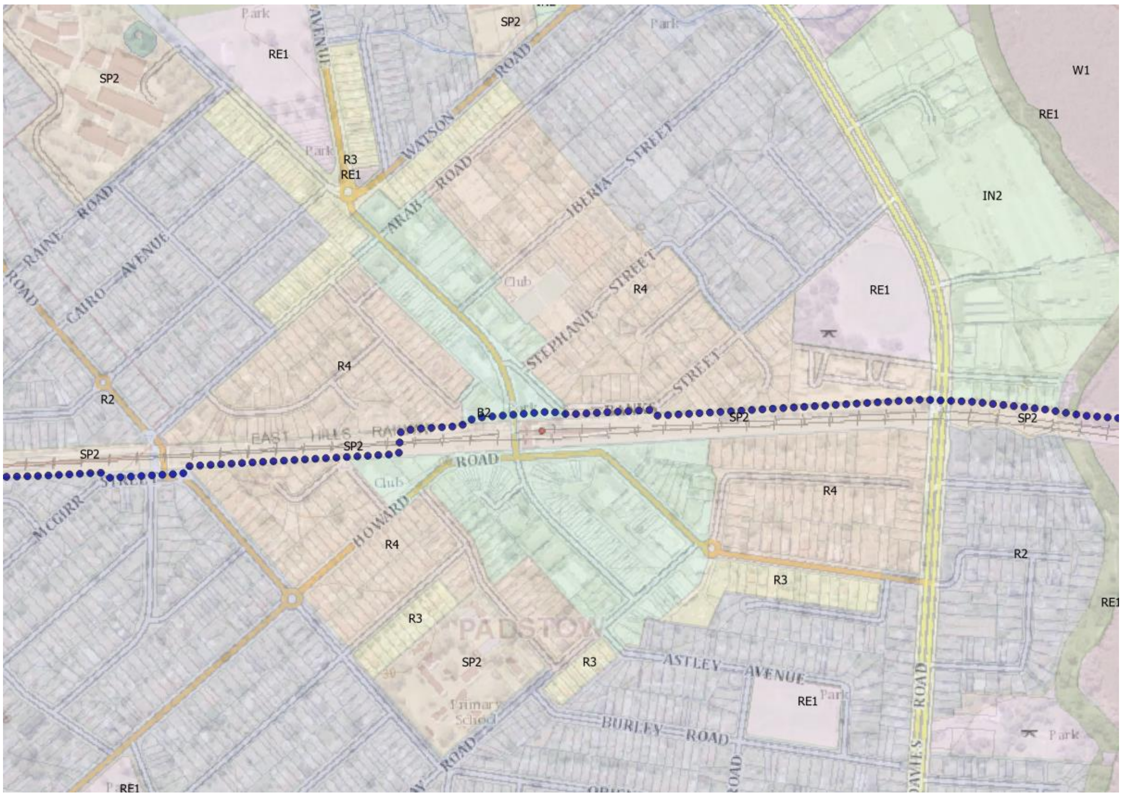
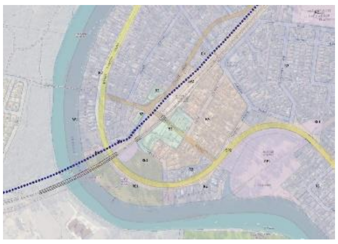
LUSS for the Moomba-Sydney High Pressure Ethane Pipeline

For Canterbury Bankstown Council

1 July 2022





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Document History and Authorisation

Rev	Date	By	Description	Check	Approved
A	10-Jun-22	JL	First draft for client review.	PS	JL
B	28-Jun-22	JL	Incorporating client comments	PS	JL
C	29-Jun-22	JL	Incorporating Fire Engineering comments on DtS provisions of NCC	PS	JL
D	1-Jul-22	JL	Change to SGA Fire recommendations and additional notes on population estimates.		JL

Summary

The Canterbury Bankstown Council (CBC) has developed a draft consolidated Local Environmental Plan (LEP) that includes the rezoning of sites within the four town centres along the East Hills railway (Padstow, Revesby, Panania, and East Hills). The plan aims to accommodate projected population growth in the area, utilising existing infrastructure.

The presence of the Moomba Sydney Ethane pipeline (MSE) in the area creates an industrial risk, and CBC requested Arriscar Pty Limited (Arriscar) prepare a Land Use Safety Study (LUSS) relating to the MSE along the East Hills railway corridor within the City. This report summarises the LUSS activity, and recommendations to reduce land use conflicts between city revitalisation and transport of ethane through the high pressure transmission pipeline.

In developing the estimates for use in any LUSS, 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 DP&E’s guidelines for undertaking this type of assessment.

Findings

The following findings were made from the risk assessment:

- The individual risk of fatality within some properties along the route of the MSE exceeds 1.0×10^{-6} p.a., but is always less than 10×10^{-6} p.a. The DP&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.
- If the relevant planning instruments are modified so that buildings within the area defined by the outdoor 1.0×10^{-6} p.a. contour have increased fire resistance, the LSIR, as defined by indoor risk levels is less than 1.0×10^{-6} p.a., and intensification may be permitted.
- The individual risk of fatality within some properties exceeds the DP&E criterion for sensitive use development (0.5×10^{-6} p.a.). There should be no intensification of sensitive use development in these properties.
- The individual risk of fatality never exceeds 5.0×10^{-6} p.a. and therefore intensification of other land uses (such as business use) as proposed within the Study Area is consistent with DP&E criteria.
- In consultation with CBC, the following argument is put forward that the LEP has reduced risk to as low as reasonably practicable:
    - Quantitative LSIR criteria for development in the vicinity of hazardous facilities are satisfied after additional development controls are put in place to increase the fire resistance of dwellings in the vicinity of the MSE,
    - The societal risk is in the ALARP region, but is not intolerable,
    - The societal benefits of developing an LEP consistent with the plans and strategies listed in 1 – 5 below outweigh the risk reduction that could be obtained by further

restricting development near the pipeline, and hence also near already existing public transport infrastructure:

1. Greater Cities Commission's *Greater Sydney Region Plan*
2. Greater Cities Commission's *South District Plan*
3. Department of Planning and Environment's *Ministerial Direction 5.1 (Integrating Land Use and Transport)*
4. Transport for NSW's *Future Transport 2056*
5. Council's *Connective City 2036* and Housing Strategy

- Similarly, further measures to address the HIPAP 4 qualitative criteria in addition to the recommendations made for the draft LEP are not reasonably practicable while also delivering the societal benefits of the *Greater Sydney Region Plan.*

Recommendations

1. Restrict sensitive use developments on properties where the outdoor LSIR is greater than 0.5 x 10^{-6} p.a. Sensitive use developments are those for use by sectors of the community who may be unable to protect themselves from the consequences of a pipeline failure event, and include the following land uses as per Standard Instrument—Principal Local Environmental Plan (2006 EPI 155a) – NSW Legislation:
   - School
   - Hospital
   - Seniors housing
   - Respite day care centre
   - Early education and care facility
   - Correctional centre

   The properties where this restriction applies are those bounded by the green lines in Figure 17 through to Figure 20.

2. Ensure development on land where the outdoor individual risk of fatality is greater than 1 x 10^{-6} p.a. incorporates risk mitigation measures for features exposed to the pipeline to withstand a heat flux of 20 kW/m^2. With reference to Table CV1 of the NCC, this would be the equivalent to incorporating measures as if the building is 3 m from an allotment boundary. Deemed to satisfy (DtS) provisions for this requirement include:
   - Fire-resisting construction (shafts, walls, floors, roofs)
     - Fire-resistance level (FRL) dependent on the type of construction required, but details specified in BCA Spec C1.1.
     - Note: FRL is achieved when subjecting a system to the AS1530.4 standard fire test.
   - Openings exposed to the pipeline (i.e., doors, windows – if any) protected in accordance with BCA Clause C3.4, with measures such as:
     - Fire-rated windows, drenchers, fire-shutters etc.
     - Note: If passive protection is relied upon, the system would need to achieve the same FRL as the fire-resisting element it is located within.

- Service openings (e.g., mech, hydraulic – if any) protected in accordance with BCA Clause C3.15.
- Construction joints, spaces and the like in and between building elements required to be fire resisting (including external walls) with respect to integrity and insulation must be protected in a manner identical to a tested prototype in accordance with AS1530.4-2012 to achieve the required FRL.
- Exits must discharge into locations that are shielded and away from the pipeline location.
- The proponent must prepare an appropriate emergency response plan/s for use by the building occupants.

The objective is to ensure development on land where the outdoor individual risk of fatality is greater than 1 x 10-6 p.a. is constructed to withstand 20 kW/m^2 as per Table CV1, Volume 1 of the National Construction Code. The properties impacted by this recommendation are those within the red lines on Figure 13 through to Figure 16.

3. Ensure construction activities in the Study Area do not impact upon the existing potentially hazardous pipelines. At the development application stage, the proponent should demonstrate how this will be achieved by submitting a safety management study in accordance with the State Environmental Planning Policy (Transport and Infrastructure) 2021.

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Notation

Abbreviation	Description
24/7	24 hours in the day, 7 days a week
ABS	Australian Bureau of Statistics
AG	Above Ground
ALARP	As Low As Reasonably Practicable
APA	APA Group
Arriscar	Arriscar Pty Limited
AS	Australian Standard
BoM	Bureau of Meteorology
BSI	British Standards Institute
CBC	Canterbury Bankstown Council
CFR	Code of Federal Regulations (USA)
CONCAWE	CONservation of Clean Air and Water in Europe
CP	Cathodic Protection
DBYD	Dial Before You Dig
DG	Dangerous Good
DN	Diameter Nominal
DoT	Department of Transport (USA)
DP&E	NSW Department of Planning and Environment
DtS	Deemed to Satisfy
EGIG	European Gas Industry Group
FBR	Full Bore Rupture
F-N	Cumulative Frequency vs. Number of Fatalities
HDD	Horizontal Directional Drilling
HIPAP	Hazardous Industry Planning Advisory Paper
HRA	Hazard and Risk Assessment
HSL	Health & Safety Laboratory (UK)
HVL	Highly Volatile Liquid (includes ethane)
kg	kilograms
kg/m3	kilograms/ cubic metre
kg/s	kilograms/ second
km	kilometres

Abbreviation	Description
kPa	kilo-Pascals
kPag	kilo-Pascals gauge
kW/m2	Kilo-Watts per square metre
LEP	Local Environment Plan
LFL	Lower Flammability Limit
m	metres
m/s	metres per second
m^2	Square metres
m^3	Cubic metres
MAE	Major Accident Event
MAHP	Major Accident Hazard Pipeline
MAOP	Maximum Allowable Operating Pressure
mg/m^3	milligrams per cubic metre
mm	millimetres
MSE	Moomba – Sydney Ethane pipeline
NA	Not Available
NCC	National Construction Code
OGP	International Association of Oil & Gas Producers
OSHA	Occupational Safety and Health Agency (USA)
PHMSA	Pipeline and Hazardous Materials Safety Administration
psig	Pounds per Square Inch Gauge
PSR	Pipelines Safety Regulations
QRA	Quantitative Risk Assessment
s	second
SCADA	Supervisory Control and Data Acquisition
SDS	Safety Data Sheet
TNO	The Netherlands Organisation for applied scientific research
TPA	Third Party Activity
UFL	Upper Flammability Limit
UG	Underground
UK HSE	UK Health & Safety Executive
UKOPA	UK Onshore Pipeline Operators Association
v/v	Volume fraction

Abbreviation	Description
VCE	Vapour Cloud Explosion
VIC EPA	Victorian Environment Protection Authority
W/m^2	Watt per square metre

1 INTRODUCTION

The City of Canterbury Bankstown (the City) was proclaimed on the 12 May 2016, and at June 2018, had the largest local government resident population in NSW. It is located between eight and 23 kilometres south-west of the Sydney CBD.

The City covers an area just over 100 square kilometres, with 41 suburbs and 30 urban centres. Four of the urban centres, Padstow, Revesby, Panania and East Hills are located along the East Hills railway corridor. Along the railway corridor also runs the high-pressure Moomba Sydney Ethane pipeline (MSE).

The Canterbury Bankstown Council (CBC) has developed a draft consolidated Local Environmental Plan (LEP) that includes the rezoning of sites within the the four town centres along the East Hills railway corridor. The plan aims to accommodate projected population growth in the area, utilising existing infrastructure.

The presence of the MSE in the area creates an industrial risk, and CBC engaged Arriscar Pty Limited (Arriscar) prepare a Land Use Safety Study (LUSS) relating to the MSE along the East Hills railway corridor within the City.

2 SITE DESCRIPTION

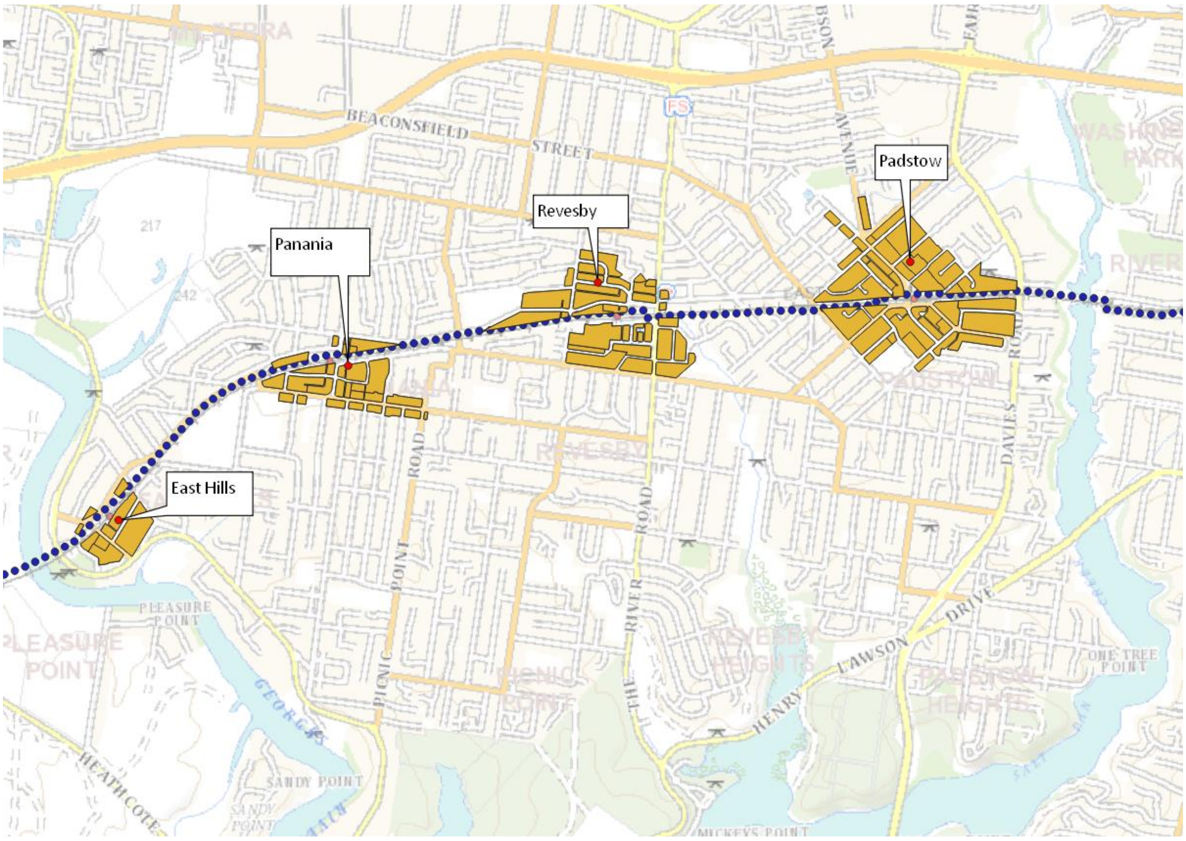
2.1 Town Centres and Land Use

There are four distinct town centres in the study area of interest, from East to West:

- Padstow
- Revesby
- Panania
- East Hills

The locations of the four town centres comprising the scope of the study are shown in Figure 1.

Figure 1 Town Centre Locations



The land use and height of buildings proposed in the draft LEP are shown in Figure 2 through to Figure 9. Of note, the tallest allowable building height of the four town centres is in Revesby (Figure 5) and includes properties either abutting the MSE easement or through which the easement travels.

Figure 2 Padstow Town Centre – Proposed Land Use

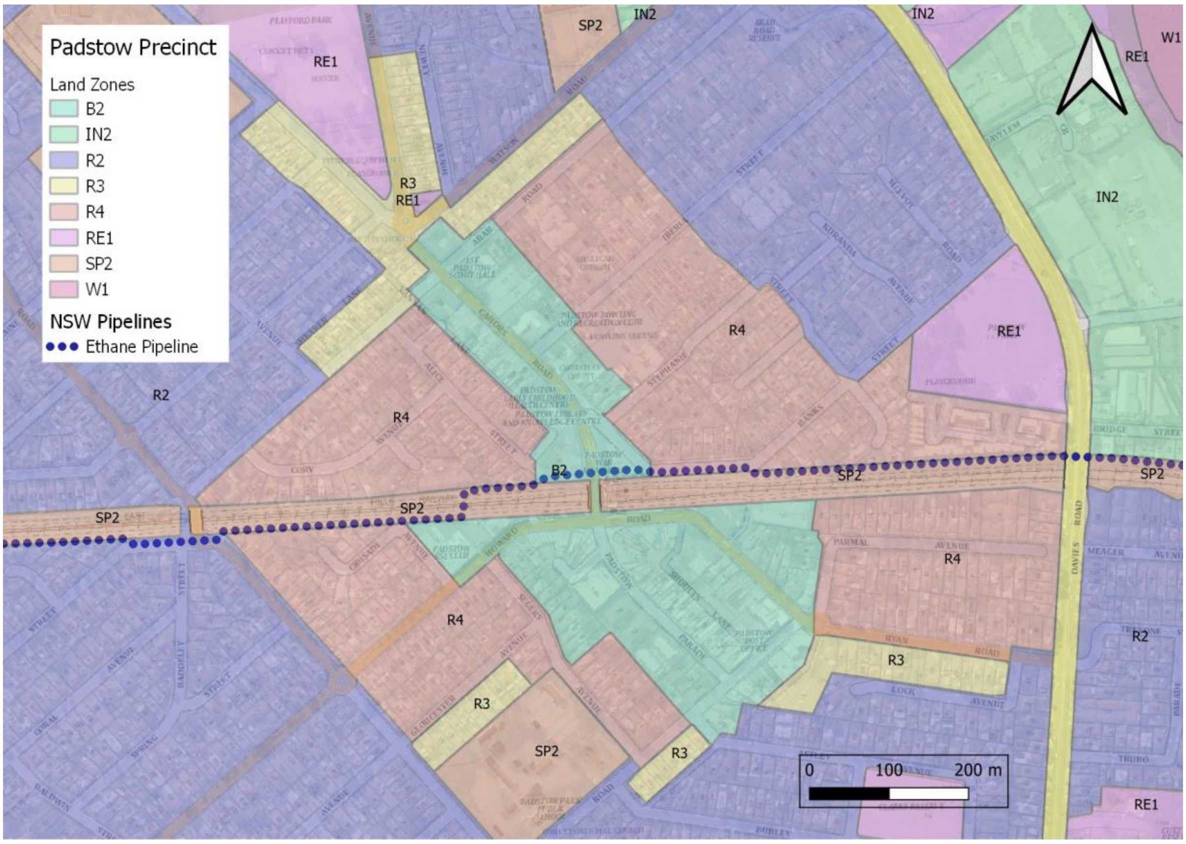


Figure 3 Padstow Town Centre – Proposed Height of Buildings

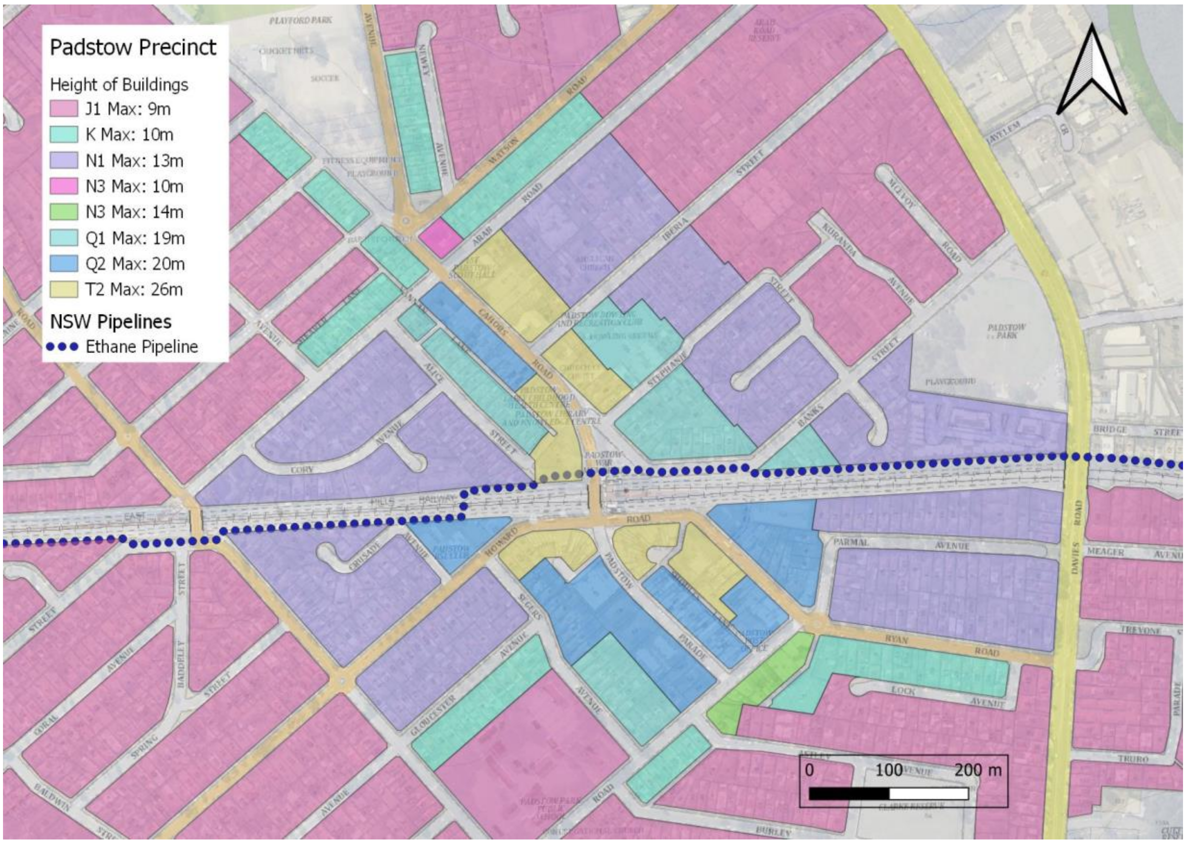


Figure 4 Revesby Town Centre – Proposed Land Use

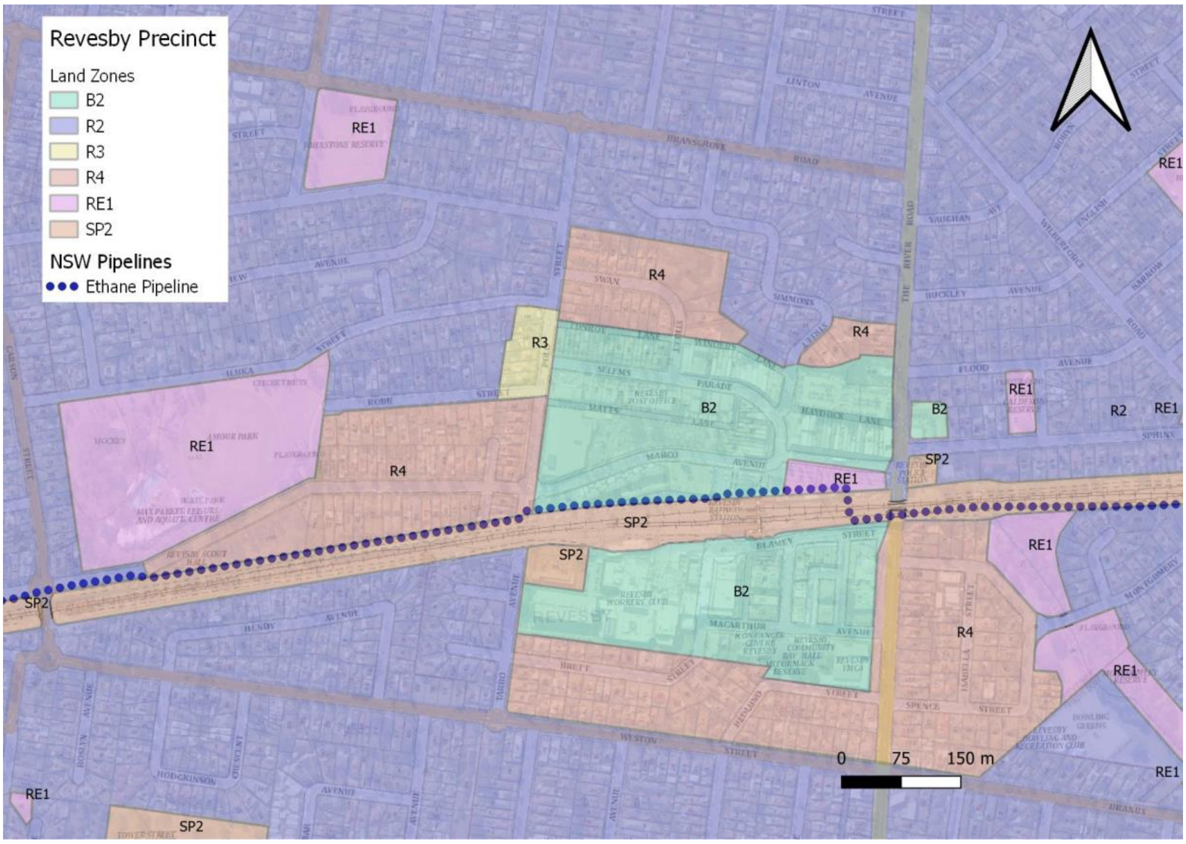


Figure 5 Revesby Town Centre – Proposed Height of Buildings

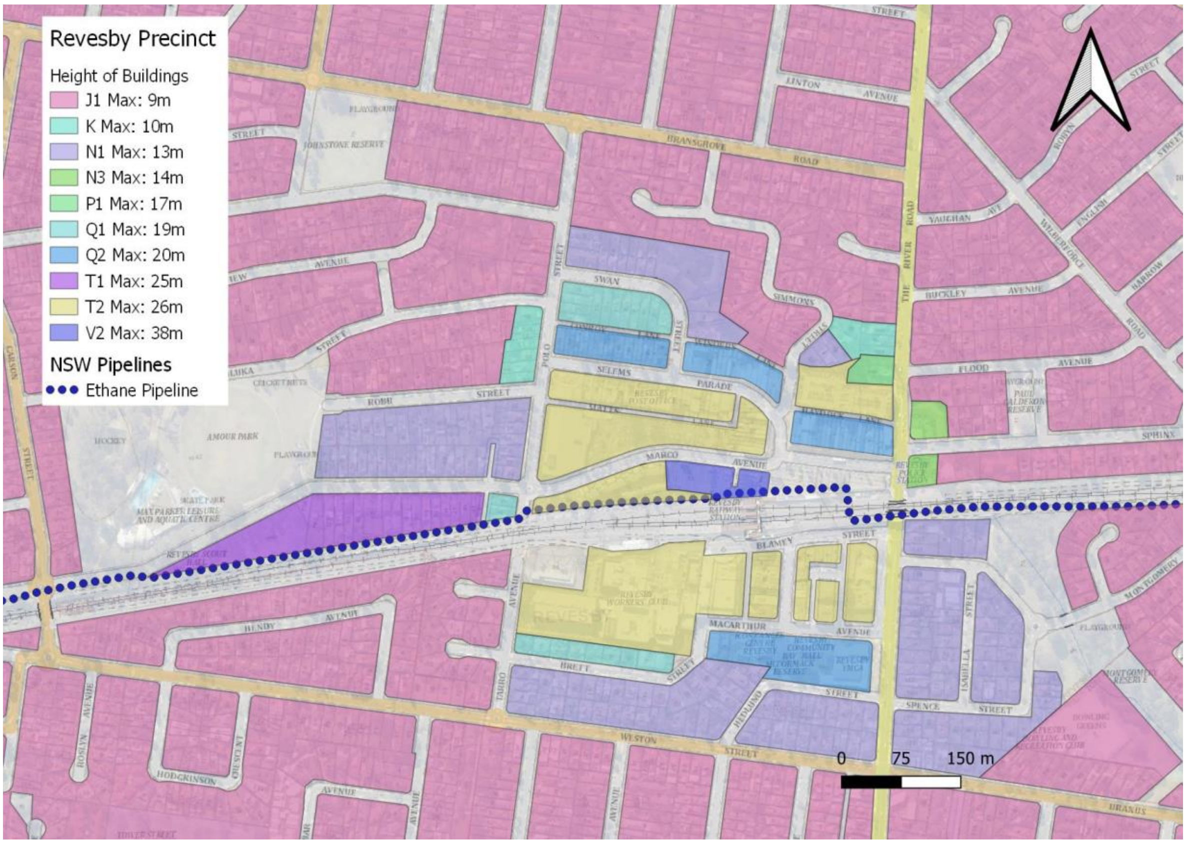


Figure 6 Panania Town Centre – Proposed Land Use

Figure 7 Panania Town Centre – Proposed Height of Buildings

Figure 8 East Hills Town Centre – Proposed Land Use

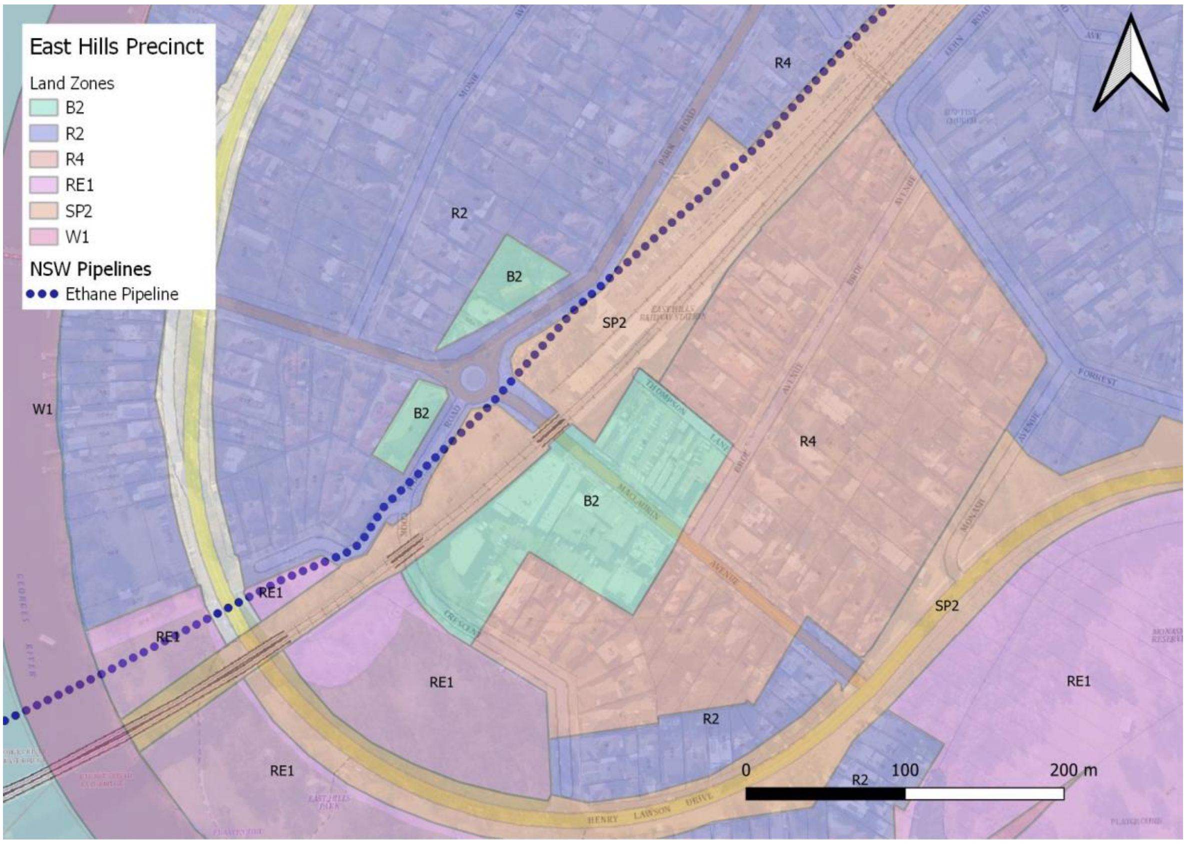
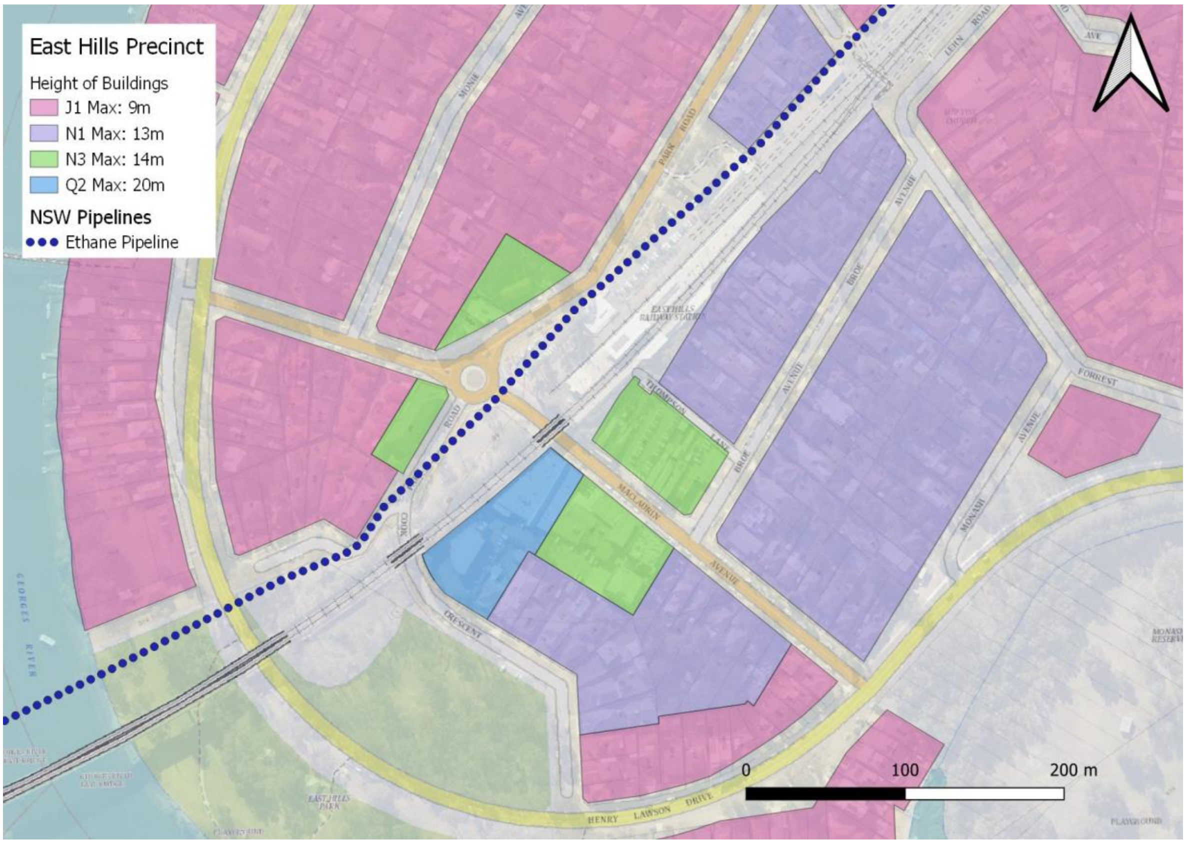


Figure 9 East Hills Town Centre – Proposed Height of Buildings



2.1.1 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

Stab. Class	D	D	D	E	F	Total
Wind Speed (m/s)	7.3	4	1	2.6	1	
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
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

2.2 Surrounding Suburbs and Populations

2.2.1 Existing Residential Population

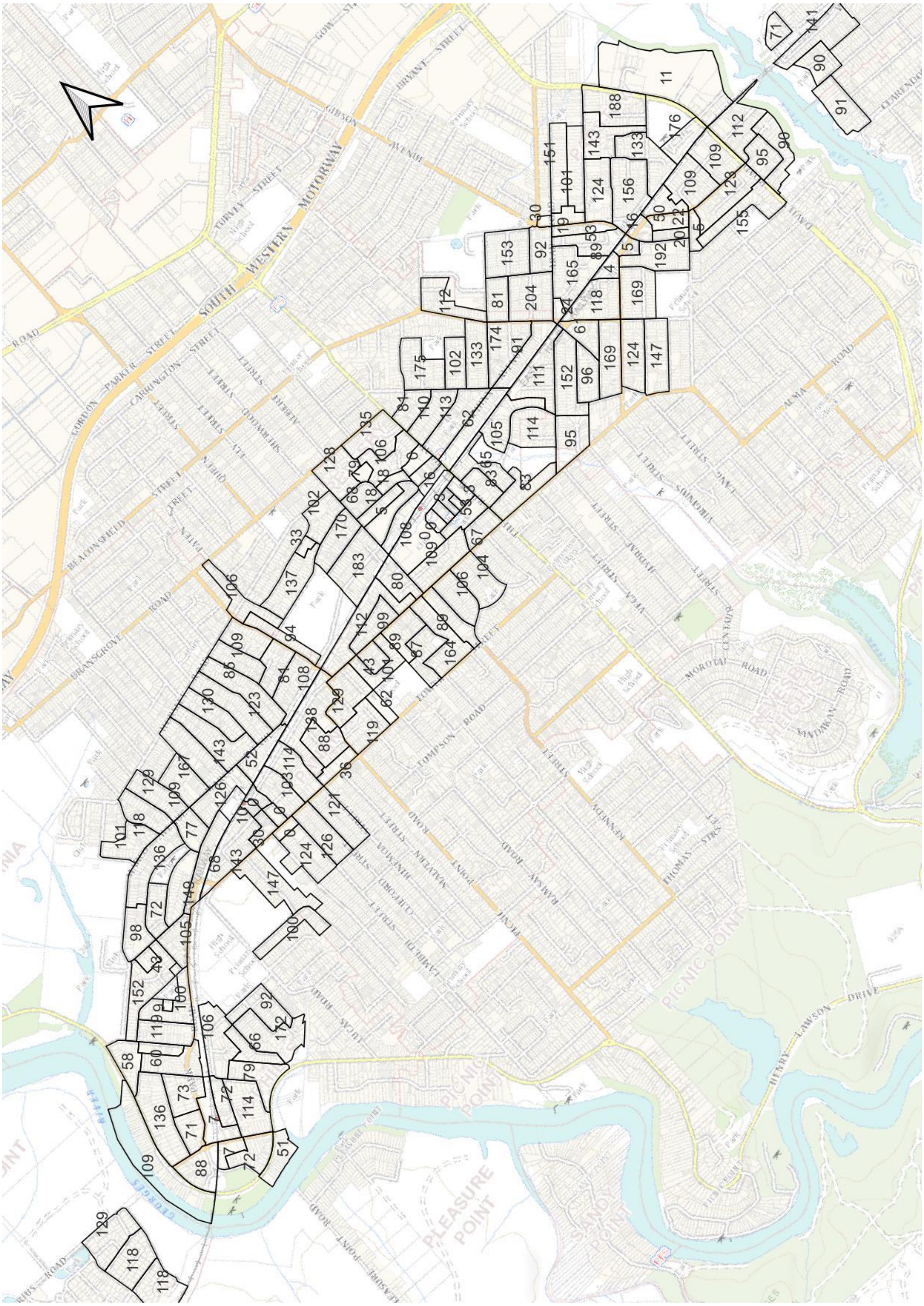
The current residential population has been based on the mesh block counts of the 2016 Census of Housing and Population. The current population used for the study is shown in Figure 10. This has been assumed to be the population present during the night.

Mesh blocks outside the CBC local government area have been included for societal risk calculations as these mesh blocks could be impacted by events that also impact the town centres within the scope of this study.

Day time population has been assumed to be 40% of the night-time population.

The future population growth for the Study area has been assumed to occur only in the town centres. This is further discussed in Section 2.2.3.

Figure 10 Current Population in the Surrounding Area, 2016 Census Mesh Block Count



2.2.2 School Population

There are seven schools in the area of interest. The estimated daytime population for each school has been determined using the 2016 enrolments and full time equivalent (FTE) staff as published in the My School website (https://myschool.edu.au/). The FTE staff, student enrolments and total estimated population are presented in Table 3. No increase in school population has been considered in the study.

Table 3 Nearby School Populations

School	Staff	Students	Total
East Hills Public School	17	156	173
Southside Montessori School	9	47	56
East Hills Girls Technology High School	83	1050	1133
Tower Street Public School	13	189	202
St. Christopher's Catholic Primary School	34	561	595
Padstow Park Public School	28	342	370
East Hills Boys Technology High School	76	818	894

2.2.3 Commercial and Future Town Centre Populations

CBC provided estimates of the existing and future populations based on 2016 Census results for average people per dwelling in the Statistical Area 1 geographies associated with the town centres, and an assumption that the workforce would average 1 person per 20 m^2 Gross Floor Area (GFA). As the existing residential population is already considered in Section 2.2.1, only the incremental residential population was considered for the town centres, while the total future workforce was also considered, because the existing workforce was not considered in the existing residential population.

For the model, the workforce was distributed proportionally by land area amongst all land zoned for mixed use activity (B2). The incremental residential population was distributed proportionally based on building volume available for residential use. This was the land area multiplied by maximum building height for residential zones, and land area multiplied by maximum building height less six metres for mixed use areas. This assumed the bottom two floors of mixed use zones were commercial and only floors above the commercial floors were available for residential purposes.

The total additional residential populations and future workforce in each of the town centres are presented in Table 4 and Table 5. The distribution of the population within the town centres during day-time and night-time is presented in Table 4, and also Appendix A Figure 22 through to Figure 25

Table 4 Town Centre Residential Population Analysis

Town Centre	2016 Existing Average Household size (SA1)	2016 Population (SA1)	Estimated additional population subject of draft LEP 2022	Total estimated additional population (current controls and LEP 2022 changes)	Total population (Existing +estimated)
East Hills	2.55	881	697	765	**1646**
Panania	2.84	999	1011	1562	**2561**
Revesby	2.76	1904	2162	3036	**4940**
Padstow	2.72	2711	666	2040	**4751**

** Note: Only part of the population growth forecast in these centres is a result of the planned uplift. The forecast population in these centres is a combination of potential for new residents under the LEP 2022, in addition to what is permitted under current planning controls.*

Table 5 Town Centre Workforce Analysis

Town Centre	Existing Commercial GFA (sqm)	Existing Workers (1 per 20sqm)	Estimated Additional Commercial GFA	Estimated Additional Workers (1 per 20sqm)	Total workers (Existing +estimated)
East Hills	6,184	309	No change	No change	**309**
Panania	15,554	778	9,812	491	**1,268**
Revesby	63,041	3,152	9,204	460	**3,612**
Padstow	32,907	1,645	17,155	858	**2,503**

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. The pipeline is owned by APA Group. Information obtained from APA about the MSE in a similar location is presented in Table 6.

Table 6 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
Pipeline Wall Thickness	11.9mm in area of concern
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.

Description	MSE Pipeline
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

3 RISK ASSESSMENT METHODOLOGY

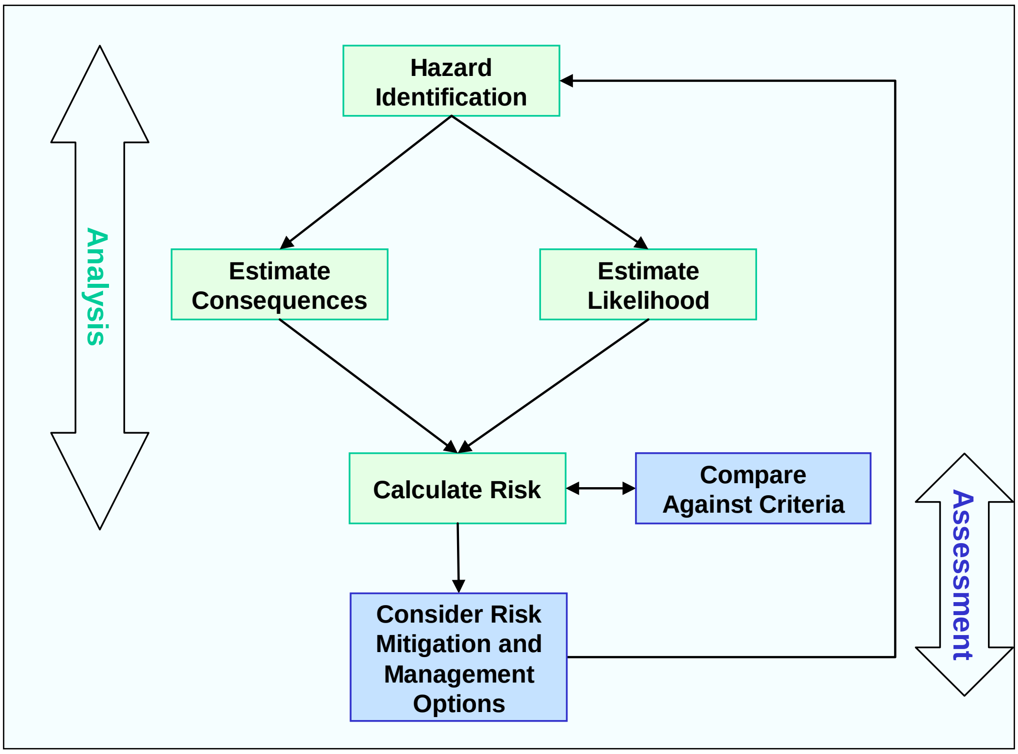
3.1 Introduction

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 DP&E's guidelines for undertaking this type of assessment [1].

Diagrammatically, the QRA process is as follows:

Figure 11 Overview of QRA Process [1]



3.2 Methodology Overview

3.3 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 DP&E has defined an acceptable risk criterion – Refer to Section 3.5).

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.

3.3.1 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.

3.3.2 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 Overpressure

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 7 and Table 8.

Table 7 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 8 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 – Radiant Heat

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 9 depicts the probability of fatality for various radiation intensities and a thirty second exposure.

Table 9 Probability of Fatality for 30 Second Outdoor Exposure

Heat Flux (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

Buildings provide some protection to occupants from radiated heat. The vulnerability of building occupants to heat flux received on the *outside of buildings* used in this study is given in Table 10.

Table 10 Probability of Fatality Inside a Buildings Exposed to Given Heat Flux

Outside Heat Flux (kW/m^2)	Probability of Fatality
4.7	0
10	0.03
20	0.30
35	1.0

<u>Fire – Flash Fire</u>

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.

3.3.3 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.

3.3.4 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 8.61 software package was used to generate the iso-risk contours / transects and societal risk results (Refer to Section 6).

3.4 Study Assumptions

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

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

3.5 Quantitative Risk Criteria

3.5.1 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 DP&E [2] and [3].

The following criteria apply to *residential and sensitive use development* in the vicinity of existing industry [2]:

- *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.*

Note that the third dot point criterion effectively overrides that of the second dot point.

The DP&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.

Sensitive use as defined in 2885.6 is land “developed for use by sectors of the community who may be unable to protect themselves from the consequences of a pipeline failure event” and includes “schools, hospitals, aged care facilities and prisons”. HIPAP documents provide examples only; “such as schools, nursing homes and hospitals”. Based on the broad definition in AS 2885.6, and examples provided, the following land uses as per Standard Instrument—Principal Local Environmental Plan (2006 EPI 155a) - NSW Legislation dictionary could be considered “sensitive”:

- School
- Hospital
- Seniors housing
- Respite day care centre
- Early education and care facility
- Correctional centre

3.5.2 Other Land Uses

Criteria for land uses other than Residential and Sensitive are presented in Table 11

Table 11 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'.

3.5.3 Injury Risk

The DP&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 [3] for potential injury caused by exposure to heat radiation, explosion overpressure and toxic gas/ smoke/dust.

The DP&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 DP&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 DP&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.*

3.5.4 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 DP&E's criteria for risk of damage to property and accident propagation are as follows [3]:

- *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.*

3.6 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.

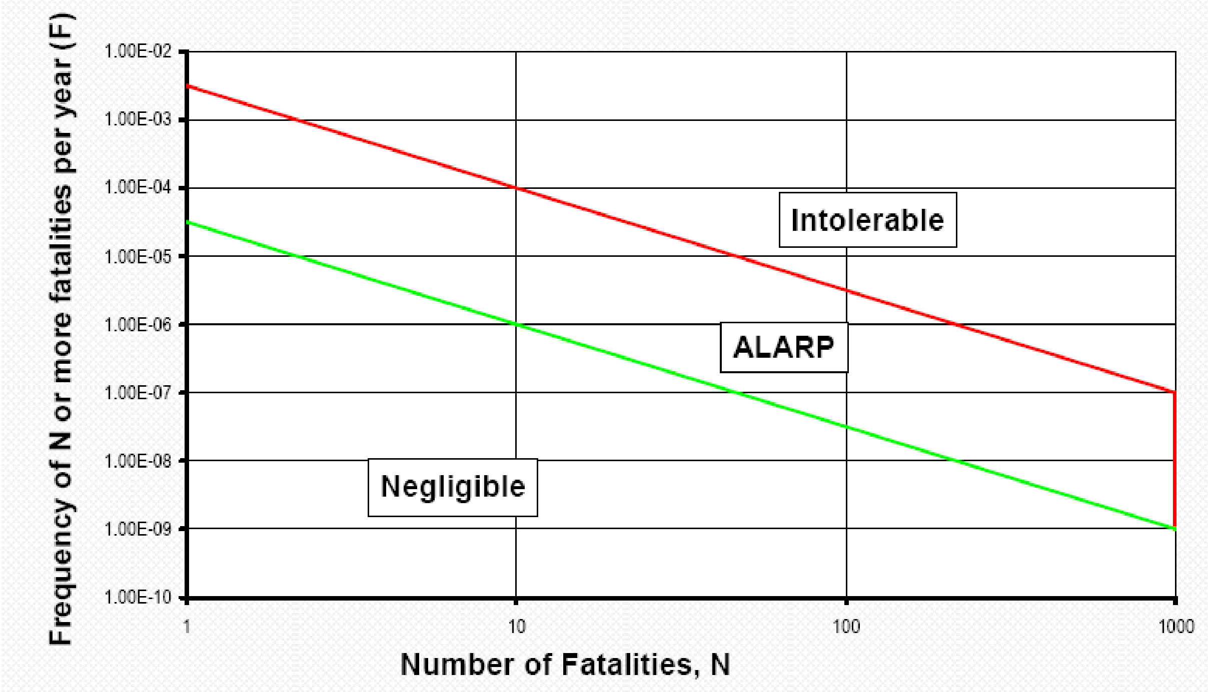
The F-N plot is cumulative in the sense that, for each frequency on the plot, N is the number of fatalities that could be equalled ***or exceeded***, and F is the frequency of exceedance of the specified number of fatalities.

The DP&E's suggested societal risk criteria (Refer to Figure 12), recognise that society is particularly intolerant of accidents, which though infrequent, have a potential to create multiple fatalities. Below the negligible line, provided other individual criteria are met, societal risk is not considered significant. Above the intolerable level, an activity is considered undesirable, even if individual risk criteria are met. Within the 'As Low As Reasonably Practicable' (ALARP) region, the emphasis is on reducing risks as far as possible towards the negligible line. Provided other quantitative and qualitative criteria of HIPAP 4 [3] are met, the risks from the activity would be considered tolerable in the ALARP region.

In HIPAP 10 [2], 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 12 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 12 Indicative Societal Risk Criteria



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

HIPAP No.4 [3] also states that the criteria in Figure 12 are indicative criteria and provisional only and do not represent a firm requirement in NSW.

3.7 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 [3] 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 4.4.7 - Control Measures.

The representative MAEs carried forward to the consequence analysis are listed in Section 4.4.13.

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 12.

Table 12 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 [4]:

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

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

An atmosphere with marginally less than 21% oxygen can be breathed without noticeable effects. However, at 19.5% (which is OSHA's lower limit for confined space entry in 29 CFR 1915.12 [5]) 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 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). 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 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.).

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 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 is 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.

4.4.7 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 [6] 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.

4.4.8 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 [7] 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.

4.4.9 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).

4.4.10 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 [8], 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).

4.4.11 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 [9].

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

4.4.12 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).

4.4.13 MAEs for Risk Analysis

The list of MAEs included in the risk analysis is provided in Table 13.

Table 13 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 C):

- 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 14 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.

Table 15 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 [10]. 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.

For the purposes of this study, the duration of interest was set to 10 minutes (600 seconds). This duration was sufficient for gas clouds arising from full bore ruptures to reach the maximum extent to the LEL. Limiting the model to 10 minutes also ensured source terms for gas dispersion had a much greater initial flowrate than would have occurred specifying a 30 minute or one hour duration of interest.

5.2 Fire Modelling

The latest SAFETI software package (Version 8.61) was used to model all the representative fire events included in the risk analysis.

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

5.2.1 Jet Fire

Example distances to heat radiation levels of 4.7, 10, 20, 23 and 35 kW/m^2 are tabulated in Appendix B 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 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.

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.) arising from the MSE for each town centre development is shown in Figure 13 through to Figure 16.

At all town centres, the LSIR of fatality exceeds both 0.5 x 10^{-6} and 1.0 x 10^{-6} per annum. These levels exceed the criteria for both residential intensification and sensitive land use intensification.

As the risk arising from the pipeline is less than 10 x 10^{-6}per annum, residential intensification may be permitted, provided mitigating measures are put in place to reduce the risk below 1 x 10^{-6} per annum.

The risk mitigation measures are:

- The bounding construction of development must comply with all the relevant '3 metre from boundary' deemed-to-satisfy provisions of the National Construction Code.
- Openings that face the pipeline must comply with clause C3.4 of the National Construction Code.
- Exits must discharge into locations that are shielded and away from the pipeline location.
- The proponent must prepare an appropriate emergency response plan/s for use by the building occupants.

Assuming typical Class 2 buildings, additional provisions of the BCA that allow for constructions within 3 m of a property boundary (and hence achieve resistance to 20 kW/m^2) are:

- Fire-resisting construction (walls, floors, roofs)
  - Fire-resistance level (FRL) dependent on the type of construction required, but details specified in BCA Spec C1.1.
  - FRL is achieved when subjecting a system to the AS1530.4 standard fire test.
  - A system achieving an FRL of 60/60/60 is tested to heat flux levels of more than 20 kW/m^2.
- Openings (i.e., doors, windows – if any) protected in accordance with BCA Clause C3.4, with measures such as:
  - Fire-rated windows, drenchers, fire-shutters etc.
  - If passive protection is relied upon, it would need to achieve the same FRL as the fire-resisting element it is located in.
- Service openings (e.g., mech, hydraulic - if any) protected in accordance with BCA Clause C3.15.

Note, the BCA considers one fire-source feature (i.e., neighbouring building on fire) in relation to the above measures.

Such mitigating measures may include development where building fire resistance is greater than default deemed to satisfy provisions of the National Construction Code (NCC). Given most of the development in the town centres will be apartments with minimal outdoor living area, credit for protection afforded by buildings is reasonable. An estimate of the indoor risk for each town centre is presented in Figure 17 through to Figure 20

In general, the results suggest that outdoor risk of fatality exceeds 1.0 x 10^{-6} per annum in the town centres on the same side of the East Hills rail line as the MSE is located. An exception to this is where there are sharp turns in the alignment of the pipeline, in which case the location specific individual risk of fatality exceeds 1 x 10^{-6} per annum on both sides. This is due to the pipeline risk overlapping.

Figure 13 Padstow Town Centre Outdoor LSIR

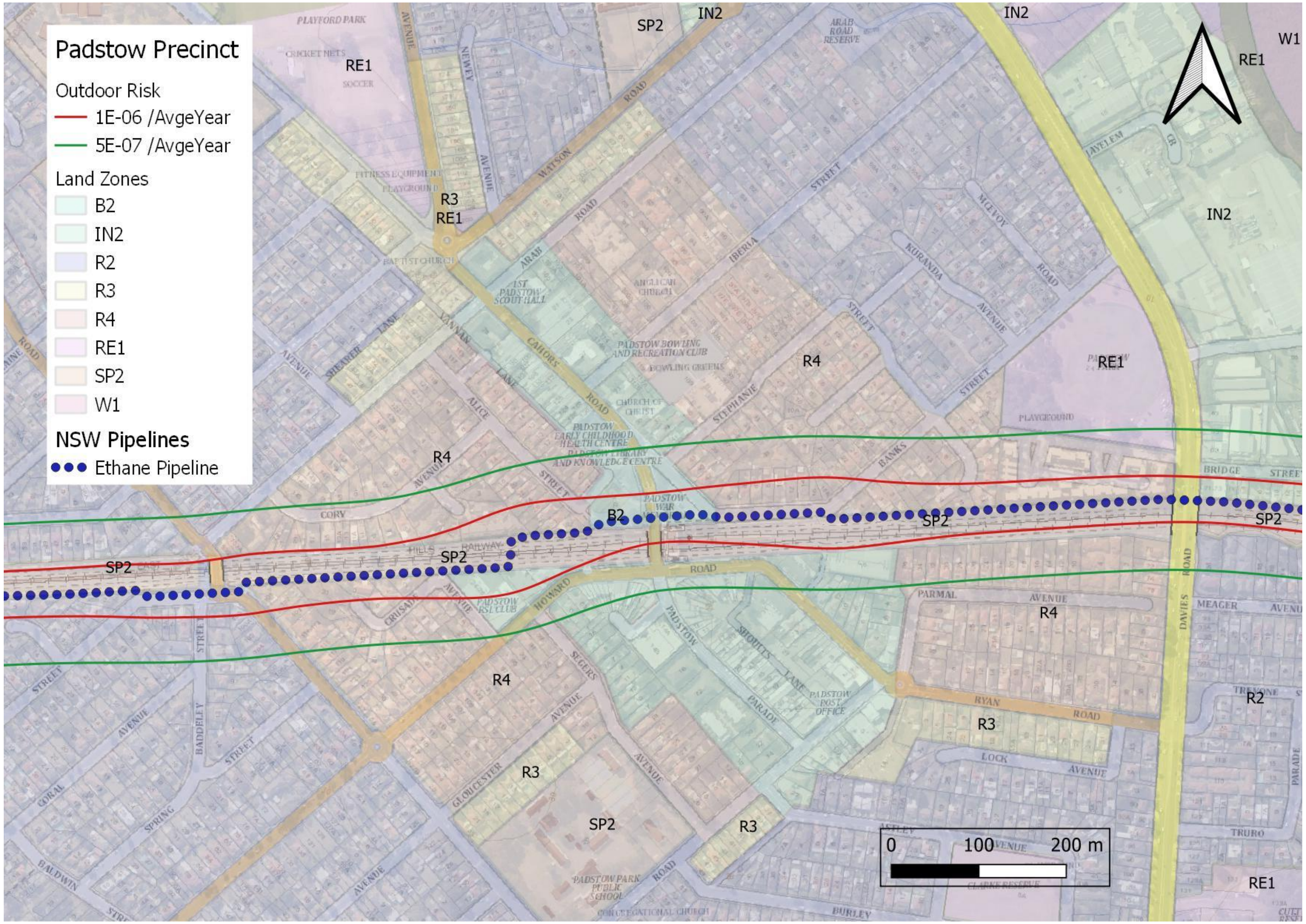


Figure 14 Revesby Town Centre Outdoor LSIR

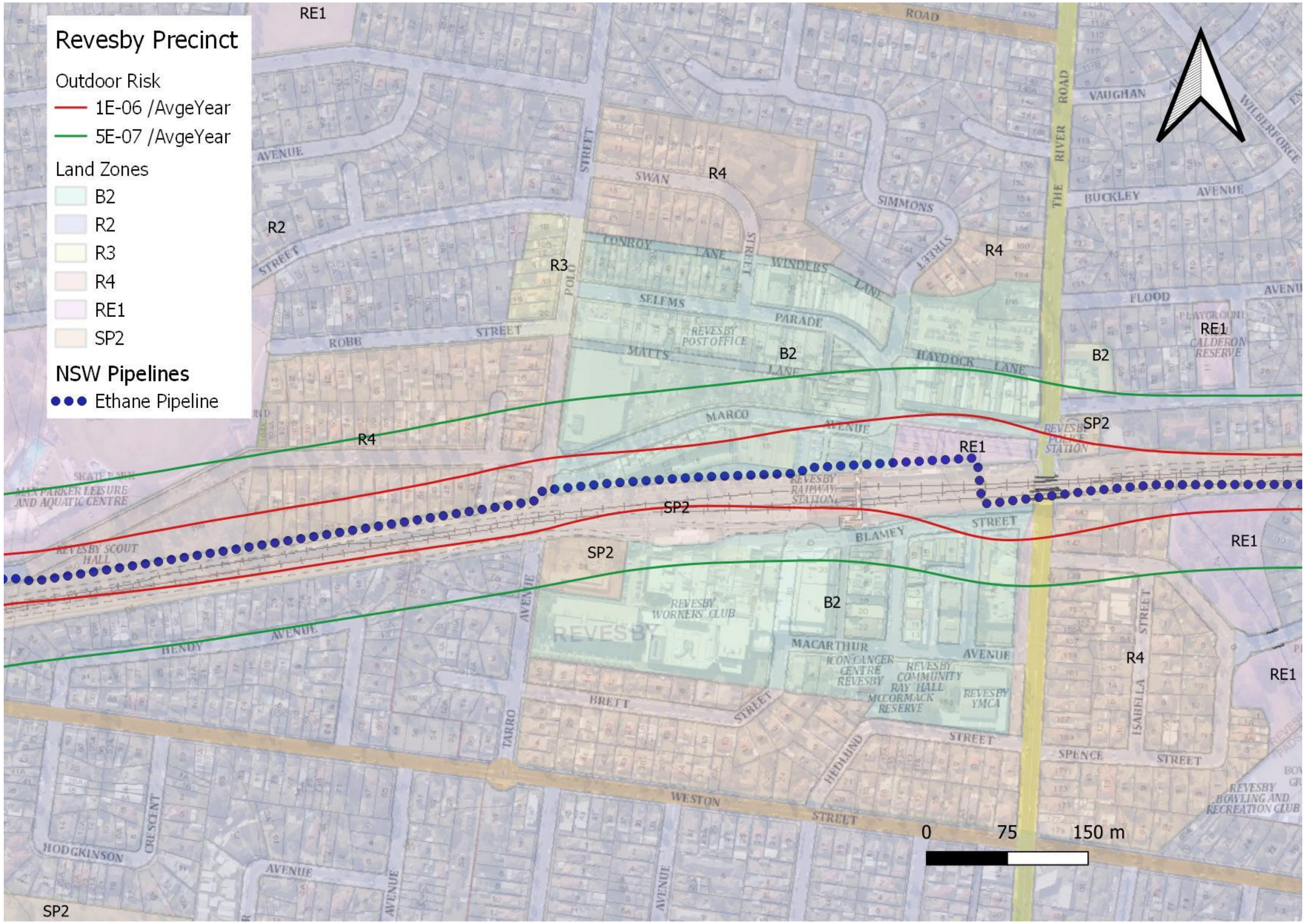


Figure 15 Panania Town Centre Outdoor LSIR

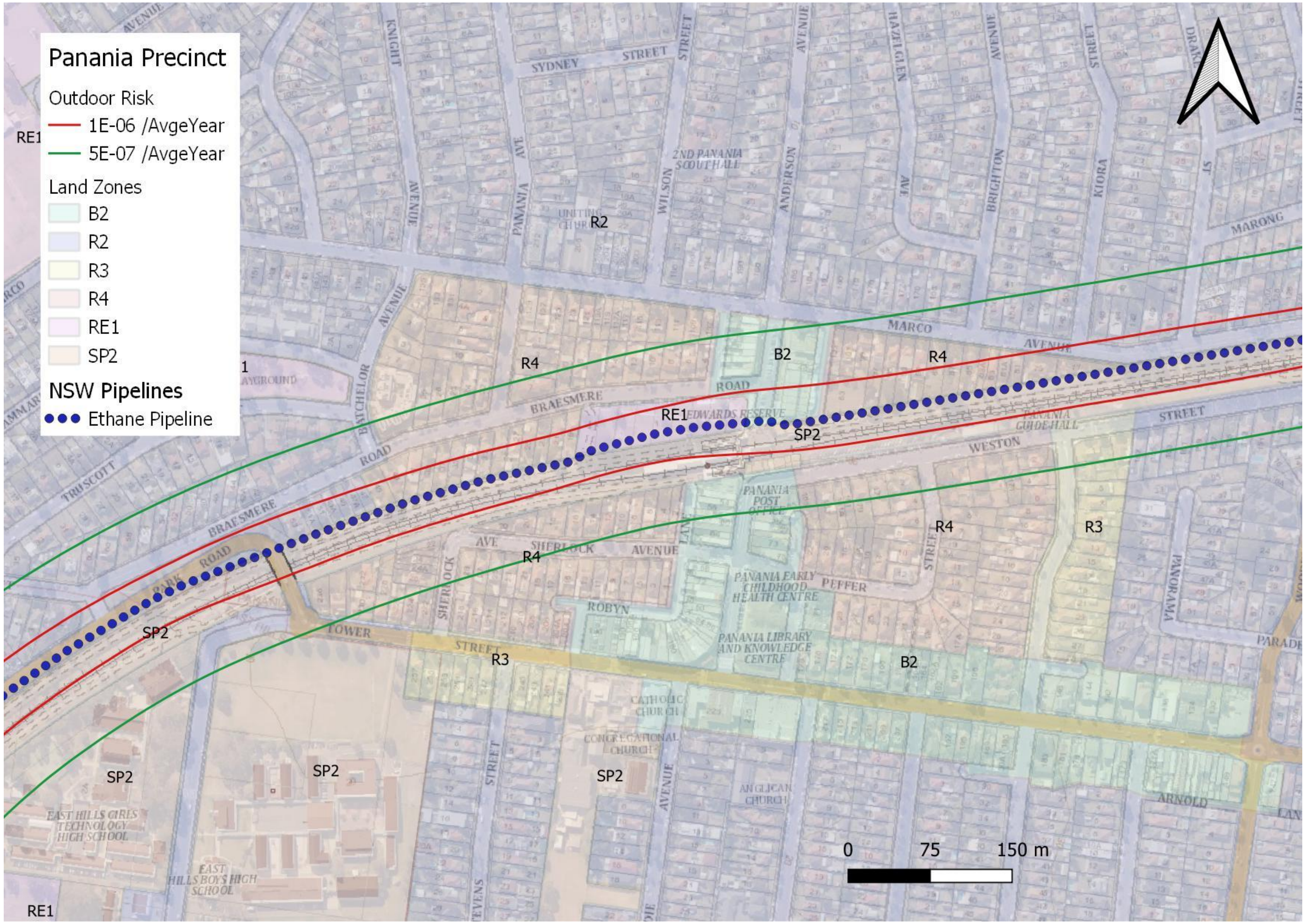


Figure 16 East Hills Town Centre Outdoor LSIR

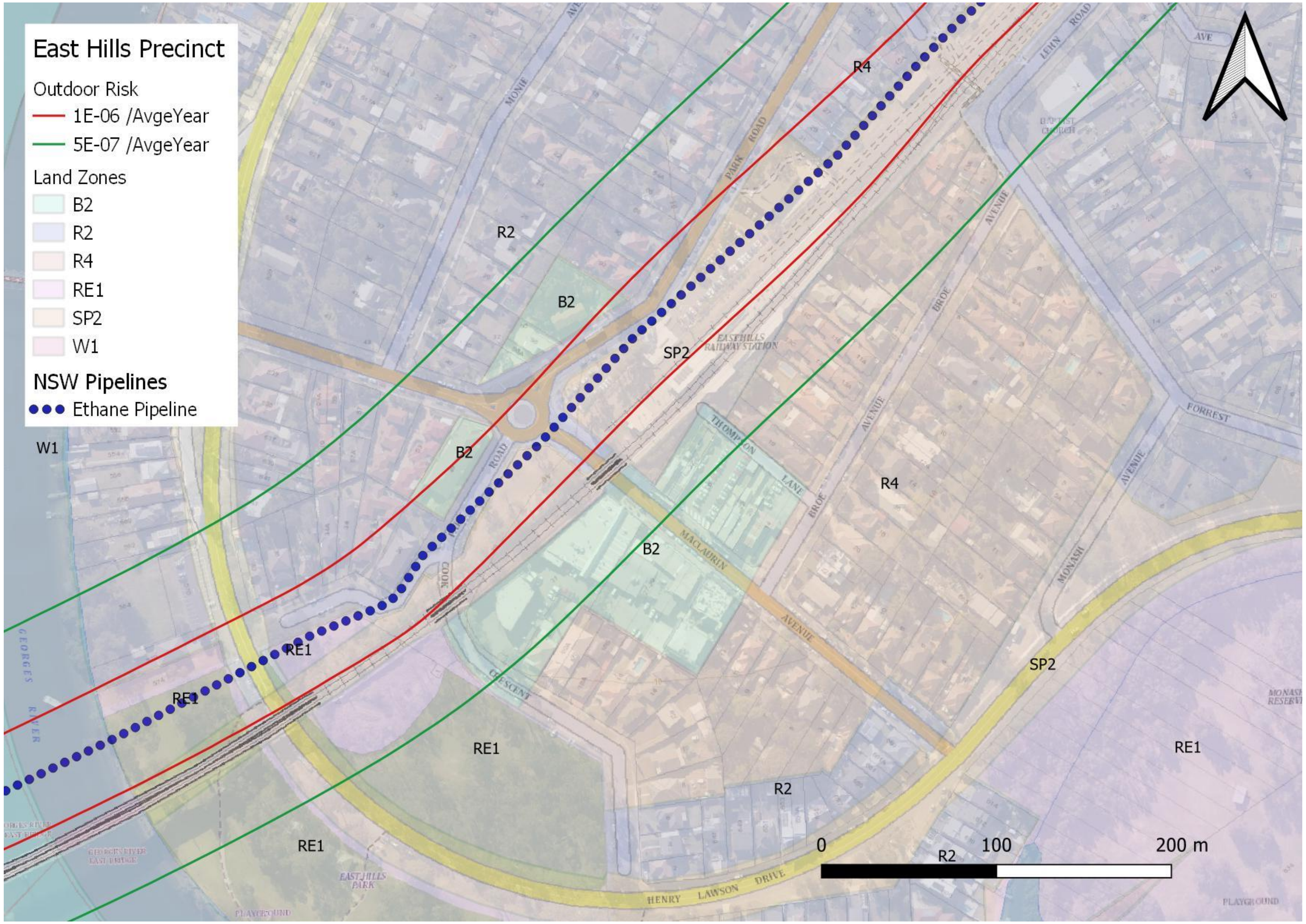


Figure 17 Padstow Town Centre Indoor LSIR

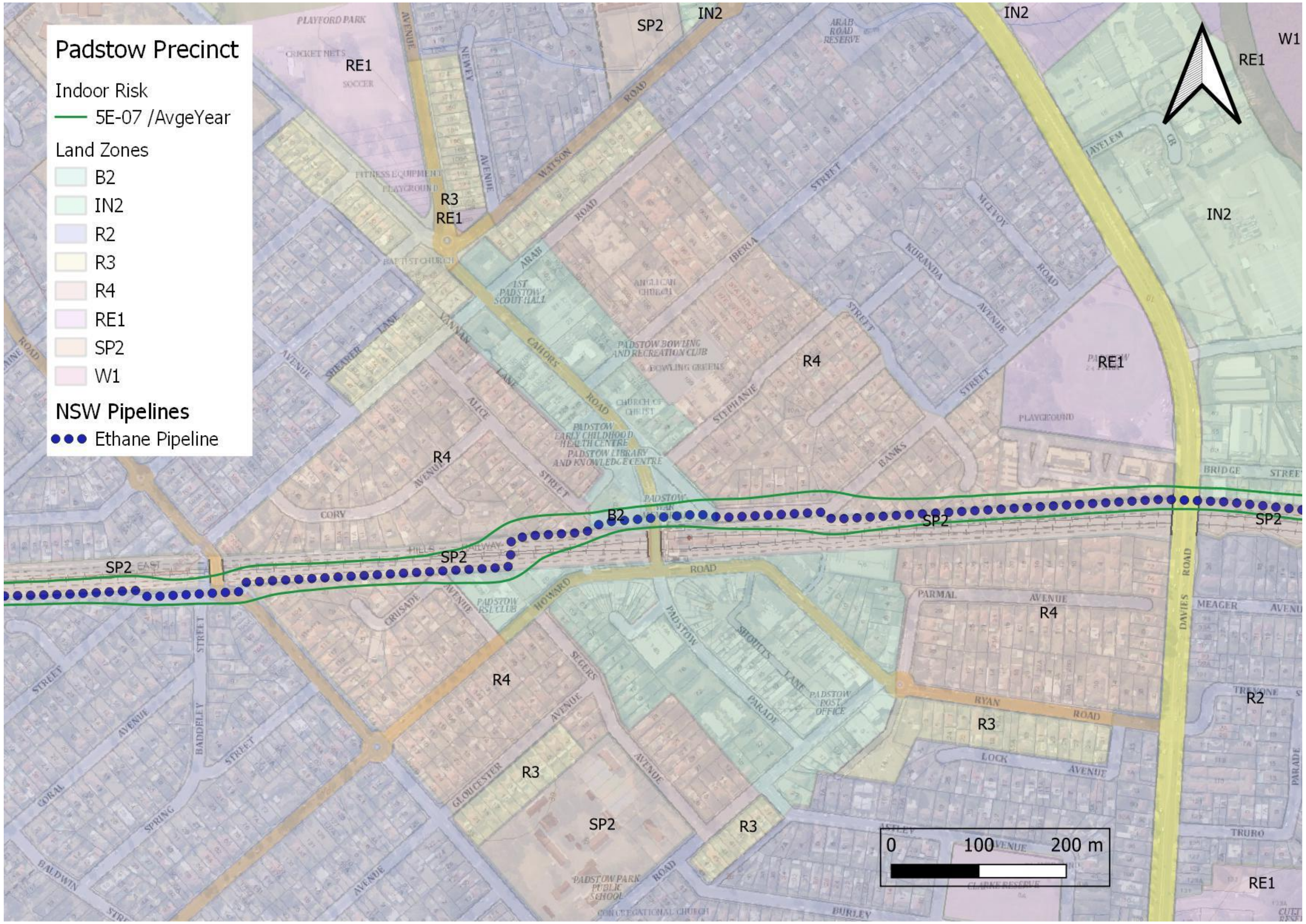


Figure 18 Revesby Town Centre Indoor LSIR

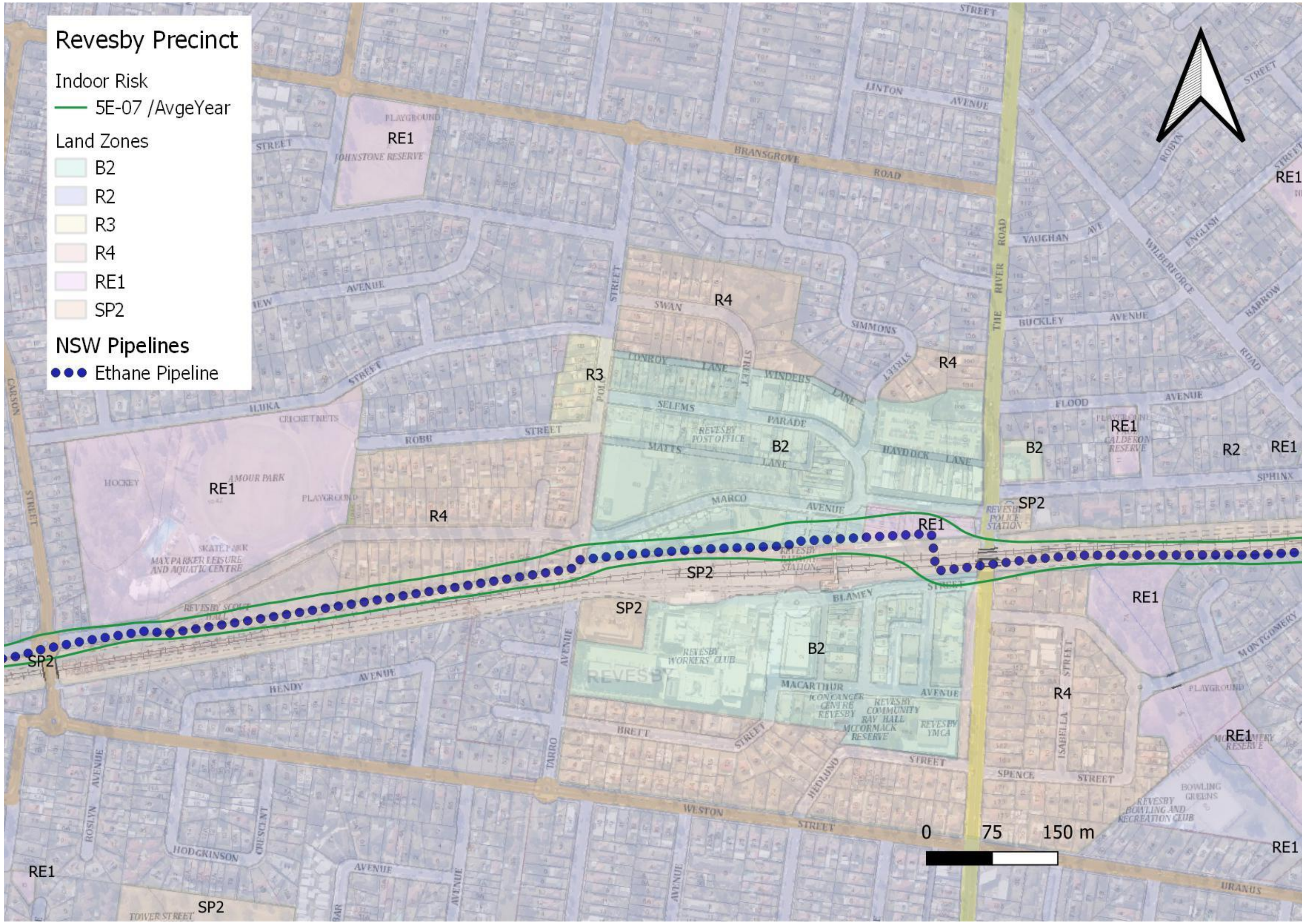
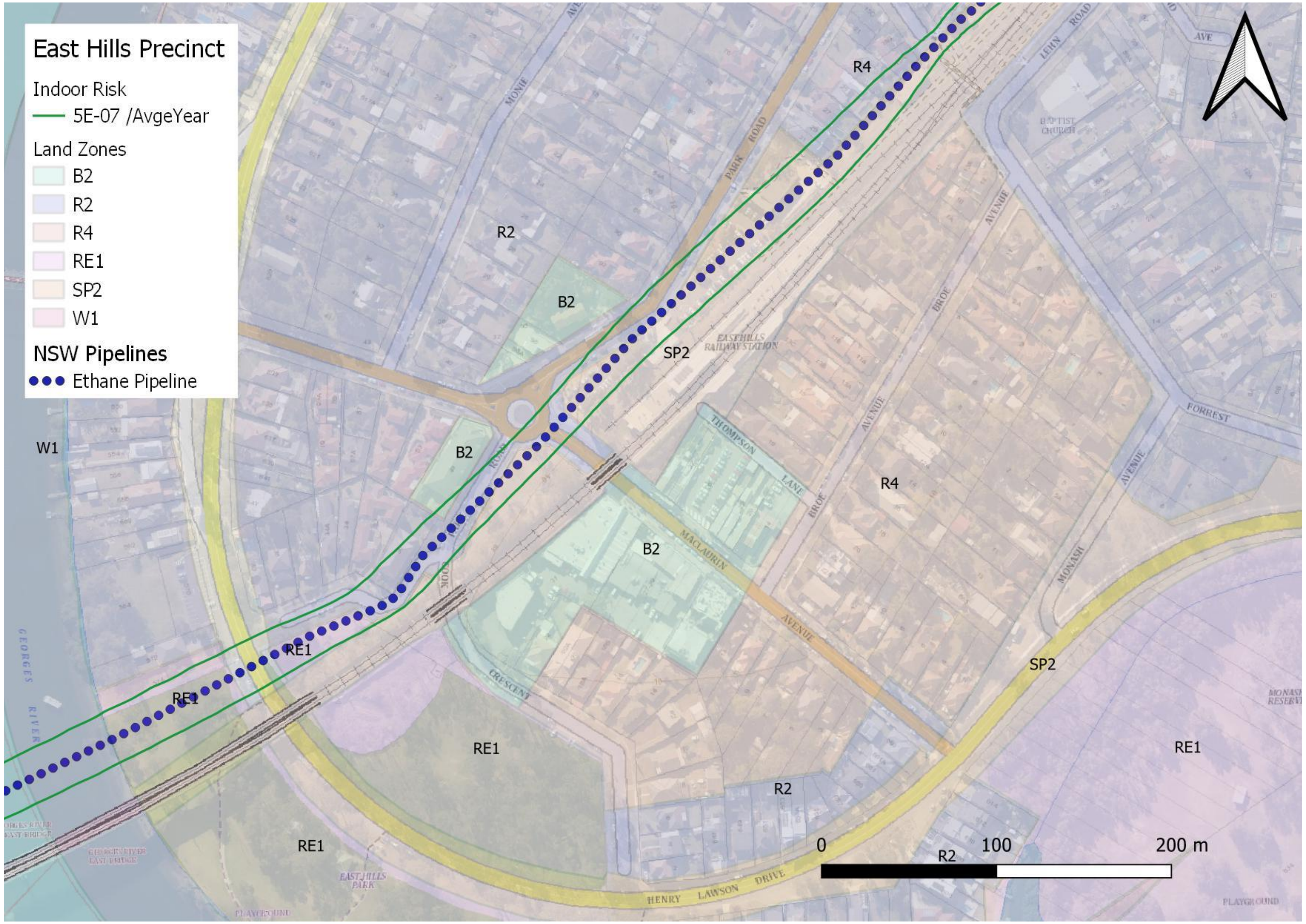


Figure 19 Panania Town Centre Indoor LSIR

Figure 20 East Hills Town Centre Indoor LSIR



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 draft LEP complies with the relevant DP&E risk criteria (Refer to Section 3.5.3).

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 3.5.4).

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 draft LEP (Refer to Section 3.5.4).

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 draft LEP complies with the relevant DP&E risk criteria (Refer to Section 3.5.3).

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 draft LEP complies with the relevant DP&E risk criteria (Refer to Section 3.5.3).

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 following is an assessment the proposed LEP against the qualitative risk criteria outlined in HIPAP No. 4:

- *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*. – There is already a desire for residential development in an area where the outdoor LSIR would normally preclude residential development. It is recommended that building controls be put in place to ensure new buildings new the MSE have greater fire resistance than otherwise required (Section 6.9). In implementing various State Government growth strategy objectives, the LEP encourages increased populations near transport corridors, and hence, nearer the hazard source (pipeline). The practicability of reducing the intensity of development along the railway corridor while also achieving growth objectives is discussed in Section 6.10.

- *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

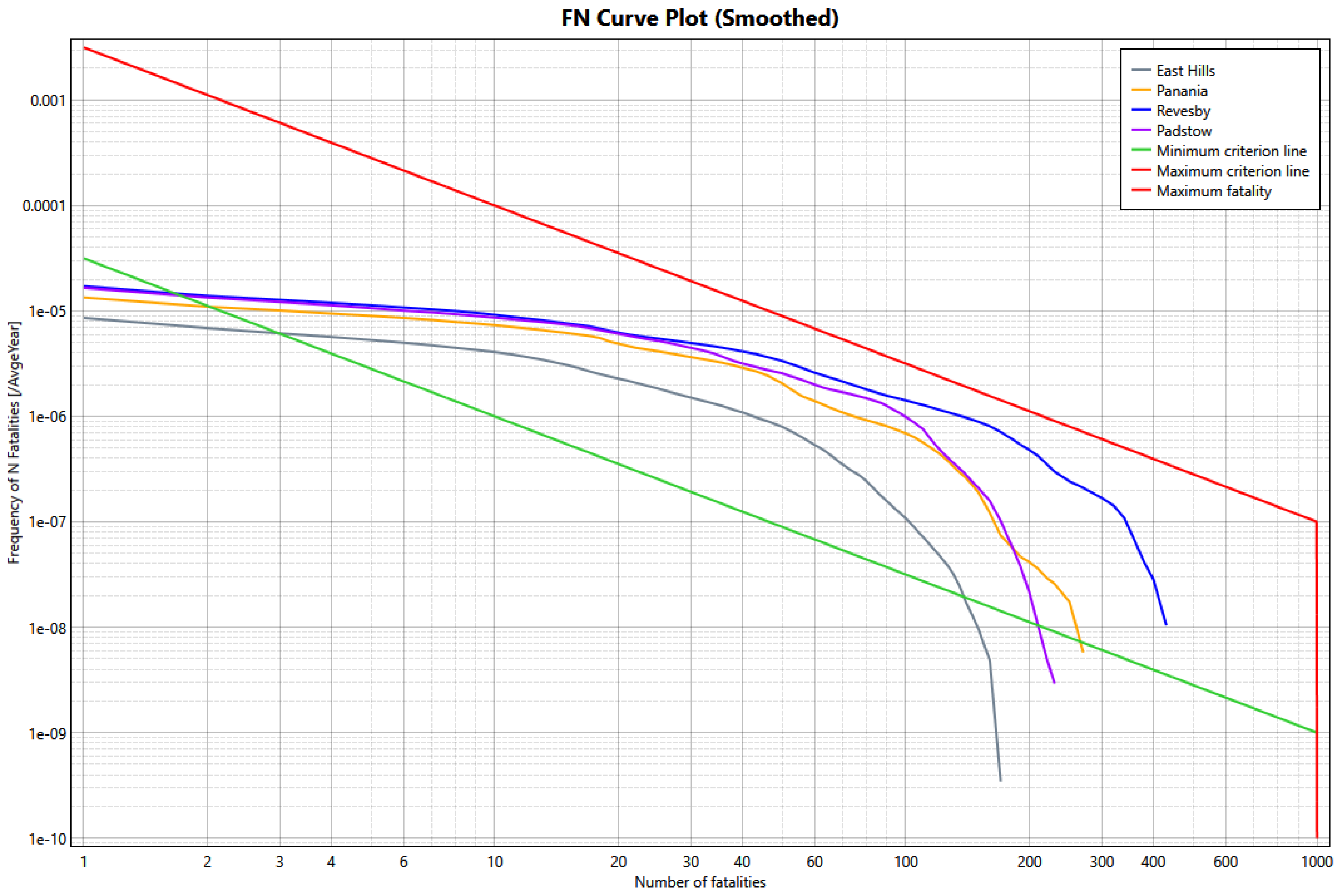
  Only some parts of the study are impacted by risk levels that exceed the criteria for residential or sensitive uses:

  - As the risk arising from the pipeline is less than 10 x 10^{-6}per annum, residential intensification may be permitted, provided mitigating measures are put in place to reduce the risk below 1 x 10^{-6} per annum. The properties impacted by this recommendation are those within the red lines on Figure 17 through to Figure 20.
  - However, the individual risk of fatality within some properties exceeds the DP&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. The properties impacted by this recommendation are those within the green lines on Figure 17 through to Figure 20.

6.8 Societal Risk

An FN curve depicting the societal risk from the MSE in the Study Area is shown in Figure 21. This shows the societal risk associated with each of the Town Centres. The risk is within the ALARP region for all town centres.

Figure 21 Societal Risk (Smoothed FN plot)



6.9 Risk Reduction Measures

Risk reduction measures to enable residential intensification in the region between the MSE and where the risk from the pipeline is greater than 1.0 x 10^{-6} p.a. are [11]:

- Bounding construction to be constructed to satisfy all the relevant DTS Provisions of the BCA that would be required if the external walls of the building were set back 3 m from the boundary.
- In addition, it would also be recommended to provide openings that face the pipeline with any of the measures specified in Clause C3.4 of the NCC.
- Exits should be designed so that they discharge into locations that are shielded and away from the pipeline location.
- The proponent must prepare an appropriate emergency response plan/s for use by the building occupants.

Assuming typical Class 2 buildings, additional provisions of the BCA that allow for constructions within 3 m of a property boundary (and hence achieve resistance to 20 kW/m^2) are:

- Fire-resisting construction (walls, floors, roofs)
  - Fire-resistance level (FRL) dependent on the type of construction required, but details specified in BCA Spec C1.1.
  - FRL is achieved when subjecting a system to the AS1530.4 standard fire test.
- Openings (i.e., doors, windows – if any) protected in accordance with BCA Clause C3.4, with measures such as:
  - Fire-rated windows, drenchers, fire-shutters etc.
  - If passive protection is relied upon, it would need to achieve the same FRL as the fire-resisting element it is located in.
- Service openings (e.g., mech, hydraulic - if any) protected in accordance with BCA Clause C3.15.
- Construction joints, spaces and the like in and between building elements required to be fire resisting (including external walls) with respect to integrity and insulation must be protected in a manner identical to a tested prototype in accordance with AS1530.4-2012 to achieve the required FRL.

Note, the BCA considers one fire-source feature (i.e., neighbouring building on fire) in relation to the above measures.

6.10 ALARP Discussion

The draft LEP encourages intensification near railway stations and hazard source. The risks associated with the LEP as proposed need to be assessed against the societal benefits facilitated by the LEP. A qualitative consideration developed with CBC is presented below and makes use of the societal benefits implied in the following:

1. Greater Cities Commission's *Greater Sydney Region Plan* [12]
2. Greater Cities Commission's *South District Plan* [13]
3. Department of Planning and Environment's *Ministerial Direction 5.1 (Integrating Land Use and Transport)*
4. Transport for NSW's *Future Transport Strategy 2056* [14]
5. Council's *Connective City 2036* [15] and Housing Strategy

6.10.1 Greater Sydney Region Plan

The Greater Sydney Region Plan (GSRP) aims to create capacity for new housing in the right locations. Locational criteria for urban renewal opportunities include catchment areas *within walking distance of centres with rail transport* (Objective 10, page 61). The map on page 65 of the GRSRP indicates preferred locations, which include the centres along the East Hills Line. The benefits are:

- Links the delivery of new homes with local infrastructure (Objective 10, page 60).
- Optimises existing infrastructure (Objective 10, page 62).
- Delivers a '30-minute city' by integrating new housing with public transport, so that people can access services and jobs (Objective 14, page 84).

6.10.2 South District Plan

The Greater Cities Commission projects that 'in the South District, the greatest increase in population is expected in Canterbury Bankstown Local Government Area, where 70 per cent of new residents (142,450 additional residents by 2036) will be accommodated due to anticipated urban renewal' (South District Plan, page 26).

To accommodate this growth, '*local centres are a focal point of neighbourhoods, and, where they include public transport and transport interchanges, they are an important part of a 30-minute city … Future Transport 2056 identifies the importance of transport interchanges as places which will have a high level of accessibility which is enhanced as service frequencies and travel times are improved. There will be potential for interchanges to deliver mixed-use, walkable, cycle-friendly centres and neighbourhoods.*' (Planning Priority S6, page 47). This will involve locating new housing within walking distance of rail transport, so that people can access services and jobs. This will apply to the centres along the East Hills Line, as shown on the map on page 49.

6.10.3 Ministerial Direction 5.1 (Integrating Land Use and Transport)

The objectives of the Ministerial Direction are to improve access to new housing, support the operation of public transport services, and reduce growth in the number and length of private car journeys. Rezoning proposals must give effect to the Department's Guideline 'Improving Transport Choice' by concentrating the highest appropriate densities of housing, employment, services and public facilities within an acceptable walking distance of major public transport nodes, such as railway stations (page 8).

6.10.4 Future Transport 2056

The Strategy aims to deliver sustainable transport through integrated land use planning. According to the Strategy, '*making cities better places to live is a major focus for the NSW Government. NSW Government agencies work together to integrate planning of land use, transport networks and the built environment to create a sense of 'place*'' (page 44).

6.10.5 Connective City 2036

Council's Local Strategic Planning Statement '*Connective City 2036*' and Housing Strategy implement the NSW Government's strategic directions by locating 80% of new housing growth within walking distance of centres. The Greater Cities Commission has assured *Connective City 2036*, confirming it is consistent with State priorities and the Department of Planning and Environment has endorsed the Housing Strategy.

6.10.6 ALARP Conclusion

Based upon quantitative risk analysis, changes have been recommended for the draft LEP and planning instruments to increase fire resistance of buildings close to the MSE, to allow residential intensification while still complying with the DP&E quantitative location specific risk criteria as documented in HIPAP 4 and HIPAP 10.

Quantitative calculations indicate societal risk is in the ALARP region, where it should be demonstrated that further risk reduction measures are not reasonably practicable. Also, HIPAP 4 and 10 have qualitative criteria that need to be considered. A land use planning proposal should only be approved if benefits clearly outweigh the risks.

NSW State Government and CBC strategies and plans guiding the development of the LEP include:

1. Greater Cities Commission's *Greater Sydney Region Plan* [12]
2. Greater Cities Commission's *South District Plan* [13]
3. Department of Planning and Environment's *Ministerial Direction 5.1 (Integrating Land Use and Transport)*
4. Transport for NSW's *Future Transport Strategy 2056* [14]
5. *Connective City 2036* [15] and Housing Strategy

In consultation with CBC, the following argument is put forward that the LEP has reduced risk to as low as reasonably practicable:

- Quantitative LSIR criteria for development in the vicinity of hazardous facilities are satisfied after additional development controls are put in place to increase the fire resistance of dwellings in the vicinity of the MSE,
- The societal risk is in the ALARP region, but is not intolerable,
- The societal benefits of developing an LEP consistent with the plans and strategies listed in 1 – 5 above outweigh the risk reduction that could be obtained by further restricting development near the pipeline, and hence also near already existing public transport infrastructure.

7 FINDINGS AND RECOMMENDATIONS

7.1 Findings

The following findings were made from the risk assessment:

- The individual risk of fatality within some properties along the route of the MSE exceeds 1.0 x 10^{-6} p.a., but is always less than 10 x 10^{-6} p.a. The DP&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.
- If the relevant planning instruments are modified so that buildings within the area defined by the outdoor 1.0 x 10^{-6} p.a. contour have increased fire resistance, the LSIR, as defined by indoor risk levels is less than 1.0 x 10^{-6} p.a., and intensification may be permitted.
- The individual risk of fatality within some properties exceeds the DP&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.
- The individual risk of fatality never exceeds 5.0 x 10^{-6} p.a. and therefore intensification of other land uses (such as business use) as proposed within the Study Area is consistent with DP&E criteria.
- In consultation with CBC, the following argument is put forward that the LEP has reduced risk to as low as reasonably practicable:
  - Quantitative LSIR criteria for development in the vicinity of hazardous facilities are satisfied after additional development controls are put in place to increase the fire resistance of dwellings in the vicinity of the MSE,
  - The societal risk is in the ALARP region, but is not intolerable,
  - The societal benefits of developing an LEP consistent with the plans and strategies listed in 1 – 5 below outweigh the risk reduction that could be obtained by further restricting development near the pipeline, and hence also near already existing public transport infrastructure.
    1. Greater Cities Commission's Greater Sydney Region Plan
    2. Greater Cities Commission's South District Plan
    3. Department of Planning and Environment's Ministerial Direction 5.1 (Integrating Land Use and Transport)
    4. Transport for NSW's Future Transport 2056
    5. Council's Connective City 2036 and Housing Strategy
- Similarly, further measures to address the HIPAP 4 qualitative criteria in addition to the recommendations made for the draft LEP are not reasonably practicable while also delivering the societal benefits of the *Greater Sydney Region Plan.*

7.2 Recommendations

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

7.2.1 Recommendation 1

Restrict sensitive use developments on properties where the outdoor LSIR is greater than 0.5 x 10^{-6} p.a. Sensitive use developments are those for use by sectors of the community who may be unable to protect themselves from the consequences of a pipeline failure event, and include the following land uses as per Standard Instrument—Principal Local Environmental Plan (2006 EPI 155a) - NSW Legislation:

- *School*
- *Hospital*
- *Seniors housing*
- *Respite day care centre*
- *Early education and care facility*
- *Correctional centre*

The properties where this restriction applies are those bounded by the green lines in Figure 17 through to Figure 20.

7.2.2 Recommendation 2

Ensure development on land where the outdoor individual risk of fatality is greater than 1 x 10^{-6} p.a. incorporates risk mitigation measures for features exposed to the pipeline to withstand a heat flux of 20 kW/m^2. With reference to Table CV1 of the NCC, this would be the equivalent to incorporating measures as if the building is 3 m from an allotment boundary. Deemed to satisfy (DtS) provisions for this requirement include:

- *Fire-resisting construction (shafts, walls, floors, roofs)*
  - *Fire-resistance level (FRL) dependent on the type of construction required, but details specified in BCA Spec C1.1.*
  - *Note: FRL is achieved when subjecting a system to the AS1530.4 standard fire test.*
- *Openings exposed to the pipeline (i.e., doors, windows – if any) protected in accordance with BCA Clause C3.4, with measures such as:*
  - *Fire-rated windows, drenchers, fire-shutters etc.*
  - *Note: If passive protection is relied upon, the system would need to achieve the same FRL as the fire-resisting element it is located within.*
- *Service openings (e.g., mech, hydraulic - if any) protected in accordance with BCA Clause C3.15.*
- *Construction joints, spaces and the like in and between building elements required to be fire resisting (including external walls) with respect to integrity and insulation must be protected in a manner identical to a tested prototype in accordance with AS1530.4-2012 to achieve the required FRL.*
- *Exits must discharge into locations that are shielded and away from the pipeline location.*
- *The proponent must prepare an appropriate emergency response plan/s for use by the building occupants.*

The objective is to ensure development on land where the outdoor individual risk of fatality is greater than 1 x 10-6 p.a. is constructed to withstand 20 kW/m^2 as per Table CV1, *Volume 1 of the National Construction Code. The properties impacted by this recommendation are those within the red lines on Figure 13 through to Figure 16.*

7.2.3 Recommendation 3

Ensure construction activities in the Study Area do not impact upon the existing potentially hazardous pipelines. At the development application stage, the proponent should demonstrate how this will be achieved by submitting a safety management study in accordance with the State Environmental Planning Policy (Transport and Infrastructure) 2021

8 REFERENCES

[1] NSW Department of Planning, "Hazardous Industry Planning Advisory Paper No.6 - Hazard Analysis," Sydney, 2011.

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

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

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

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

[6] Standards Australia, "AS 2885.0 - Pipelines - Gas and Liquid Petroleum. Part 0 - General Requirements," 2008.

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

[8] Standards Australia, "Pipelines - Gas and liquid petroleum Design and construction," 2018.

[9] NSW Planning & Environment, "New South Wales 2017-18 Gas Networks Performance Report," 2018.

[10] DNVGL, "SAFETI 8.2.3 Technical reference manual," 2019.

[11] SGA Fire - a Jensen Hughes Company, "Technical Note – Canterbury Bankstown LEP Modification, Vulnerability Criteria," 2022.

[12] Greater Sydney Commission, "Greater Sydney Region Plan: A Metropolis of Three Cities - connecting people," 2018.

[13] Greater Sydney Commission, "South District Plan," 2018.

[14] Transport for NSW, "Future Transport Strategy 2056," 2020.

[15] Canterbury Bankstown Council, "Connective City 2036," [Online]. Available: https://cbcity.nsw.gov.au/council/planning-for-the-city/connective-city-2036. [Accessed 28 June 2022].

[16] C. Symonds, "Experience with the Australian/New Zealand Pipeline Incident Database," 2018.

[17] E. N. F. e. M. P. a. K. Silva, "Underground parallel pipelines domino effect: An analysis based on pipeline crater models and historical accidents," vol. 43, no. June, 2016.

Appendices

Appendix A Assumptions

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

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

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

It is important that the assumptions be supported by:

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

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

List of Assumptions

A.1 Operational Data

Assumption No. 1 Pipeline Operating Conditions
Subject: Operational Data
Assumption/s: • All pipeline operating conditions (pressure, temperature, etc.) are as reported in Table 6
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. • The pipeline supplies a manufacturing site operating 24 hours per day, seven days per week.
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. • 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 between four km and six kilometres from each of the Town Centres under investigation. The next closest station, Canterbury Racecourse, is 8.9 km from Padstow, the nearest town centre included in the study. • 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 suitable for the analysis.

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 16. Canterbury-Bankstown Council is a metropolitan LGA within Greater Sydney, and the description “regular large obstacle coverage (suburb, forest)” is most accurate.

Table 16 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 maps, 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: Population (Day and Night)
Subject: Locational Data
Assumption/s: • Residential and working populations outside the town centres are based upon the Census of Population and Housing, 2016, obtained from the Australian Bureau of Statistics TableBuilder service. The residential population is based upon mesh blocks, while employment figures are based on SA2. • Residential population within the town centres are based on a residential dwelling occupancy calculated from the 2016 census. • Number of dwellings in town centres is based on estimated number of dwellings by 2036. • Employment population is based upon 1 person per 20 square metres GFA for commercial purposes • Employment populations and additional residential population are presented in Figure 22 through to Figure 25
Justification and Impact/s of Assumption/s: • The 2016 Census data is the most recent census data available.
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.

Figure 22 Padstow Estimated Workforce and Estimated Additional Residential Population

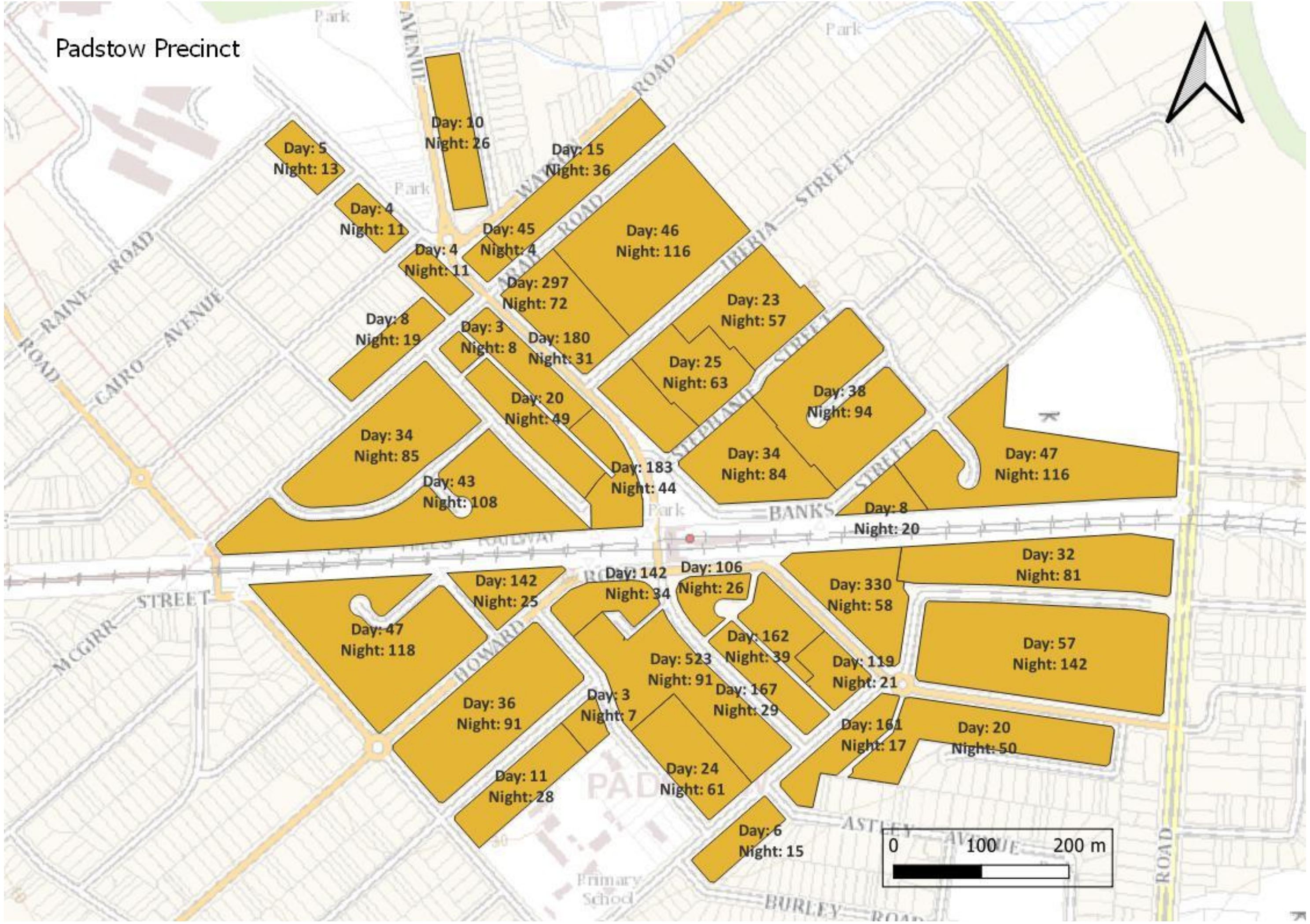


Figure 23 Revesby Estimated Workforce and Estimated Additional Residential Population

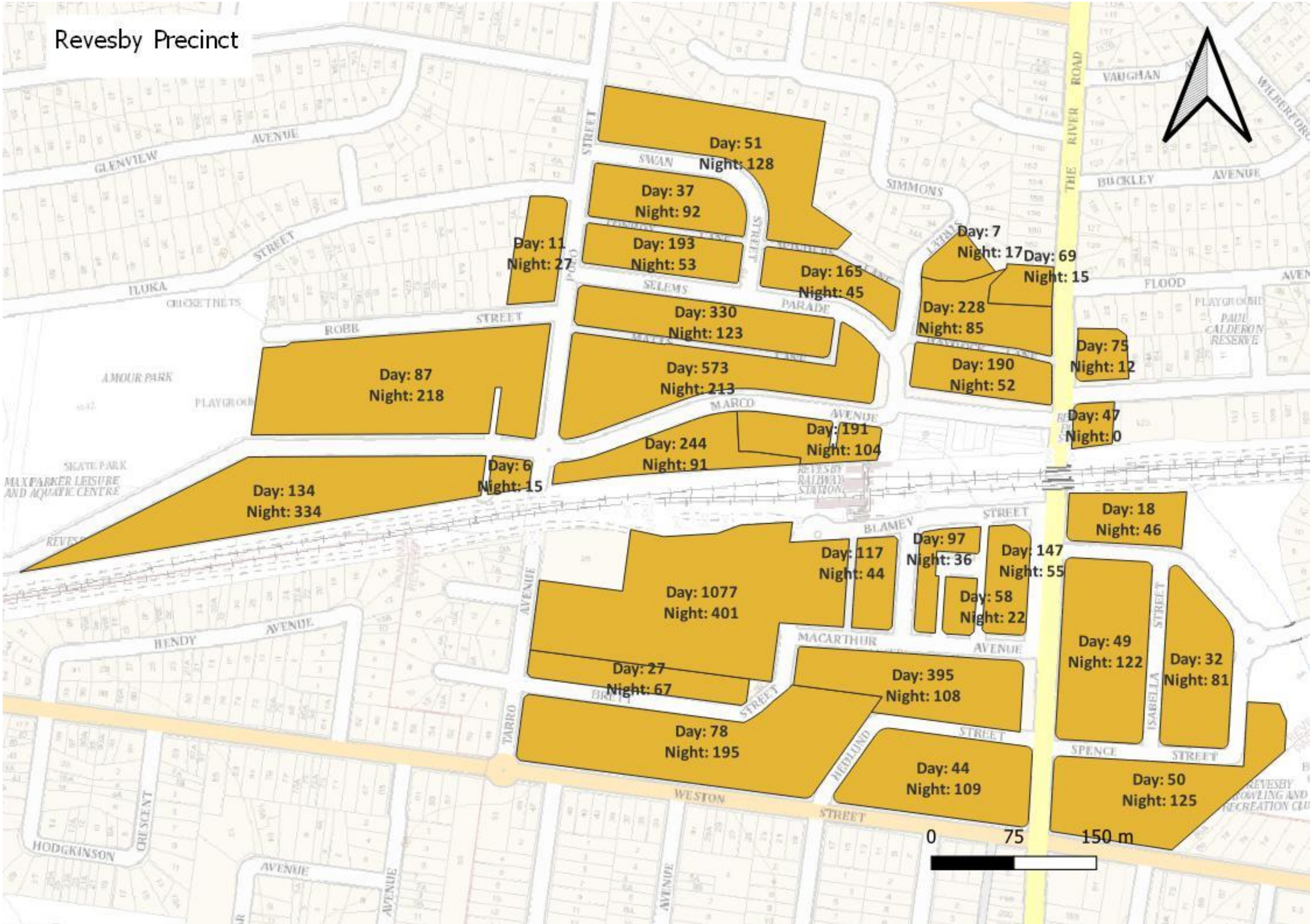


Figure 24 Panania Estimated Workforce and Estimated Additional Residential Population

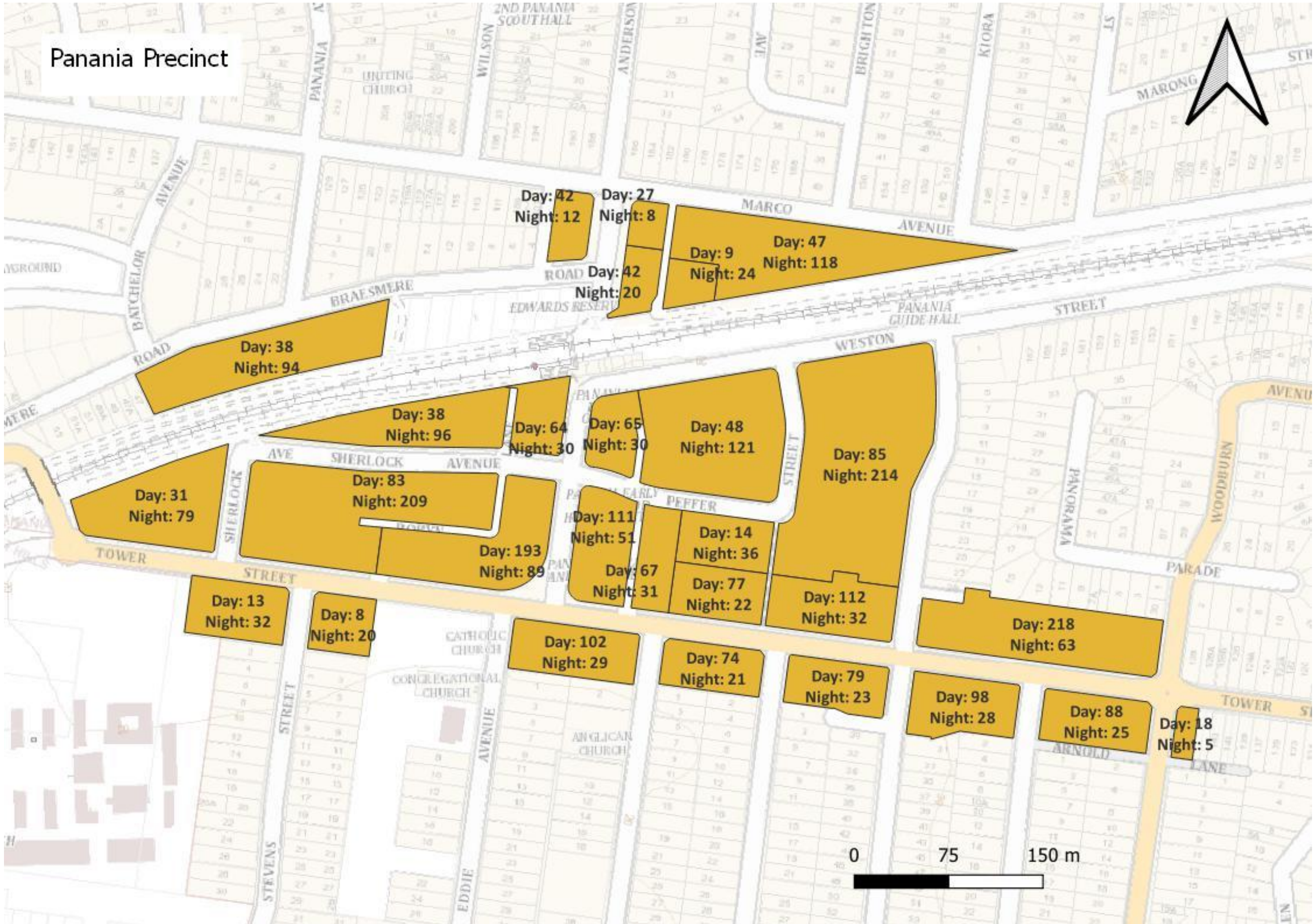
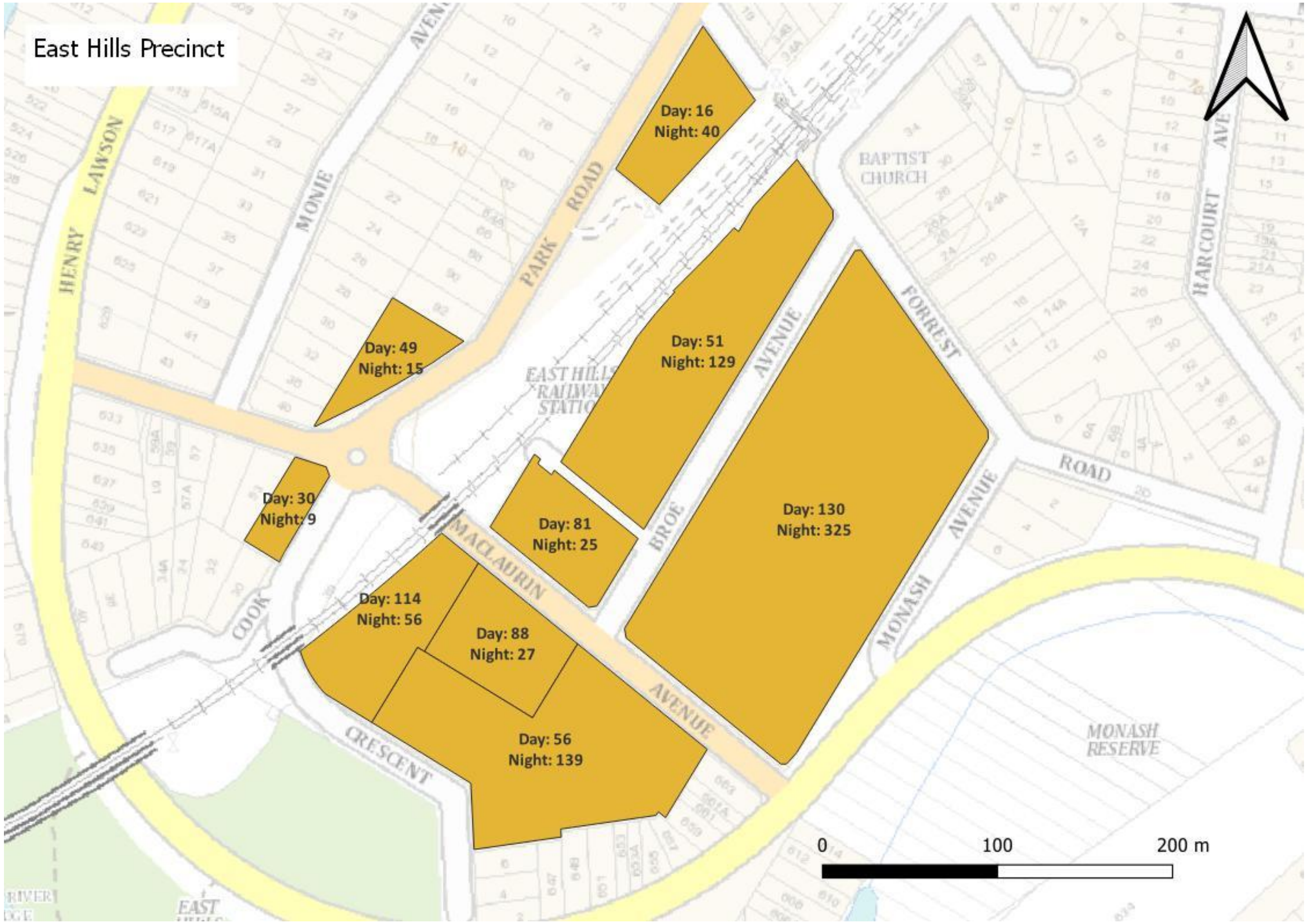


Figure 25 East Hills Estimated Workforce and Estimated Additional Residential Population



Assumption No. 7: Indoor / Outdoor distribution of people
Subject: Locational Data

Assumption/s:

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

Justification and Impact/s of Assumption/s:

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

Table 17 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 DP&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 18 Representative Hole Diameters Selected for Consequence Analysis

Pipeline/s	Material	Internal Pipeline Diameter (mm)	Representative Hole Diameter (mm)			
			Pinhole	Small Hole	Large Hole	Rupture
			(≤ 25 mm)	(> 25 mm to ≤ 75 mm)	(> 75 mm to ≤ 110 mm)	(> 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 Appendix C.1), which includes four hole size categories: Pinhole (≤ 25 mm); Small Hole (> 25 mm to ≤ 75 mm), Large Hole (> 75 mm to ≤ 110 mm); and, Rupture (> 110 mm). The representative hole diameter/s in each hole size category were selected based on a review of the available historical data (Refer to Appendix C):
  - 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 Appendix C.1). Ethane is transported as a liquefied flammable gas.

MAE/s Affected:

- All.

Reference/s:

- Refer to Appendix C.

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. $\pm 71^{o}$ from vertical) was estimated to occur for 63% of the releases and an obstructed release was estimated to occur for the balance (37% of releases). The distribution is not reported for different failure modes.
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation. • UK HSE, 2015, *Review of the Event Tree Structure and Ignition Probabilities used in HSE's Pipeline Risk Assessment Code MISHAP*, Research Report (RR) 1034.

Assumption No. 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 an 18.75s averaging time.

Justification and Impact/s of Assumption/s:

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

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

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

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

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

  Hanna claims that experimentally:

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

  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 a 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 C.2.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.2.

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 19 Probability of Fatality for Exposure to Heat Radiation (Outdoor)

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

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

Table 20 Probability of Fatality Inside Buildings Exposed to Heat Radiation

Radiant Heat Flux (kW/m^2)	Probability of Fatality
35	1.0
20	0.3
10	0.03

- 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.

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 21 Effects of Thermal Radiation

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

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

MAE/s Affected:

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

Assumption No. 20: Exposure to Heat Radiation from a Fire (Indoor or Outdoor)
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 22 (Person located outdoors) and Table 23 (Person located indoors).

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

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

Table 23 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 24 Effects of Explosion Overpressure

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

B.1 Jet Fire Results

Distances to various heat flux are presented in Table 25 and Table 26.

Table 25 Day-time Jet Fire Results

Scenario	Weather	Flame length [m]	Distance downwind to 4.7 kW/m^2 [m]	Distance downwind to 10 kW/m^2 [m]	Distance downwind to 20 kW/m^2 [m]	Distance downwind to 23 kW/m^2 [m]	Distance downwind to 35 kW/m^2 [m]
Section breach 10mm mid	1.9B	22.65	33.34	21.04	13.96	11.52	5.779
	7.5D	16.02	36.94	26.61	22.79	21.74	18.42
	4.1D	18.31	36.05	23.55	19.99	18.99	15.5
	1.5D	23.93	33.12	19.04	11.28	8.461	4.35
Section breach 25mm mid	1.9B	47.23	76.77	47.83	33.59	28.31	14.57
	7.5D	33.42	82.71	56.65	46.85	43.7	37.42
	4.1D	38.18	80.93	52.38	44.01	41.16	32.89
	1.5D	49.92	76.24	44.26	27.81	22	10.68
Section breach 75mm mid	1.9B	107.5	193.4	111.1	59.59	61.03	27.26
	7.5D	76.08	179.2	115.1	75.59	91.05	75.96
	4.1D	86.93	181.1	119.4	79.65	87.81	64.14
	1.5D	113.6	192.7	104.5	47.85	48.92	19.37

Scenario	Weather	Flame length [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 10 kW/m² [m]	Distance downwind to 20 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
Section breach 75mm top	1.9B	100.6	162	82.86	37.86	31.06	9.815
	7.5D	71.15	156.5	101.4	64.65	78.92	62.68
	4.1D	81.31	154.5	95.54	56.63	60.85	32.76
	1.5D	106.3	163.1	78.12	31.17	22.68	6.894
Section breach 110mm mid	1.9B	102.1	184.7	106.6	76.37	59.22	26.72
	7.5D	72.22	171	109.7	94.04	86.87	72.76
	4.1D	82.53	173	114	96.43	84.2	61.96
	1.5D	107.9	181.8	98.38	62.76	45.52	17.97
Section breach 110 mm top	1.9B	96.18	157.5	98.81	44.25	32.48	10.69
	7.5D	68.04	152.1	107.7	81.69	76.98	62.2
	4.1D	77.75	149.9	105.7	69.31	61.56	35.28
	1.5D	101.6	158.5	95.73	35.8	24.39	7.559
Section breach FBR	1.9B	136.8	250.1	157.6	117.2	103.7	64.83
	7.5D	96.75	220	143.2	119.2	113.4	95.41
	4.1D	110.6	248.3	161.5	133	124.3	98.25

Scenario	Weather	Flame length [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 10 kW/m² [m]	Distance downwind to 20 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
	1.5D	144.5	249.1	150.5	105.9	90.86	52.1

Table 26 Night-time Jet Fire Results

Scenario	Weather	Flame length [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 10 kW/m² [m]	Distance downwind to 20 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
Section breach 10mm mid	7.3D	16.09	36.99	28.6	22.66	21.58	18.04
	4.0D	18.43	35.99	25.69	19.95	18.91	15.28
	1.0D	25.86	31.86	18.89	6.607	5.248	2.919
	2.6E	20.84	33.76	25.01	17.6	15.77	9.116
	1.0F	25.86	31.89	18.93	6.624	5.259	2.923
Section breach 25 mm mid	7.3D	33.86	83.25	62.19	46.83	43.84	37.71
	4.0D	38.79	81.29	57.64	43.91	41.33	32.8
	1.0D	54.42	74.08	45.52	18.03	14.03	7.13
	2.6E	43.85	77.79	56.75	39.66	35.86	22.71
	1.0F	54.42	74.18	45.61	18.09	14.08	7.146

Scenario	Weather	Flame length [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 10 kW/m² [m]	Distance downwind to 20 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
Section breach 75 mm mid	7.3D	57.97	141.8	102.6	75.78	71.85	61.6
	4.0D	66.42	149.8	106.7	79.73	74.64	58.69
	1.0D	93.18	135.3	80.61	29.88	21.64	9.096
	2.6E	75.08	146.3	105	72.16	65.31	42.37
	1.0F	93.18	135.6	80.81	29.91	21.74	9.128
Section breach 75 mm top	7.3D	52.6	120.5	85.34	64.63	61.15	50.24
	4.0D	60.27	118.4	84.03	56.22	50.38	30.42
	1.0D	84.56	120.7	67.82	16.63	10.39	3.27
	2.6E	68.13	123	82.08	46.57	38.62	15.62
	1.0F	84.56	120.9	68.01	16.75	10.59	3.278
Section breach 110 mm mid	7.3D	73.94	176.6	126.3	94.33	89.66	75.35
	4.0D	84.72	182.4	131.3	96.56	89.71	67.69
	1.0D	118.9	178.5	106.9	40.3	29.14	11.32
	2.6E	95.76	191.2	135.9	91.69	82.59	52.7
	1.0F	118.9	178.8	107.1	40.52	29.31	11.37

Scenario	Weather	Flame length [m]	Distance downwind to 4.7 kW/m² [m]	Distance downwind to 10 kW/m² [m]	Distance downwind to 20 kW/m² [m]	Distance downwind to 23 kW/m² [m]	Distance downwind to 35 kW/m² [m]
Section breach 110 mm top	7.3D	68.32	152.1	107.8	81.58	26.25	13.73
	4.0D	78.29	150.4	105.7	68.75	60.86	34.19
	1.0D	109.8	159.3	90.37	23.71	14.91	4.599
	2.6E	88.49	155.7	102.6	55.71	45.17	17.42
	1.0F	109.8	159.6	90.64	23.88	15.01	4.612
Section breach FBR	7.3D	97.71	221	159.6	119.8	113.9	95.56
	4.0D	112	250.5	178.7	133.8	125.3	98.86
	1.0D	157.1	245.5	160.3	84.48	69.93	37.52
	2.6E	126.6	252.7	182.9	129.4	118.6	84.31
	1.0F	157.1	245.9	160.7	84.78	70.2	37.65

B.2 Flash Fire Results

Distance to the furthest extent of LEL at any height, and the height the furthest extent is reached are presented in Table 27 and Table 28.

Table 27 Day-time Flash Fire Results

Scenario	Weather	Distance downwind to LFL [m]	Height of the max flash fire distance [m]
Section breach 10mm mid	1.9B	4.73	7.576
	7.5D	4.888	3.943
	4.1D	5.561	5.747
	1.5D	7.195	9.255
Section breach 25 mm mid	1.9B	12.25	14.56
	7.5D	12.63	7.901
	4.1D	15.52	11.56
	1.5D	16.5	15.36
Section breach 75 mm mid	1.9B	17.86	33.98
	7.5D	23.81	19.13
	4.1D	25.41	25.65
	1.5D	28.81	39.5
Section breach 75 mm top	1.9B	10.4	41.71
	7.5D	15.68	23.59
	4.1D	14.05	32.15
	1.5D	12.36	50.3
Section breach 110 mm mid	1.9B	21.19	45.02
	7.5D	33.2	28.3
	4.1D	32.2	39.6
	1.5D	34.27	48.62
Section breach 110 mm top	1.9B	15.07	57.05
	7.5D	23.91	32.81
	4.1D	21.25	44.92

Scenario	Weather	Distance downwind to LFL [m]	Height of the max flash fire distance [m]
	1.5D	18.49	67.31
Section breach FBR	1.9B	116.4	0
	7.5D	72.9	25.01
	4.1D	66.75	36.06
	1.5D	215.2	0

Table 28 Night-time Flash Fire Results

Scenario	Weather	Distance downwind to LFL [m]	Height of the max flash fire distance [m]
Section breach 10mm mid	7.3D	4.874	4.079
	4.0D	5.529	5.796
	1.0D	7.077	9.926
	2.6E	5.848	7.688
	1.0F	6.21	10.42
Section breach 25 mm mid	7.3D	12.59	7.977
	4.0D	15.47	11.67
	1.0D	14.4	14.13
	2.6E	16.66	13.93
	1.0F	14.09	16.3
Section breach 75 mm mid	7.3D	23.55	19.35
	4.0D	24.92	25.83
	1.0D	26.9	50.27
	2.6E	24.52	31.45
	1.0F	27.65	41.7
Section breach 75 mm top	7.3D	15.46	23.77
	4.0D	13.85	32.39
	1.0D	11.76	59.46

Scenario	Weather	Distance downwind to LFL [m]	Height of the max flash fire distance [m]
	2.6E	12.51	37
	1.0F	10.6	50.52
Section breach 110 mm mid	7.3D	32.34	28.52
	4.0D	31.51	39.9
	1.0D	31.65	73.27
	2.6E	29.62	40.73
	1.0F	33.07	50.79
Section breach 110 mm top	7.3D	23.6	33.05
	4.0D	20.96	45.22
	1.0D	17.87	83.28
	2.6E	18.39	50.74
	1.0F	16.04	67.78
Section breach FBR	7.3D	73.39	26.16
	4.0D	65.95	37.46
	1.0D	307	0
	2.6E	111.2	1.254
	1.0F	265.9	0

B.3 Explosion Results

Side-on overpressure results are presented in Table 29 and Table 30. Overpressures 0.14 bar (14 kPa) and above were not reached.

Table 29 Day-time Explosion Overpressure Results

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
Section breach 25 mm mid	1.9B	0.07	17	26.72
	7.5D	0.07	13.23	18.3
	4.1D	0.07	15.23	22.12

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
	1.5D	0.07	19.29	30.28
Section breach 75 mm mid	1.9B	0.07	21.6	38
	7.5D	0.07	25.21	34.04
	4.1D	0.07	27.45	39.7
	1.5D	0.07	33.48	52.75
Section breach 75 mm top	1.9B	0.07	21.5	37.62
	7.5D	0.07	17.92	27.3
	4.1D	0.07	18.85	30.85
	1.5D	0.07	21.77	38.8
Section breach 110 mm mid	1.9B	0.07	37.23	61.26
	7.5D	0.07	35.21	47.1
	4.1D	0.07	38.49	54.85
	1.5D	0.07	46.08	71.96
Section breach 110 mm top	1.9B	0.07	23.35	42.84
	7.5D	0.07	28.69	41.29
	4.1D	0.07	31.58	48.65
	1.5D	0.07	24.01	44.33
Section breach FBR	1.9B	0.07	75.26	110.5
	7.5D	0.07	78.56	93.11
	4.1D	0.07	83.66	108.8
	1.5D	0.07	145.6	127.7

Table 30 Night-time Explosion Overpressure Results

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
Section breach 25 mm mid	7.3D	0.07	13.29	18.46
	4.0D	0.07	15.26	22.22
	1.0D	0.07	20.59	33.57

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
	2.6E	0.07	16.64	25.03
	1.0F	0.07	20.69	33.02
Section breach 75 mm mid	7.3D	0.07	25.21	34.21
	4.0D	0.07	27.51	39.9
	1.0D	0.07	36.81	59.58
	2.6E	0.07	29.15	43.87
	1.0F	0.07	33.99	54.24
Section breach 75 mm top	7.3D	0.07	17.63	27.12
	4.0D	0.07	18.7	30.76
	1.0D	0.07	23.74	42.96
	2.6E	0.07	20.94	35.08
	1.0F	0.07	24.64	42.84
Section breach 110 mm mid	7.3D	0.07	35.27	47.35
	4.0D	0.07	38.41	54.96
	1.0D	0.07	51.27	81.66
	2.6E	0.07	35.85	56.03
	1.0F	0.07	45.52	70.53
Section breach 110 mm top	7.3D	0.07	28.77	41.56
	4.0D	0.07	31.56	48.87
	1.0D	0.07	25.21	47.54
	2.6E	0.07	22.09	39.02
	1.0F	0.07	25.73	47.41
Section breach FBR	7.3D	0.07	78.96	93.9
	4.0D	0.07	84.12	109.6
	1.0D	0.07	212.4	138.4
	2.6E	0.07	81.71	113.4
	1.0F	0.07	182.4	132.9

Appendix C Likelihood Analysis - Data and Results

C.1 Likelihood of Release from Underground Pipelines

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

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

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

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

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

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

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

C.1.1 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.

C.1.2 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. 1.31E-04 per km per year for a pipeline with wall thickness ≥ 10 mm to < 15 mm) and was adopted in the QRA for the underground HP Ethane pipeline (Refer to Table 31).

Table 31 Leak Frequencies for Underground LPG Pipelines

Failure Mode	Pipeline Diameter (mm)	Wall Thickness (mm)	Leak Frequency (per km per yr)					
			Pinhole (≤ 10 mm)	Pinhole (> 10 mm ≤ 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		1.30E-05	6.70E-06	8.30E-06	8.50E-05
Corrosion	All	< 5	1.6E-04		8.90E-07	4.50E-07	1.30E-06	1.63E-04
		5 to < 10	8.4E-05		2.40E-07	4.80E-07	7.30E-07	8.55E-05
		10 to < 15	4.5E-06		1.30E-08	2.60E-08	3.90E-08	4.58E-06
		≥ 15	4.3E-07		1.20E-09	2.50E-09	3.70E-09	4.37E-07
Ground Movement / Other	All	All	1.2E-05		2.50E-06	1.50E-07	2.50E-06	1.72E-05
TPA	All	All	0.00E+00	2.20E-05	2.40E-06	1.00E-07	1.00E-07	2.46E-05
Total Leak Freq.	All	<5	2.29E-04	2.20E-05	1.88E-05	7.40E-06	1.22E-05	2.89E-04
		5 to < 10	1.53E-04	2.20E-05	1.81E-05	7.43E-06	1.16E-05	2.12E-04
		10 to < 15	**7.35E-05**	**2.20E-05**	**1.79E-05**	**6.98E-06**	**1.09E-05**	**1.31E-04**
		≥ 15	6.94E-05	2.20E-05	1.79E-05	6.95E-06	1.09E-05	1.27E-04

Failure Mode	Pipeline Diameter (mm)	Wall Thickness (mm)	Leak Frequency (per km per yr)					
			Pinhole (≤ 10 mm)	Pinhole (> 10 mm ≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Leak distribution	All	<5	79.1%	7.6%	6.5%	2.6%	4.2%	100.0%
		5 to < 10	72.1%	10.4%	8.5%	3.5%	5.5%	100.0%
		10 to < 15	**56.0%**	**16.8%**	**13.6%**	**5.3%**	**8.3%**	**100.0%**
		≥ 15	54.6%	17.3%	14.1%	5.5%	8.6%	100.0%

C.1.3 British Standards Institute (PD 8010-3:2009+A1:2013)

The data and approach included in Annex B of PD 8010-3:2009+A1:2013 was used to estimate the leak frequencies for the Moomba to Sydney Ethane Pipeline (Refer to Table 32). The data applicable for a pipeline with a wall thickness > 10mm, manufactured after 1980, was used.

Leak frequency data is not reported for internal corrosion; therefore, the total leak frequencies reported in Table 32 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).

Table 32 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	3.4E-06	0.0E+00	0.0E+00	0.0E+00	3.4E-06
Corrosion	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ground Movement / Other	1.0E-06	1.0E-06	1.0E-06	3.0E-07	3.3E-06
TPA	5.8E-06	5.8E-06	5.8E-06	1.2E-05	2.9E-05
Total Leak Freq. =	1.0E-05	6.8E-06	6.8E-06	1.19E-05	**3.57E-05**
% =	28.6	19.0	19.0	33.3	

C.1.4 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 33.

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 33 Leak Frequencies for Underground HVL Pipelines (Excluding Ammonia)

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

C.1.5 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 34), and
- Total number of leaks and ruptures in the period 2000 to 2018. A total of 17 are reported in the database.

Table 34 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 34 and the total of 17 release incidents, the expected total release frequency is

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

The value selected for the release of ethane from the MSE is $1.31 \times 10^{-4}\ \mathrm{km}^{-1}\mathrm{y}^{-1}$. 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.

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

C.2.1.1 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 35 Ignition Probability - UKOPA

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

C.2.1.2 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 36 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

Release Rate (kg/s)	Total Ignition Probability
20	0.0532
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 37 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 38 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.3 Likelihood of Representative Release Scenarios

The estimated likelihood of each representative release scenario is listed in Table 39.

Table 39 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		7.35E-05	7.35E-05	0.56
25mm MID	2.20E-05		2.20E-05	0.17
75mm MID	8.88E-07	5.74E-06	6.63E-06	0.05
75mm TOP	1.51E-06	9.77E-06	1.13E-05	0.09
110mm MID	3.70E-08	2.54E-06	2.58E-06	0.02
110mm TOP	6.30E-08	4.33E-06	4.39E-06	0.03
FBR	1.00E-07	1.08E-05	1.09E-05	0.08
Total	2.46E-05	1.07E-04	**1.31E-04**	1.0000

Appendix D Indoor Vulnerability from High Pressure Transmission Pipeline Releases

D.1 Context

The default setting for indoor vulnerability to thermal radiation is consistent with the TNO Purple Book;

"*It is assumed that people indoors are protected from heat radiation until the building catches fire. The threshold for the ignition of buildings is set at 35 kW m*$^{-2}$*. If the building is set on fire, all the people inside the building are assumed to die.*"

Buildings constructed in Australia complying with the National Construction Code are nominally designed and constructed to resist at least 10 kW/m^2. Due to this, a more detailed approach to vulnerability within buildings than that suggested by TNO was adopted.

D.2 Methodology

Arriscar reviewed four National Transportation Safety Bureau (NTSB) pipeline incident reports to ascertain:

- Radiant heat fluxes that resulted in building damage or destruction.
- Typical lethality levels in the case of building destruction due to radiant heat flux and building damage due to radiant heat flux.

Based on the accident reports or accident briefs, models were developed to determine the radiant heat flux experienced at damaged and destroyed buildings. Reports on the number of fatalities were also used to estimate the vulnerability within buildings damaged or destroyed through exposure through radiant heat.

D.3 Pipeline Accident Reports

The accident reports reviewed are listed in Table 40

Table 40 NTSB Reports Reviewed

Report Number	Accident Date	Location
PLD19FR002	1/8/2019	Danville, Kentucky, USA
PAR-11/01	9/9/2010	San Bruno, California, USA
PAB/99-02	21/7/1997	Indianapolis, Indiana, USA
PAR-95/01	23/3/1994	Edison, New Jersey, USA

D.3.1 PLD19FR002 - Danville, Kentucky

D.3.1.1 Report Synopsis

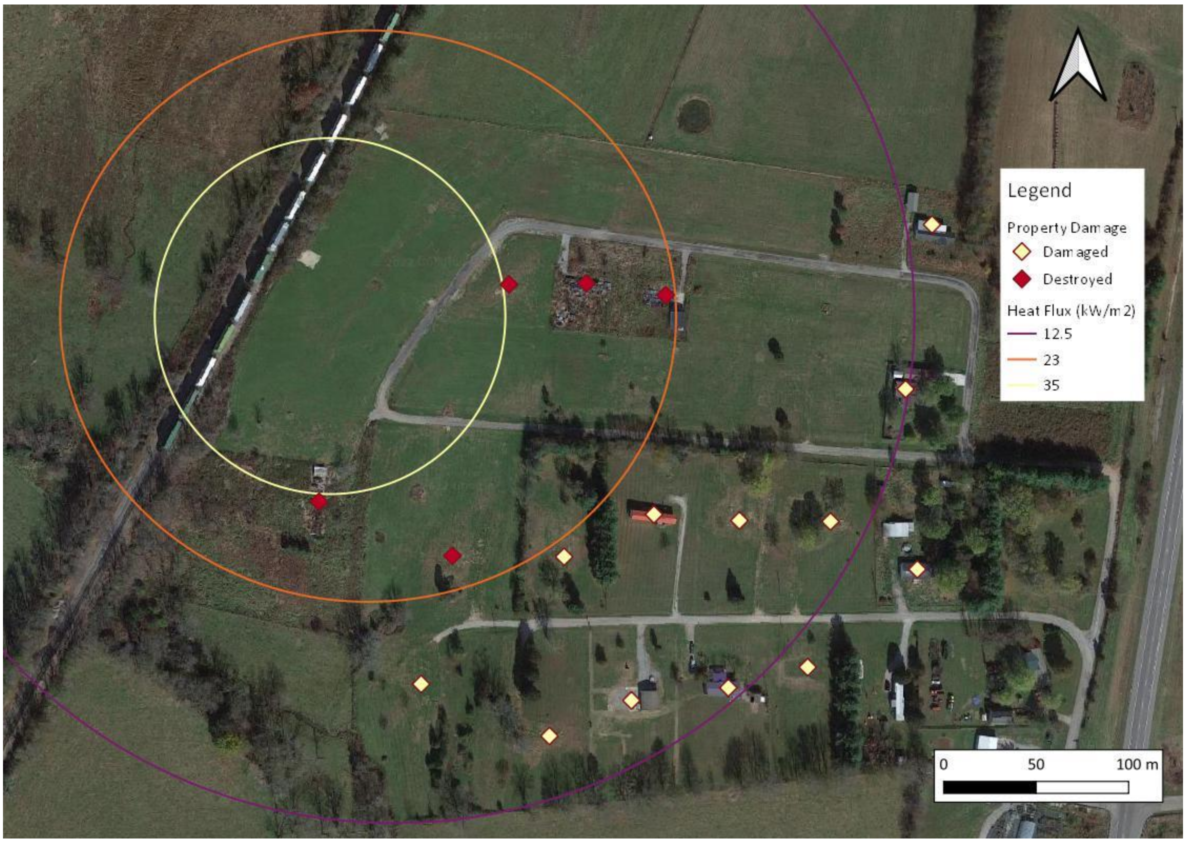
On August 1, 2019, at 1:23 a.m. local time, a 30-inch-diameter natural gas transmission pipeline owned and operated by Enbridge Inc. (Enbridge) ruptured near Danville, Lincoln County, Kentucky, about 35 miles southwest of Lexington, Kentucky. The rupture released about 66 million cubic feet of natural gas which ignited, resulting in the death of 1 person, the hospitalization of 6 people and the evacuation of 75 residents from the Indian Camp mobile home park. The fire destroyed 5 nearby residences, damaged 14 other residences, and burned about 30 acres of land including railroad tracks owned and operated by Norfolk Southern Corporation. (See figure.) As a result of the explosion, a 33.2-foot-long section of the pipeline was ejected and landed about 481 feet southwest of the rupture site.

D.3.1.2 Analysis

Temperature and humidity for the day of the accident were obtained from the US National Weather Service. Wind speed and direction were not obtained. Wind speed of 5 m/s from the west was assumed as this was consistent with the damage pattern.

Details of the pipeline operating conditions and length were obtained from the report, as was the location of destroyed and damaged houses. Using the long pipeline model in Phast, the extent of radiant heat flux generated in the first thirty seconds of the release was estimated (Figure 26).

Figure 26 Estimated Extent of Radiant Heat Flux for Pipeline Rupture in Danville, Kentucky



D.3.1.3 Findings

The 23 kW/m^2 radiant heat flux contour encapsulates most of the destroyed dwellings. This is significantly lower than the 35 kW/m^2 heat flux considered to mark fire spread to buildings from the Purple Book, though the dwellings in this case were mobile homes. The distance to 12.5 kW/m^2 appears to correlate well with building damage.

There was one fatality, yet five buildings were destroyed and more damaged. As the pipeline rupture occurred at 1:23 am, it is reasonable to assume most of the dwellings were occupied. This is supported by the evacuation of 75 residents from the community. The presumption that lethality will always occur if there is fire spread to the building appears overly conservative.

D.3.2 PAR/11-01 – San Bruno, California

D.3.2.1 Report Synopsis

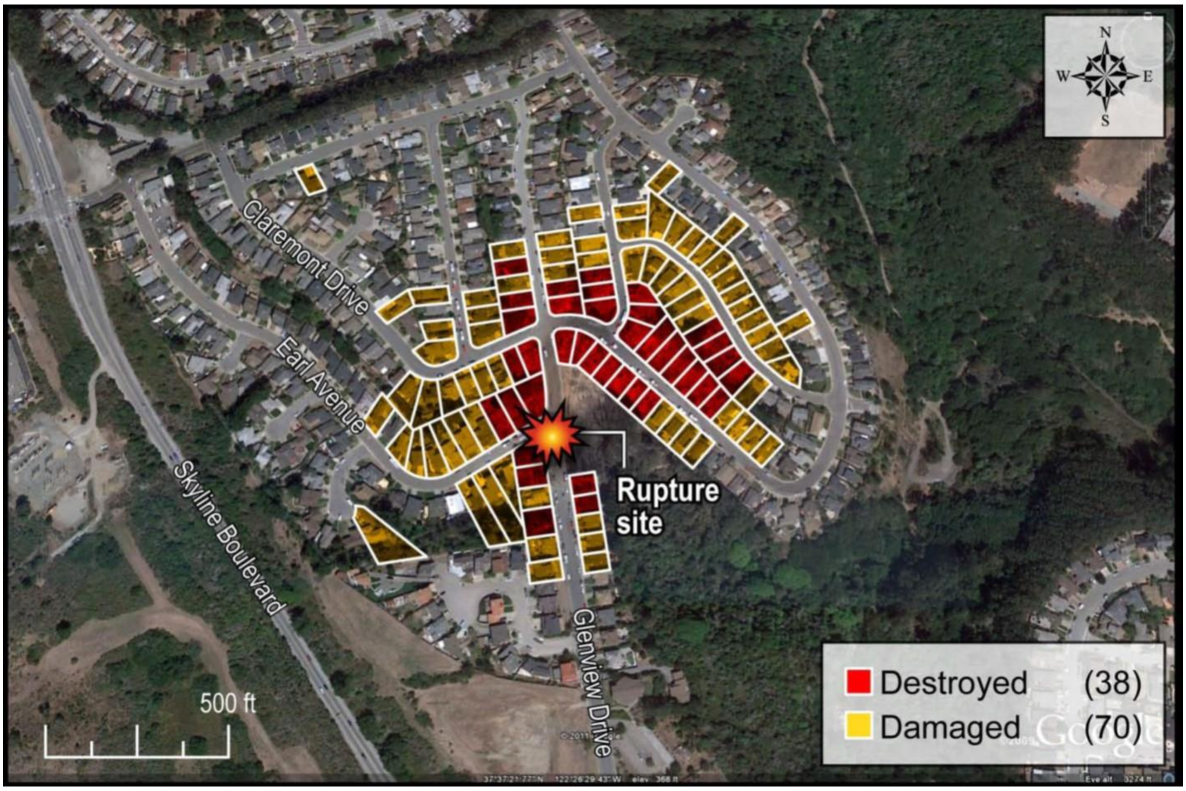
On September 9, 2010, about 6:11 p.m. Pacific daylight time, a 30-inch-diameter segment of an intrastate natural gas transmission pipeline known as Line 132, owned and operated by the Pacific Gas and Electric Company (PG&E), ruptured in a residential area in San Bruno, California. The rupture occurred at mile point 39.28 of Line 132, at the intersection of Earl Avenue and Glenview Drive. The rupture produced a crater about 72 feet long by 26 feet wide. The section of pipe that ruptured, which was about 28 feet long and weighed about 3,000 pounds, was found 100 feet south of the crater. PG&E estimated that 47.6 million standard cubic feet of natural gas was released. The released natural gas ignited, resulting in a fire that destroyed 38 homes and damaged 70. Eight people were killed, many were injured, and many more were evacuated from the area.

D.3.2.2 Analysis

The NTSB report contained meteorological information and pipeline conditions that were used to develop the model. The extent of the radiant heat flux is shown in Figure 27. Destroyed buildings can be seen in the figure, while the extent of damage may be seen in an image extracted from the investigation report

Figure 27 Radiant Heat Flux, San Bruno Pipeline Rupture and Fire

Figure 28 Extent of Damage and Destruction, San Bruno (ex NTSB)



D.3.2.3 Findings

Comparing Figure 27 and Figure 28, the extent of building destruction is reasonably consistent with the extent of the 23 kW/m^2 radiant heat contour. The 12.5 kW/m^2 contour encapsulates nearly all the damaged properties. The assumption that the threshold for ignition of a building is 35 kW/m^2 does not appear a conservative estimate.

The timing of the incident (6:11 pm) suggests many of the homes would have been occupied. A total of eight fatalities were reported with 38 homes destroyed and a further 70 damaged. The assumption that fire spread to a building leads to 100% fatalities appears overly conservative.

D.3.3 PAB/99-02 Indianapolis, Indiana

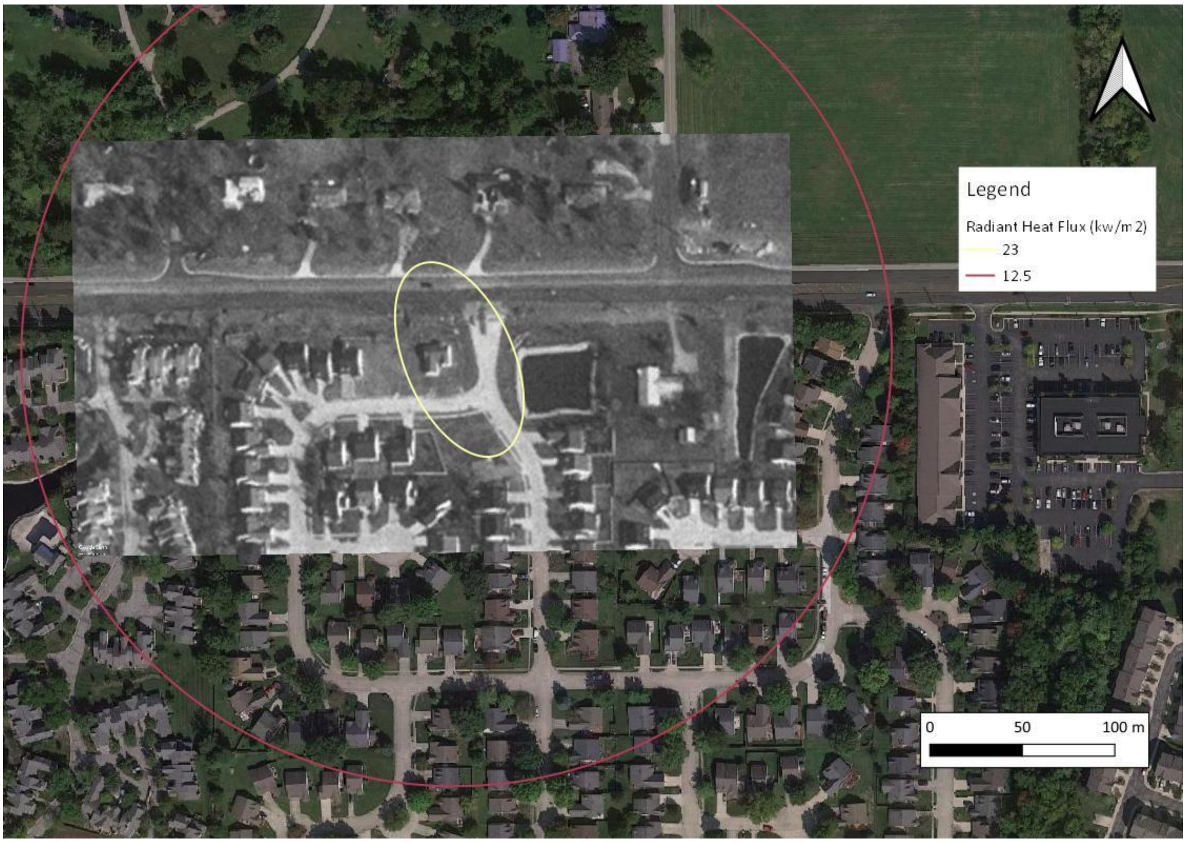
D.3.3.1 Report Synopsis

About 2:33 p.m. on July 21, 1997, a 20-inch-diameter steel natural gas transmission pipeline owned and operated by Citizens Gas & Coke Utility Company(Citizens Gas) ruptured and released natural gas near an intersection adjoining the Charter Pointe subdivision in Indianapolis, Indiana. The gas ignited and burned, killing one resident and injuring another. About 75 residents required temporary shelter. Six homes were destroyed, and about 65 others sustained damage significant enough to be documented by the local investigation team.

D.3.3.2 Analysis

Using data from the pipeline accident brief, and Indianapolis weather conditions for the day, a model was set up in Phast 8.61. Wind speed and direction was not obtained. Figure 29 shows the estimated extent of 23 kW/m^2 and 12.5 kW/m^2 radiant heat flux assuming a NNW wind at 1.5 m/s overlaid on an aerial photograph taken the year following the accident. The 23 kW/m^2 contour appears to define well the extent of destruction. The dwelling in the centre of the 23 kW/m^2 contour has a significantly different shape from a photograph taken in 1992, indicating this dwelling has been rebuilt.

Figure 29 Radiant Heat Flux, Indianapolis Pipeline Rupture and Fire



D.3.3.3 Analysis

The 23 kW/m^2 contour appears to define well the extent of destruction. As the incident occurred at 2:33 pm, it is difficult to make any estimates about the occupancy of the buildings at the time.

D.3.4 PAR-95-01 Edison, New Jersey

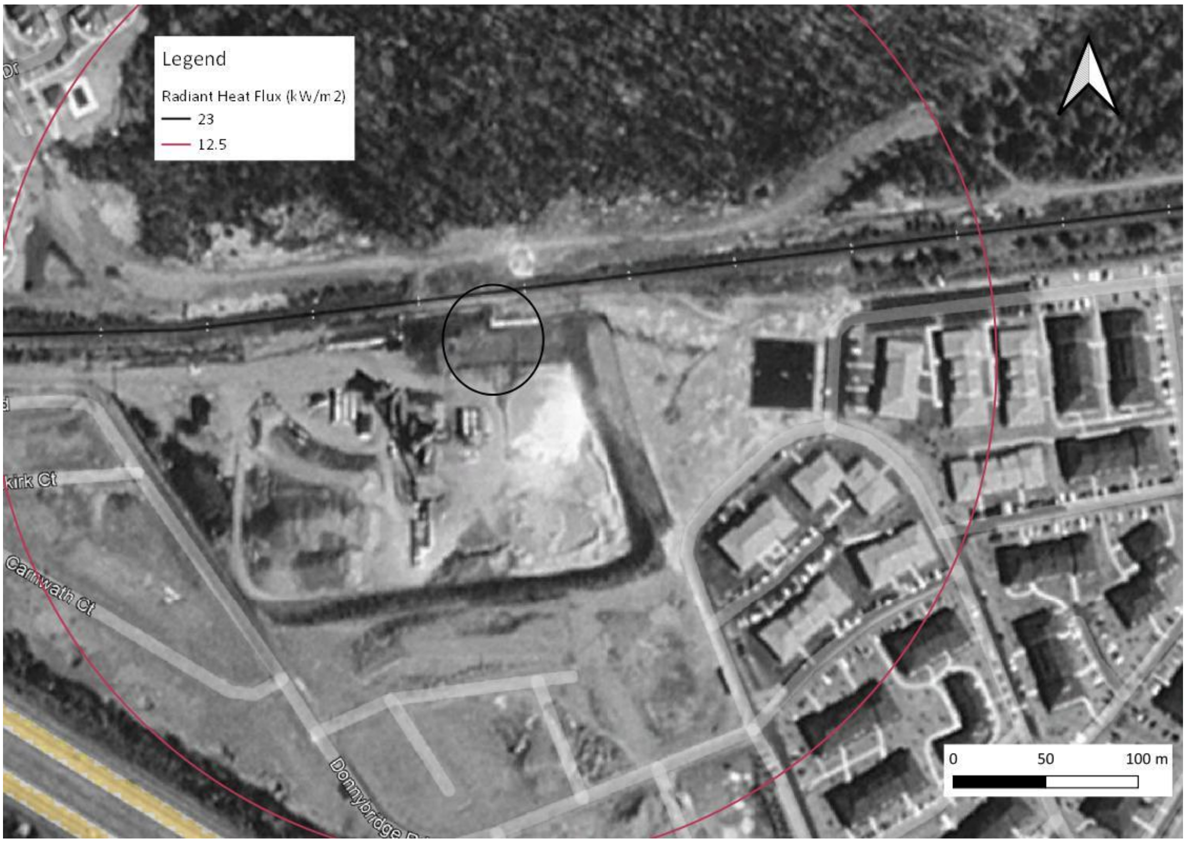
D.3.4.1 Report Synopsis

About 11:55 pm on March 23, 1994, a 36-inch diameter pipeline owned and operated by Texas Eastern Transmission Corporation ruptured catastrophically in Edison Township, New Jersey, within the property of Quality Materials, Inc., an asphalt plant. The force of the rupture and of natural gas escaping at a pressure of about 970 psig (pounds-per-square-inch gauge) excavated the soil around the pipe and blew gas hundreds of feet into the air, propelling pipe fragments, rocks, and debris more than 800 feet. Within 1 to 2 minutes of the rupture, one of several possible sources ignited the escaping gas, sending fames upward 400 to 500 feet in the air. Heat radiating from the massive fire ignited several building roofs in a nearby apartment complex. Occupants. Alerted to the emergency by noises from the escaping gas and rocks hitting the roofs, fled from the burning buildings. The fire destroyed eight buildings. Approximately 1,500 apartment residents were evacuated.

D.3.4.2 Analysis

Pipeline and weather conditions were obtained from the investigation report. The wind was calm, which was modelled in Phast as a 1.0 m/s windspeed. The extent of radiant heat flux is depicted in Figure 30. The image was taken after the incident, and the apartments with the lighter coloured roofs are the ones destroyed in the fire.

Figure 30 Radiant Heat Flux, Edison Pipeline Rupture and Fire



D.3.4.3 Analysis

This incident appears as an outlier in that destruction occurs outside the 23 kW/m^2 zone, but appears well defined by the 12.5 kW/m^2 contour. However, no fatalities due to radiant heat were recorded, indicating the potential in a built-up area for low lethality levels even with initial heat flux greater than 12.5 kW/m2.

D.4 Lethality Analysis

Both the San Bruno and Danville incidents were used to analyse the likelihood of fatality. The Indianapolis incident was excluded because the occupancy of buildings at the time of the incident is difficult to infer. The incident at Edison was excluded due to the lack of fatalities in buildings destroyed at relatively lower heat fluxes than estimated for the other incidents. The large number of people involved could also make one incident (25% of those analysed) bias the observations for the majority of incidents.

One further incident was included, that in Arizona 2021 where two members of a family of three were killed when a pipeline ruptured near their home. It was a rural setting, and no other occupied hoes were involved.

A summary of the analysis is presented in, Table 41

Table 41 Fatality Analysis

Incident	Dwelling	No. Dwellings	No. Inhabitants known	Fatalities	Estimated No. of People[1]	Lethality by Dwelling
San Bruno	CA1	1	y	3	3	100.0%
	CA2	1	y	2	2	100.0%
	CA3	1	y	1	2	50.0%
	CA4	1	y	1	2	50.0%
	CA5	1	y	1	1	100.0%
	Others destroyed	33	n	0	92	0.0%
Arizona	AZ1	1	y	2	3	66.7%
Danville	KY1	1	y	1	1	100.0%
	Other destroyed	4	n	0	11	0.0%
	Totals	**44**		**11**	**118**	
Average Lethality (by population | by dwelling)					**9.4%**	**12.9%**

A similar analysis assuming only 50% of the destroyed buildings were occupied at the time resulted in a lethality based on population of 17.1%, and a lethality per destroyed building of 22.7%.

An analysis on a population basis for the damaged (but not destroyed) buildings yielded an individual lethality risk of 3.8%. This analysis was very conservative as it assumed the same victims in the damaged building analysis as was in the destroyed building analysis, essentially double counting these victims.

[1] The number of people were estimated by reviewing news reports. Where other people were reported as being in the house, the number of others mentioned in the report was included in the estimated total within the house. If there were no reports of others present in the house, only the victims were assumed to be in the house, while for other houses where no fatality occurred, it was assumed an average of 2.8 people per house.

D.5 Conclusions

Based on an analysis of five NTSB investigation reports and pipeline accident reports, the following radiant heat fluxes calculated for the first 30 seconds of release seem to provide good correlation to building damage and building destruction:

- Building destruction at greater than 23 kW/m^2 radiant heat flux.
- Building damage at greater than 12.5 kW/m^2 radiant heat flux.

The analysis also suggests the following are conservative in relation to lethality levels:

- 30% lethality in buildings destroyed due to flame spread.
- 3% lethality in buildings damaged due to flame spread.

Recognising the National Construction Code has the minimum resistance to radiant heat for buildings as 10 kW/m^2, and combining the heat flux and lethality analyses, the recommended vulnerabilities for a QRA for pipelines are presented in Table 42

Table 42 Proposed Indoor Vulnerabilities to Thermal Radiation

Radiant Heat Flux (kW/m^2)	Probability of Fatality
35	1.0
20	0.3
10	0.03