [m]	4.7 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²
10mm MID	1.9B	21.8	32.7	20.2	10.9	5.05
	7.5D	15.4	36.2	25.7	20.8	17.4
	4.1D	17.6	35.4	22.9	18.4	15
	1.5D	23	32.2	17.9	7.38	3.56
25mm MID	1.9B	46.2	75.9	46.5	27.1	13.2
	7.5D	32.7	82.3	55.8	42.9	36.8
	4.1D	37.3	80.2	51.7	40.6	32.4
	1.5D	48.8	74.3	41.6	19.4	8.87
75mm MID	1.9B	79.9	141	82.4	46.6	21.5
	7.5D	56.6	138	89.8	69.9	59.9
	4.1D	64.6	144	93.5	71.6	55.7
	1.5D	84.5	137	73.7	33.5	13.9
75mm TOP	1.9B	73.9	124	66.1	28.6	9.5
	7.5D	52.3	120	77.3	61.2	50.6
	4.1D	59.7	119	75.3	51.5	32
	1.5D	78.1	124	61.6	21	6.59
110mm MID	1.9B	101	184	106	59.2	26.9
	7.5D	71.7	170	109	86.4	72.4
	4.1D	82	174	114	84.6	62.6
	1.5D	107	179	95.6	43.9	17.2
110mm TOP	1.9B	95.5	156	81	32.3	10.6
	7.5D	67.5	151	97.5	76.5	61.9
	4.1D	77.2	150	93.8	62	37.7
	1.5D	101	156	75.1	23.4	7.34
FBR	1.9B	134	244	153	101	63
	7.5D	94.6	215	140	111	93.6
	4.1D	108	245	159	123	97.3
	1.5D	141	241	144	86.8	49.5

B.2.3 Flash Fire Consequence Analysis Results

Flash fire consequences are summarised in Table 29 and Table 30.

Table 29 Night Conditions Flash Fire Consequence Results @ 1.5m

Scenario	Weather	Distance to UFL [m]	Distance to LFL [m]
10mm MID	7.3D	0.304	0.479
	4.0D	0.267	0.409
	1.0D	0.242	0.364
	2.6E	0.249	0.361
	1.0F	0.237	0.329
25mm MID	7.3D	0.566	0.85
	4.0D	0.545	0.811
	1.0D	n/a	n/a
	2.6E	0.53	0.753
	1.0F	0.516	1.12
75mm MID	7.3D	0.778	1.16
	4.0D	0.761	1.13
	1.0D	0.732	1.1
	2.6E	0.734	1.16
	1.0F	0.714	0.924
75mm TOP	7.3D	0.46	0.605
	4.0D	0.45	0.592
	1.0D	0.441	0.58
	2.6E	0.43	0.55
	1.0F	0.414	0.518
110mm MID	7.3D	0.893	1.28
	4.0D	0.878	1.26
	1.0D	n/a	n/a
	2.6E	0.846	1.28
	1.0F	1.05	1.46
110mm TOP	7.3D	0.587	0.765
	4.0D	0.581	0.756
	1.0D	0.574	0.747
	2.6E	0.556	0.703
	1.0F	0.539	0.668
FBR	7.3D	3.08	4.69
	4.0D	3.04	4.62
	1.0D	n/a	200
	2.6E	2.94	62.5
	1.0F	n/a	171

Table 30 Day Conditions Flash Fire Consequence Results @ 1.5m

Scenario	Weather	Distance to UFL [m]	Distance to LFL [m]
10mm MID	1.9B	0.253	0.387
	7.5D	0.308	0.487
	4.1D	0.266	0.408

Scenario	Weather	Distance to UFL [m]	Distance to LFL [m]
	1.5D	0.248	0.374
25mm MID	1.9B	0.537	0.807
	7.5D	0.569	0.854
	4.1D	0.545	0.81
	1.5D	0.533	0.788
75mm MID	1.9B	0.76	1.12
	7.5D	0.78	1.16
	4.1D	0.76	1.13
	1.5D	0.751	1.12
75mm TOP	1.9B	0.448	0.593
	7.5D	0.46	0.606
	4.1D	0.45	0.592
	1.5D	0.443	0.583
110mm MID	1.9B	0.881	1.25
	7.5D	0.894	1.28
	4.1D	0.878	1.26
	1.5D	0.869	1.25
110mm TOP	1.9B	0.581	0.762
	7.5D	0.588	0.765
	4.1D	0.58	0.756
	1.5D	0.574	0.747
FBR	1.9B	1.66	69.4
	7.5D	3.1	4.73
	4.1D	3.03	4.6
	1.5D	n/a	140

B.2.4 Explosion Consequence Analysis Results

Explosion scenarios for worst-case maximum downwind distance to defined overpressures are reported in Table 31 and Table 32.

Table 31 Night conditions distance (m) to varying overpressures

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
25mm MID	1.0D	0.07 0.1 0.14 0.3	25.1 18.7 Not reachable Not reachable	30.2 17.4 0 0
	1.0F	0.07 0.1 0.14 0.3	24.5 18.4 Not reachable Not reachable	29.1 16.7 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
75mm MID	7.3D	0.07 0.1 0.14 0.3	24.6 18.4 Not reachable Not reachable	29.2 16.9 0 0
	4.0D	0.07 0.1 0.14 0.3	27.4 20 Not reachable Not reachable	34.9 20.1 0 0
	1.0D	0.07 0.1 0.14 0.3	48.3 36.3 Not reachable Not reachable	56.6 32.6 0 0
	2.6E	0.07 0.1 0.14 0.3	28.4 20.6 Not reachable Not reachable	36.8 21.2 0 0
	1.0F	0.07 0.1 0.14 0.3	45.8 34.8 Not reachable Not reachable	51.5 29.7 0 0
75mm TOP	7.3D	0.07 0.1 0.14 0.3	23.9 18 Not reachable Not reachable	27.8 16 0 0
	4.0D	0.07 0.1 0.14 0.3	26.5 19.5 Not reachable Not reachable	33 19 0 0
	1.0D	0.07 0.1 0.14 0.3	31.4 22.3 Not reachable Not reachable	42.8 24.6 0 0
	2.6E	0.07 0.1 0.14 0.3	27.9 20.3 Not reachable Not reachable	35.7 20.6 0 0
	1.0F	0.07 0.1 0.14 0.3	31.4 22.3 Not reachable Not reachable	42.8 24.7 0 0
110mm MID	7.3D	0.07 0.1 0.14 0.3	42.2 32.8 Not reachable Not reachable	44.3 25.5 0 0
	4.0D	0.07 0.1 0.14 0.3	45.9 35 Not reachable Not reachable	51.9 29.9 0 0
	1.0D	0.07 0.1	57.2 41.4	74.4 42.9

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
		0.14	Not reachable	0
		0.3	Not reachable	0
	2.6E	0.07	47.9	55.8
		0.1	36.1	32.2
		0.14	Not reachable	0
		0.3	Not reachable	0
	1.0F	0.07	52.8	65.6
		0.1	38.9	37.8
		0.14	Not reachable	0
		0.3	Not reachable	0
110mm TOP	7.3D	0.07	26.9	33.8
		0.1	19.7	19.5
		0.14	Not reachable	0
		0.3	Not reachable	0
	4.0D	0.07	28.7	37.3
		0.1	20.8	21.5
		0.14	Not reachable	0
		0.3	Not reachable	0
	1.0D	0.07	34.3	48.6
		0.1	24	28
		0.14	Not reachable	0
		0.3	Not reachable	0
	2.6E	0.07	30.1	40.3
		0.1	21.6	23.2
		0.14	Not reachable	0
		0.3	Not reachable	0
	1.0F	0.07	33.4	46.7
		0.1	23.5	26.9
		0.14	Not reachable	0
		0.3	Not reachable	0
FBR	7.3D	0.07	80.8	81.6
		0.1	63.5	47
		0.14	Not reachable	0
		0.3	Not reachable	0
	4.0D	0.07	86.8	93.5
		0.1	67	53.9
		0.14	Not reachable	0
		0.3	Not reachable	0
	1.0D	0.07	266	113
		0.1	243	65
		0.14	Not reachable	0
		0.3	Not reachable	0
	2.6E	0.07	89.1	98.2
		0.1	68.3	56.6
		0.14	Not reachable	0
		0.3	Not reachable	0
	1.0F	0.07	228	115
		0.1	203	66.3
		0.14	Not reachable	0
		0.3	Not reachable	0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
25mm MID	1.0D	0.07 0.1 0.14 0.3	25.1 18.7 Not reachable Not reachable	30.2 17.4 0 0
	1.0F	0.07 0.1 0.14 0.3	24.5 18.4 Not reachable Not reachable	29.1 16.7 0 0

Table 32 Day conditions distance (m) to varying overpressures

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
75mm MID	1.9B	0.07 0.1 0.14 0.3	29.4 21.2 Not reachable Not reachable	38.7 22.3 0 0
	7.5D	0.07 0.1 0.14 0.3	24.5 18.4 Not reachable Not reachable	29 16.7 0 0
	4.1D	0.07 0.1 0.14 0.3	27.3 20 Not reachable Not reachable	34.6 19.9 0 0
	1.5D	0.07 0.1 0.14 0.3	45 34.4 Not reachable Not reachable	50.1 28.9 0 0
75mm TOP	7.5D	0.07 0.1 0.14 0.3	23.8 17.9 Not reachable Not reachable	27.5 15.9 0 0
	4.1D	0.07 0.1 0.14 0.3	26.4 19.4 Not reachable Not reachable	32.8 18.9 0 0
	1.5D	0.07 0.1 0.14 0.3	29.9 21.4 Not reachable Not reachable	39.7 22.9 0 0
110mm MID	1.9B	0.07 0.1 0.14 0.3	31.8 22.5 Not reachable Not reachable	43.5 25.1 0 0
	7.5D	0.07 0.1 0.14 0.3	42.1 32.7 Not reachable Not reachable	44.1 25.4 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
	4.1D	0.07 0.1 0.14 0.3	45.9 34.9 Not reachable Not reachable	51.7 29.8 0 0
	1.5D	0.07 0.1 0.14 0.3	53.5 39.3 Not reachable Not reachable	67.1 38.6 0 0
110mm TOP	1.9B	0.07 0.1 0.14 0.3	31.6 22.4 Not reachable Not reachable	43.2 24.9 0 0
	7.5D	0.07 0.1 0.14 0.3	26.7 19.6 Not reachable Not reachable	33.4 19.3 0 0
	4.1D	0.07 0.1 0.14 0.3	28.5 20.7 Not reachable Not reachable	37.1 21.4 0 0
	1.5D	0.07 0.1 0.14 0.3	31.8 22.5 Not reachable Not reachable	43.5 25.1 0 0
FBR	1.9B	0.07 0.1 0.14 0.3	90.8 69.3 Not reachable Not reachable	102 58.5 0 0
	7.5D	0.07 0.1 0.14 0.3	80.6 63.4 Not reachable Not reachable	81.1 46.7 0 0
	4.1D	0.07 0.1 0.14 0.3	86.6 66.9 Not reachable Not reachable	93.2 53.7 0 0
	1.5D	0.07 0.1 0.14 0.3	180 159 Not reachable Not reachable	100 57.7 0 0

Appendix C Likelihood Analysis - Data and Results

C.1 Likelihood of Release from Underground Pipelines

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

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

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

Contribution from ground movement for local conditions are expected to be lower than reported in RR1035 since the local terrain is flat, with minimal slopes and significant water crossings. Therefore, the HSE data for ground movement was reduced to ¼ of its value, which is consistent with the data included in BSI PD 8010-3:2009+A1:2013.

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

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

- An analysis of pipeline failure data from multiple organisations, including:
  - CONCAWE (CONservation of Clean Air and Water in Europe);
  - UKOPA (United Kingdom Onshore Pipeline Operators' Association); and
  - EGIG (European Gas pipeline Incident Group).
- A conservative, yet realistic, analysis of the available data. For example:
  - For failure mode categories where zero failures have occurred, assumptions have been made to estimate the chance of a failure, even if not seen historically (over the observation period).

- Only the most recent 22 years of historical incident data was analysed to ensure a consistent pipeline population and to remove the older incident data, which may not be as representative of current practice.
- Incident data for pipelines carrying products at elevated temperatures was excluded from the analysis.
- Although the location of failures (e.g. rural or urban) may be recorded in the various databases, it is recognised that there is insufficient data to estimate the leak frequency for different locations.
- The recommended failure rates for specific materials have been derived from the most appropriate dataset (e.g. for a specific substance the failure rates for corrosion may derived from the CONCAWE products dataset, whilst the mechanical failure rates may be derived from the UKOPA dataset).

NSW Performance Report

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

UK HSE (RR1035)

The is no leak frequency data specifically for Ethane in RR1035. The data for natural gas (methane), ethylene and LPG (propane and butane) was reviewed. The data for LPG was selected as it is slightly more conservative for the larger leak diameters and is more applicable for a liquefied gas.

The total leak frequency data reported in Section 7.6 of RR1035 for underground LPG pipelines is slightly more conservative (e.g. 2.1E-04 per km per year for a pipeline with wall thickness ≥ 5 mm to < 10 mm) and was adopted in the QRA for the underground HP Ethane pipeline (Refer to Table 33).

Table 33 Leak Frequencies for Underground LPG Pipelines

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

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

The data and approach included in Annex B of PD 8010-3:2009+A1:2013 was used to estimate the leak frequencies for the Moomba to Sydney Ethane Pipeline (Refer to Table 34). The data applicable for a pipeline with a wall thickness of 8.1 mm, manufactured after 1980, was used.

Leak frequency data is not reported for internal corrosion; therefore, the total leak frequencies reported in Table 34 may be underestimated.

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

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

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

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

Table 34 Approx. Leak Frequencies for Underground Ethane Pipeline

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

US Department of Transportation (DoT)

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

To enable a comparison with the UK data, the data for all Highly Volatile Liquids (Except Ammonia) was analysed and the leaks categorised using the same representative hole sizes as reported in the UK (i.e. RR1035 and PD8010). The results are reported in Table 35.

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

Table 35 Leak Frequencies for Underground HVL Pipelines (Excluding Ammonia)

Failure Mode	Approx. Leak Frequency (per km per yr)					Comments
	Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency	
Mechanical Failure	3.9E-05	0.0E+00	0.0E+00	0.0E+00	3.9E-05	Excludes pipelines manufactured prior to 1980.
Corrosion	5.6E-06	0.0E+00	0.0E+00	1.1E-06	6.7E-06	Excludes external corrosion (other than SCC).
Ground Movement / Other	5.6E-06	2.2E-06	1.1E-06	5.6E-06	1.4E-05	
TPA	8.9E-06	6.7E-06	2.2E-06	8.9E-06	2.7E-05	
Total Leak Freq. =	5.9E-05	8.9E-06	3.3E-06	1.6E-05	**8.7E-05**	
% =	67.9	10.3	3.8	17.9		

Australia /New Zealand Pipeline Incident Database

A comparison with limited Australian data between 2000 and 2018 extracted from the report "Experience with the Australian/New Zealand Pipeline Incident Database" [16] has been undertaken. The report [16] does not provide explicit rates for loss of containment from pipelines but provides data from which some conclusions may be drawn. These are:

- Total km of pipelines within a given interval (Table 36), and
- Total number of leaks and ruptures in the period 2000 to 2018. A total of 17 are reported in the database.

Table 36 Australian Pipeline Population by Half Decade [16]

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

From Table 36 and the total of 17 release incidents, the expected total release frequency is

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

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

C.2 Ignition Probability

The ignition probabilities adopted in the risk analysis are listed below. This was based on a review of relevant ignition probability data and ignition probability correlations (Refer to Sections C.2.1 - C.2.3).

Ethane

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

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

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

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

Natural Gas

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

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

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

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

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

C.2.1 Ignition Probability Data for Above Ground or Underground Cross-Country Pipelines – Various Materials

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

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

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

Table 37 Ignition Probability - UKOPA

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

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

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

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

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

Table 38 Ignition Probability – OGP Scenario 3

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

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

C.2.2 Ignition Probability Data for Underground Cross-Country Pipelines – Flammable or Combustible Liquids

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

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

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

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

(1) Not otherwise reportable under this section;

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

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

(4) Cleaned up promptly;

(c) Death of any person;

(d) Personal injury necessitating hospitalisation;

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

Table 39 Ignition Probability – US DoT

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

* Highly Volatile Liquids (Includes Ethane).

C.2.3 Ignition Probability Data for Underground Cross-Country Pipelines – Gases Other Than Natural Gas

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

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

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

Table 40 Ignition Probability – UK HSE (RR 1034)

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

(1) For example: ethylene

(2) For example: butane, ethane and propane

(3) For example: ammonia, carbon monoxide

C.2.4 Ignition Probability Data for Underground Cross-Country Pipelines – Natural Gas

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

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

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

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

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

P_{ign} = probability of ignition

p = pipeline operating pressure (bar)

d = pipeline diameter for ruptures (m)

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

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

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

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

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

Table 41 Ignition Probability – Acton & Baldwin

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

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

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

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

Table 42 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 43 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 44 Ignition Probability – Data Cited by UK HSE (RR 1034)

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

C.3 Likelihood of Representative Release Scenarios

The estimated likelihood of each representative release scenario is listed in Table 45.

Table 45 Release Frequency – Ethane Pipeline (MSE)

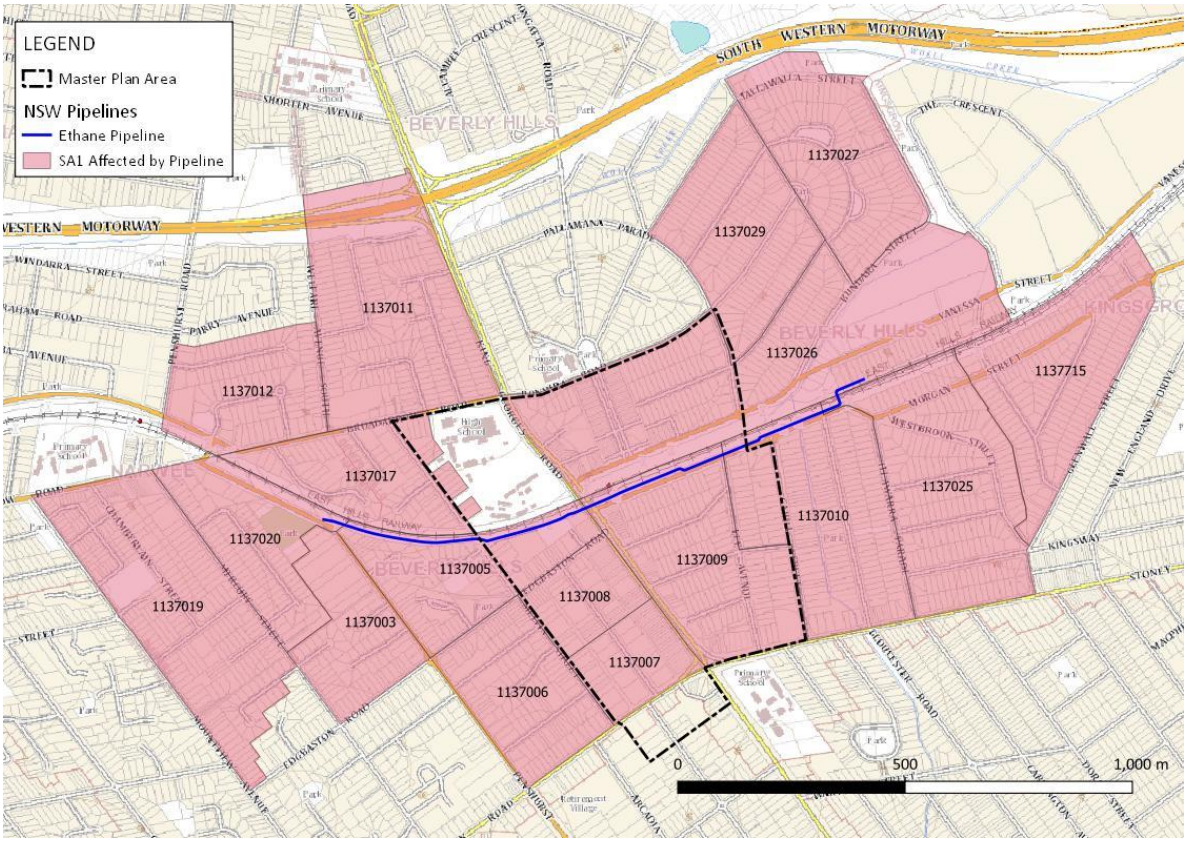
Leak Scenario	Release Frequency (per km per year)			Probability of scenario compared to total
	TPA	All Other Failure Modes	Total Release Frequency	
10mm MID		1.53E-04	1.53E-04	0.7200
10mm TOP		0.00E+00	0.00E+00	0.0000
25mm MID	2.20E-05		2.20E-05	0.1036
25mm TOP	0.00E+00		0.00E+00	0.0000
75mm MID	2.40E-06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

Appendix D Population Analysis

D.1 Current Residential Population

The 2016 Census Level 1 Statistical Areas (SA1) and their 7 Digit codes that are considered in the study are shown in Figure 21. Note that SA 1 1137017 shown in Figure 21 has had the areas of the Beverley Hills Gorls High School removed to highlight that the school population has been treated independently from the residential population.

Figure 21 2016 SA1 Areas Considered in Study



At the time of writing, the 2021 Census results are unavailable. An estimate of the 2021 population in each SA1 is based upon the LGA within which the SA1 is located and the NSW DPIE estimate for population growth in the LGA (Table 46). Table 47 presents both the 2016 Census population figures and the 2021 estimate for population. The population in Table 47 has been used for both night-time and non-working day population in the PHA.

Table 46 DPIE Projections of Population by LGA and Year

LGA	2016	2021	2026	2031	2036	2041	Population Increase to 2021
Canterbury-Bankstown	361,862	396,288	432,566	463,956	482,222	514,653	9.5%
Georges River	153,161	161,521	173,604	179,982	182,983	190,221	5.5%

Table 47 2016 Census Results by SA1 and Estimated Population in 2021

SA1	LGA	2016	2021
1137003	Georges River (A)	339	358
1137005	Georges River (A)	427	450
1137006	Georges River (A)	449	474
1137007	Georges River (A)	530	559
1137008	Georges River (A)	398	420
1137009	Georges River (A)	395	417
1137010	Georges River (A)	521	549
1137011	Canterbury-Bankstown (A)	717	785
1137012	Canterbury-Bankstown (A)	361	395
1137017	Georges River (A)	490	517
1137019	Georges River (A)	816	861
1137020	Georges River (A)	487	514
1137025	Georges River (A)	547	577
1137026	Georges River (A)	646	681
1137027	Georges River (A)	338	356
1137029	Georges River (A)	393	414
1137715	Georges River (A)	418	441

Day-time population may be significantly different from night-time population as people move from home to workplaces. The 2016 Census has again been used to estimate the population that remains in residential areas during the day. All but one of the SA1 areas under examination are in the Narwee - Beverly Hills Level 2 Statistical Areas (SA2). The Narwee-Beverly Hills SA2 has been used for the analysis of employment and work patterns, and it is assumed the results may be applied generally to the SA1 areas.

There is only one educational institution in the area under consideration, Beverly Hills Girls High School and the accompanying Intensive English Language School., and the school population is considered separately. Therefore all people engaged in some form of education with the exception of Preschool were considered to leave the area during the day. This was factored by the part-time (0.5) or full-time status (1.0) of the person. All primary and Secondary students were assumed to be in full time education.

TYSTAP Educational Institution: Attendee Status	Number	Factor	Adjusted Number
Preschool	196	0	0
Infants/Primary - Government	687	1	687
Infants/Primary - Catholic	240	1	240
Infants/Primary - Other Non Government	67	1	67
Secondary - Government	538	1	538
Secondary - Catholic	202	1	202
Secondary - Other Non Government	90	1	90
Technical or Further Educ Inst (incl. TAFE Colleges): Full-time student: Aged 15-24 years	42	1	42
Technical or Further Educ Inst (incl. TAFE Colleges): Full-time student: Aged 25 years and over	58	1	58
Technical or Further Educ Inst (incl. TAFE Colleges): Part-time student: Aged 15-24 years	33	0.5	16.5
Technical or Further Educ Inst (incl. TAFE Colleges): Part-time student: Aged 25 years and over	79	0.5	39.5
Technical or Further Educ Inst (incl. TAFE Colleges): Full-time/Part-time student status not stated	0	1	0
University or other Tertiary Institution: Full-time student: Aged 15-24 years	540	1	540
University or other Tertiary Institution: Full-time student: Aged 25 years and over	161	1	161
University or other Tertiary Institution: Part-time student: Aged 15-24 years	61	0.5	30.5
University or other Tertiary Institution: Part-time student: Aged 25 years and over	105	0.5	52.5
University or other Tertiary Institution: Full-time/Part-time student status not stated	3	1	3
Other: Full-time student	71	1	71
Other: Part-time student	70	0.5	35
Other: Full-time/Part-time student status not stated	3	1	3
Type of educational institution not stated	778	0	0

TYSTAP Educational Institution: Attendee Status	Number	Factor	Adjusted Number
Type of educational institution not applicable	9758	0	0
Total	13781		2876

Hours Worked	Number	Factor	Adjusted Number
None	151	0	0
1-15 hours	634	0.210526	133
16-24 hours	691	0.526316	364
25-34 hours	603	0.776316	468
35-39 hours	1,336	1	1336
40 hours	1,300	1	1300
41-48 hours	474	1	474
49 hours and over	628	1	628
Not stated	152	0	0
Not applicable	7,826	0	
Total	13,781		4703

In addition, 129 people nominated that they work from home within the Narwee-Beverly Hills SA2.

The fraction of people remaining in the residential areas of Narwee-Beverly Hills less those leaving for education or work, plus those who work from home.

Table 48 Analysis of Fraction of Population Remaining During Working Days

Total population	13781
Leave residential area for education	-2876
Leave for employment	-4703
Work from home in the local area	129
Remain in residential area outside schools and workplace	6331
Fraction of population in residential area during the day.	**46%**

SA1	LGA	2016	2021
1137003	Georges River (A)	153	161
1137005	Georges River (A)	192	202
1137006	Georges River (A)	202	213
1137007	Georges River (A)	239	252
1137008	Georges River (A)	179	189
1137009	Georges River (A)	178	188
1137010	Georges River (A)	234	247
1137011	Canterbury-Bankstown (A)	323	354
1137012	Canterbury-Bankstown (A)	162	177
1137017	Georges River (A)	221	233
1137019	Georges River (A)	367	387
1137020	Georges River (A)	219	231
1137025	Georges River (A)	246	259
1137026	Georges River (A)	291	307
1137027	Georges River (A)	152	160
1137029	Georges River (A)	177	187
1137715	Georges River (A)	188	198

D.2 Future Residential Population

Residential population has been assumed to be only in areas identified for further residential development. This includes areas within the Study Area, and the Narwee Housing Investigation Area (HIA). The areas for residential intensification are shown in

Figure 22 Future Possible Residential Intensification

D.3 Current Employment

Current estimates of employment in the Study Area has been obtained from GRC and is based upon 29,320 m^2 of existing non-residential floor space in the Study Area and one job per 25 m^2 floor area. The estimated current employment is 1,169. This compares well with the 1,754 people identifying as having a place of work in the Narwee-Beverly Hills SA2 and the existing commercial area in the Study Area comprising approximately 54% of the total business and industrial zoned land in the SA2.

D.4 Future Employment

The forecast of employment in the Study Area has been obtained from GRC and is based upon 64,493 m^2 of future non-residential floor space in the Study Area and more intense employment to area ratio of one job per 20 m^2 floor area. It has been assumed this population will be present during both working and non-working days. The estimated future employment is 3,225, or an additional 2056 employment opportunities.