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Technical Report

GMGA - QRA review

Prepared for: LendLease
28 January 2022

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Abbreviation

Table 1: table of Abbreviations

Abbreviation	Meaning
ALARP	As Low As Reasonably Practicable
APA	APA Group (Pipeline Licensee)
AS	Australian Standard
AS2885	Australian Standard for “Pipelines-Gas and Liquid Petroleum’
CDL	Critical Defect Length (mm) is a hole size where a pipeline is likely to rupture
CIC	Common Infrastructure Corridor
CMP	Construction Management Plan
CP	Cathodic Protection
CHW	Central Highlands Water
CTE	Coal Tar Enamel Pipe Coating
CTMS	Custody Transfer Meter Station
DBYD	Dial Before You Dig
DET	Department of Education & Training
DN	Diameter nominal
DPIE	NSW Department of Planning, Industry and Environment
DOC	Depth of Cover
EIP	External Interference Protection
GIS	Geographical Information System
GJ/s	Gigajoules per Second (energy release rate)
GMGA	Greater McArthur Growth Area
GPT	General Purpose Teeth (used on excavator buckets)
HDD	Horizontal Directional Drill (used for installation of utilities under existing assets)
HIPAP	Hazardous Industry Planning Advisory Paper
Jemena	Jemena (Pipeline Licensee)
km	Kilometre(s)
KP	Kilometre Point
kPag	kiloPascals (gauge)
kW/m2	Kilowatts per metre squared (heat radiation flux)
LOPA	Layers of Protection Analysis (Likelihood/Probability of Failure Calculation)
m	Metre(s)
MAOP	Maximum Allowable Operating Pressure
ML	(4.7 kW/m2 radiation contour in the event of a full-bore rupture of the pipeline, results in 2nd degree burns within 30 sec of exposure at this distance)
MLV	Main Line Valve

Abbreviation	Meaning
PE	Polyethylene plastic gas pipe
PIMP	Pipeline Integrity Management Plan
PL	Pipeline License
PPC	Primary Pressure Control
PPV	Peak Particle Velocity, related to degree of ground movement or vibration
QRA	Quantitative Risk Assessment
R1	Rural location classification
R2	Rural Residential location classification
ROW	Right of Way
RTP	Resistance to Penetration
S	Sensitive Use location classification
SAOP	Safety and Operating Plan
SMS	Safety Management Study (as defined by AS2885)
SMYS	Specified Minimum Yield Stress
SWMS	Safe Work Method Statement
T1	Residential location classification
T2	High Density location classification
TP	Transmission Pressure (operating pressure >1050kPag)
TT	Tiger Teeth
WT	Wall Thickness

Executive Summary

Greater Macarthur is a Growth Area (GMGA) incorporating Glenfield to Macarthur urban renewal precincts and the land release precincts to the south of Campbelltown, including Gilead, North Appin and Appin. In 2021, NSW Department of Planning, Industry and Environment (DPIE) commissioned Arriscar Pty Ltd (Arriscar) to undertake a Quantitative Risk Assessment (QRA) from high pressure gas pipelines in the GMGA.

The QRA undertaken references Hazardous Industry Planning Advisory Papers (HIPAPs) No. 4, 6 and 10, however there are inconsistencies within both the HIPAPs and the Arriscar QRA report when compared to Australian Standard AS2885 - “Pipelines-Gas and Liquid Petroleum. AS2885 is the standard used to govern The Australian Transmission Pressure Gas Pipeline Industry for design, operation, maintenance and to maintain their license(s) to operate. It is worth noting that the Arriscar does reference within item 5.5 of its report that the pipelines are to be managed in accordance with AS2885 and Australian legislation, however this statement appears at odds with their approach and recommendations.

LendLease have commissioned SMEC and subject matter experts Delphi Risk Management Consulting to review the report and recommendations prepared by Arriscar for their suitability in englobo land use planning.

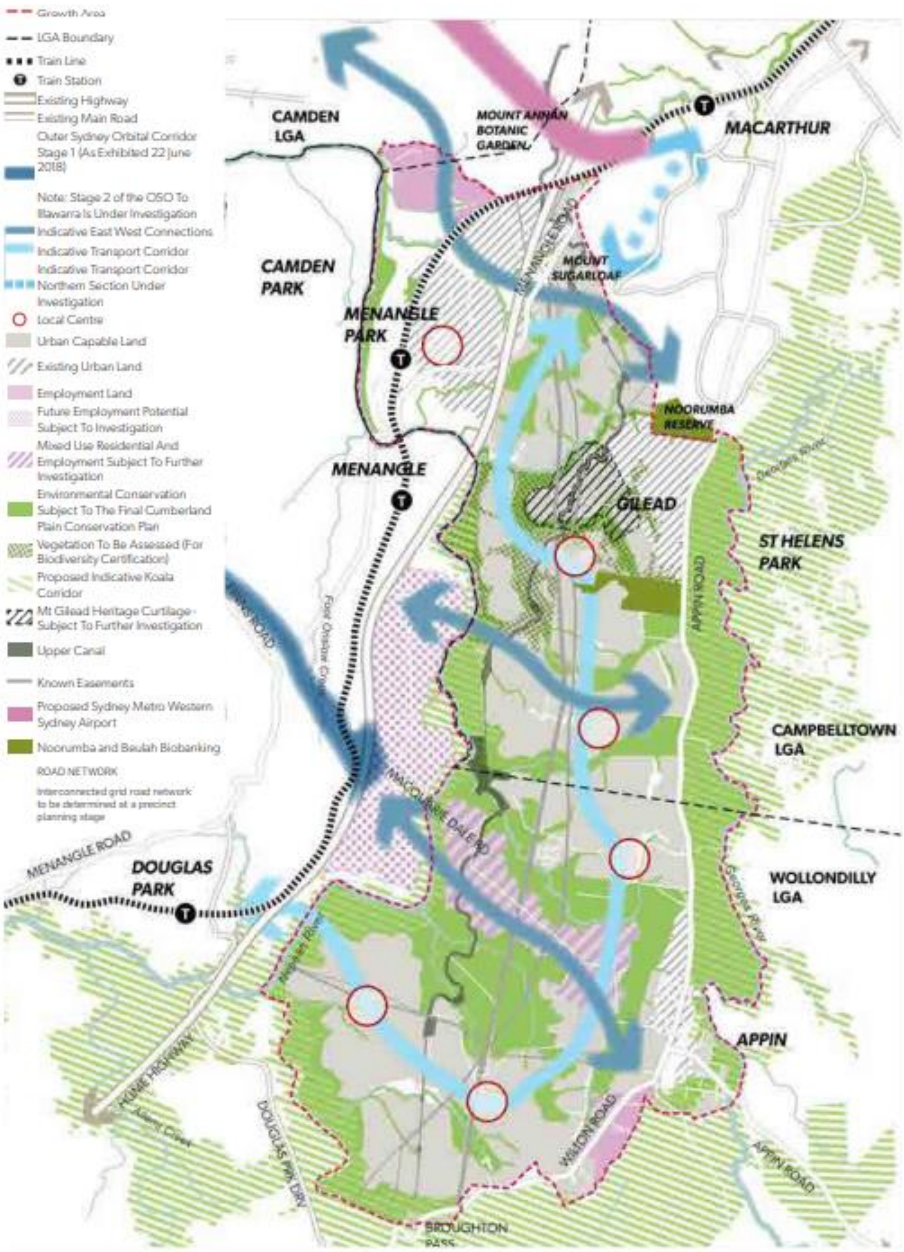

Figure 1: Greater Macarthur Structure Plan (land release areas) 2018 Sourced from DPIE Greater Macarthur 2040

Recommendations

The follow recommendations are provided to allow the formulation of suitable land zonings and structure plans within the GMGA. It is imperative, that at these early formative stages, a collaborative and cautious approach is taken. This approach must balance the protection of the public and future residents, however equally important consideration must be given that decisions taken don't unnecessarily sterilise developable land. This Iterative and consultative approach, will ensure that the overall housing targets for the precinct are achieved

Recommendation 1

Given that AS2885 specifically advises that "It is not appropriate to use overseas data to estimate Australian pipeline failure rates. This is one reason that conventional quantitative risk analysis [QRA] is non-preferred for Australian or New Zealand pipelines" (AS2885.6 App F3) we recommend that the proposed buffers presented within the Arriscar QRA report be urgently and critically revisited by DPIE.

Recommendation 2

A Preliminary Land Use Change Safety Management Study as outlined within AS2885 Part 6 Section 5.5.2 should be undertaken prior to the formalisation of any notional buffering. This should occur as part of the Technical Assurance Panels for Appin and Gilead.

It is our strong view that early engagement with the pipeline licensees, in this case APA and Jemena, in a SMS workshop (either together or in separate workshops) is prudent when government authorities are considering releasing large parcels of land adjacent to, or overlapping major TP gas pipelines. These workshops will engage beyond just the pipeline licensees, including the utility service providers, state government and local government authorities (Refer Appendix B). This Preliminary SMS will review a concept level layout for the GMGA and will provide clarity with respect to the following:-

a. what land use is acceptable within the various pipeline ML's,

b. how close the new land use can co-exist with the pipeline(s),

c. likely road and utility crossing locations along with minimum design requirements

d. what control measures are required during construction of any new developments

e. and whether additional physical protections of the pipeline(s) are required?

By undertaking this Preliminary SMS, it will inform any planning requirements, including appropriate buffering or mitigation measures. It will also inform of any equipment limitations on developers and contractors for works occurring within the existing easements and/or near the pipelines.

Recommendation 3

Following on from recommendation 1, we would expect that as development sites, either individual parcels, or larger amalgamations, within the GMGA are readied for development planning that a Detailed Design Safety Management Study is undertaken.

The Detailed Design SMS would include participation from the relevant pipeline licensee(s), developer, utility service provider and the construction contractor, ensuring that the guiding principles established in the Preliminary SMS, have been incorporated into the detailed design, while further exploring and mitigating, any specifically identified threats to the pipeline not previously considered.

1. Background

The NSW Department of Planning, Industry and Environment (DPIE) engaged Arriscar Pty Ltd (Arriscar) in early 2021 to undertake a risk assessment from high (transmission) pressure gas pipelines in the Greater McArthur Growth Area (GMGA) in NSW. The findings of this report have resulted in several recommendations which do not appear to be consistent with the typical findings for pipeline risk assessments in the Australian Transmission Pipeline Industry.

A copy of the Arriscar report can be found within Appendix A

The Report has been co-authored by Mark Harris from Delphi Risk Management Consulting Pty Ltd and Cameron Miles from SMEC.

Mark Harris

Years of experience: 33

Qualifications

BE Chem(Hons), University of Adelaide

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Relevant experience

Mark Harris is a process safety and risk assessment professional with 33+ years of process design experience in the Oil & Gas Industry and 22+ years of process safety leadership and facilitation experience.

Mark has been facilitating AS2885 pipeline safety management studies for the likes of APA, Jemena, Santos, AGL, Esso, Beach Energy, BHP, Epic Energy, Senex, DBNGP, SEAGas, QGC, APLNG, GLNG and has been consulting to industry, developers, councils and government authorities on the application of AS2885 in the planning and development process..

Cameron Miles

Years of experience:20

Qualifications

B.Eng(Geomatics) UNSW

MBA(Technology) UNSW

Relevant experience

With 20+ years industry experience, a Registered Surveyor and practised business leader Cameron has extensive experience in both infrastructure and urban redevelopment, having held Project Director roles on the St Mary's ADI and Menangle Park redevelopments, Utility Investigations Sydney Metro City and Southwest, Parramatta North Urban Transformation, Parramatta Stadium mapping and Western Sydney Airport projects

2. Key Findings of 3rd Party review

2.1 Basis of Arriscar Report

The authors of the Arriscar Report have endeavoured to apply a QRA methodology consistent with the requirements of the HIPAP guidelines which specifically refer to various types of Major Hazard Facilities. It is important to note that HIPAP 4,6 & 10 referenced in the Arriscar Report do not refer to any high consequence <u>linear</u> assets such as Transmission Pressure Gas Pipelines (>1050kPag). The Australian Transmission Pressure Gas Pipeline Industry is governed by the Australian Standard AS2885 for design, operation and maintenance to maintain their license to operate. Importantly, AS2885 is very clear on how risk should be assessed with AS2885 Part 6 - Pipeline Safety Management specifically dedicated to transmission pressure pipeline risk management.

AS2885 specifically identifies that any land use changes in the immediate vicinity of a transmission pressure gas pipeline (i.e. within Measurement Length, ML) must be subjected to a Safety Management Study (SMS) to review all possible threats to the safe operation and maintenance of the pipeline and ensure that any threats that cannot be mitigated by design or procedures are risk assessed and confirmed to be As Low As Reasonably Practical (ALARP).

The Arriscar Report relies on international data which does not reflect the actual design of the three pipelines affected. The AS2885 SMS process identifies the actual penetration resistance of the pipeline(s) and the actual threats which are considered “credible” during construction of a new development and for the remaining life of the pipeline. It also assesses the actual consequence of failure and allows for a more detailed probability analysis if necessary.

2.2 Use of the QRA Methodology for the Australian Pipeline Industry

The Australian Standard AS2885 has been developed for the Australian Pipeline Industry from the early 1970’s and has been founded on risk management processes (consistent with ISO31000) and based specifically on individual pipeline design, the credible threats unique to the pipeline’s route and land use surrounding the pipeline.

The data used in the Arriscar QRA methodology is largely unrelated to the design of the individual pipelines having been developed in overseas jurisdictions and licensing regimes which can lead to unnecessarily conservative outcomes and results inconsistent with AS2885.

AS2885 specifically advises the following advice on the QRA process for Australian Pipelines:-

“There are other sources of pipeline incident data such as the European Gas Pipeline Incident Group (EGIG) and the US Department of Transportation (DOT). While this data might have some uses, it has been shown that the average failure rate of Australian pipelines has been very much lower than in other regions for which data is available (Tuft and Cunha, 2013). **<u>It is not appropriate to use overseas data to estimate Australian pipeline failure rates</u>**. **<u>This is one reason that conventional quantitative risk analysis [QRA] is non-preferred for Australian or New Zealand pipelines</u>**, given that the failure rates used in such analyses are commonly based on incident data from elsewhere. QRA may be applicable to facilities for which relevant process plant data does exist.” (AS2885.6 App F3)

2.3 Critique of findings from Arriscar Report

2.3.1 Arriscar Finding 1

Finding 1 of the Arriscar Report suggested that there should be a 125m exclusion zone for residential use around the pipelines under review. This type of exclusion zone is largely unheard of in the Australian Pipeline Industry and inconsistent with precedence zoning in neighbouring , as shown in section 2.4 of this report.

This finding and recommended exclusions is also inconsistent with the observations within Section 8.9 of the Arriscar report, which recommends that a SMS is undertaken as the QRA is a generic form of assessment.

2.3.1.1 Alternate approach from the Australian Pipeline Industry

Typically, physical structures associated with new residential developments near TP gas pipelines are set back approximately 50m where a hole is considered a credible threat to the pipeline. Pipeline corridors/easements are typically used as linear parks or passive open space as part of any new development.

This approach is endorsed by APA and promoted within their publication APA Site Planning and Landscape National Guidelines, a copy of which can be found in Appendix G.

2.3.2 Finding 2

Finding 2 of the Arriscar Report suggested that sensitive use developments should not be located within 200m of the pipelines under review. The strong preference in the pipeline industry is to avoid locating sensitive uses within the defined Measurement Length (ML) of the pipeline(s) under review.

However, it is acknowledge that in some cases, in order for developments to be “functional” it is not possible to exclude sensitive use within the ML, particularly as MLs in Australia can range from 100m to 1000m+ depending on the specifics of the pipeline design.

2.3.2.1 Alternate approach from the Australian Pipeline Industry

AS2885 asks us to risk assess the specific sensitive use and if the risk is found to be Intermediate then a more detailed probability calculation (LOPA) or cost benefit analysis (ALARP) can be undertaken.

Based on this assessment, the proposed development may need to provide additional protection to the pipeline in the vicinity of the sensitive use to further lower the probability of failure to a level that can be considered ALARP for the pipeline industry. These additional protection measures then allow the sensitive use to co-exist with the pipeline into the future.

AS2885 offers a range of potential mitigations that can be considered until it is demonstrated that the risk from significant loss of containment is As Low As Reasonably Practical “ALARP”.

(Clause AS2885.6.4.2 A to E)

The assessment shall include analysis of at least the alternatives of the following:

a) MAOP reduction.

b) Pipe replacement (with no rupture pipe).

c) Pipeline relocation.

d) Modification of land use; and

e) Implementing physical and procedural protection measures that are effective in controlling threats capable of causing rupture of the pipeline.

Typical mitigation measures described in option e) above could include

- concrete slabbing
- fencing or bollarding of the easement
- Increased separation (horizontal or vertical)

Concrete slabbing is the preferred physical protection but decisions around protections are made during the SMS workshop or during the follow up LOPA or ALARP assessment with the full participation and agreement of the pipeline licensee. Depending on the specific risk being considered, further physical or procedural protections may not be necessary subject to the approval of the pipeline licensee.

2.3.3 Findings 3 & 4

Findings 3 & 4 of the Arriscar Report suggested that population density immediately either side of the pipeline corridor where the three pipelines run parallel should be restricted to uses where the average population density should not exceed 0.0126 ppl/m2.

2.3.3.1 Alternate approach from the Australian Pipeline Industry

AS2885 does not rely on population density criteria but does take into account likely “actual” population densities when considering the Consequence of a particular failure and then balances that against the actual Likelihood of failure for such a Consequence. AS2885 asks whether there is anything that can be reasonably applied to make the Likelihood “ALARP” such as those identified in the previous section above.

The AS2885 SMS process fully engages the pipeline licensee in getting their acceptance of all findings and recommendations to ensure they can accept and manage their pipeline risks appropriately going forward.

An SMS will take into account the local population density based on the development being proposed to ascertain the consequences of specific failure events but does not set a population density limit allowing each development to be considered on its individual merits.

2.4 Examples of Urbanisation and Gas Pipeline Co-location

The following pages provide contextual examples of urban development in proximity to gas pipelines. From these examples it can clearly be seen that setbacks are substantially less than the suggestions from the Arriscar report.

Denham Court Example

Figure 2: Examples of Energy Infrastructure pipelines within an urbanised environment – Denham Court

Indicates Approximate position of major transmission pipelines

Source of Information - https://portal.spatial.nsw.gov.au/

Bingara Gorge Wilton Example

Figure 3: Examples of Energy Infrastructure pipelines within an urbanised environment – Bingara Gorge Wilton

Indicates Approximate position of major transmission pipelines

Source of Information - https://portal.spatial.nsw.gov.au/

Glenfield Example

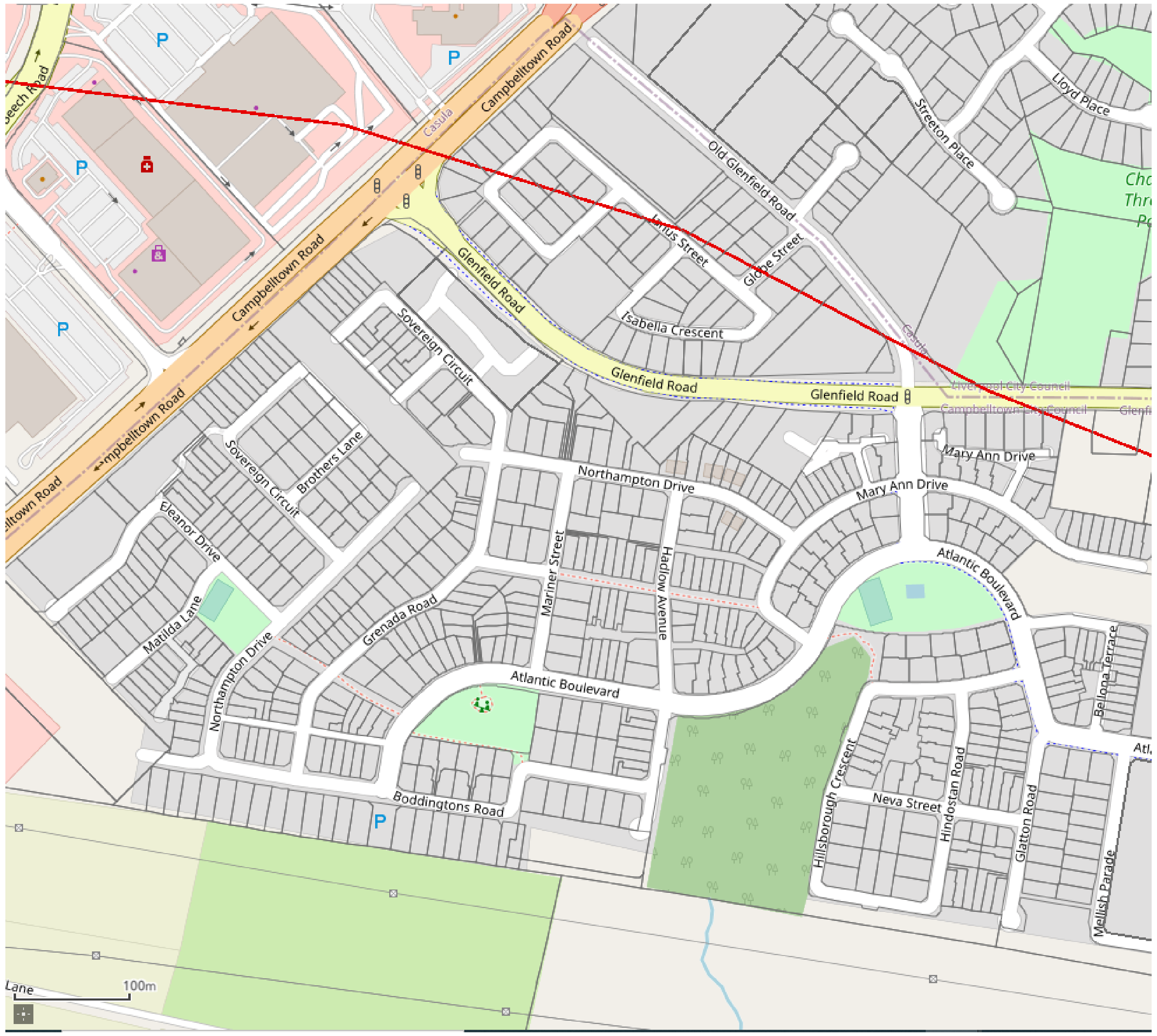

Figure 4: Examples of Energy Infrastructure pipelines within an urbanised environment – Glenfield

Indicates Approximate position of major transmission pipelines

Source of Information - https://portal.spatial.nsw.gov.au/

Menangle Park Example

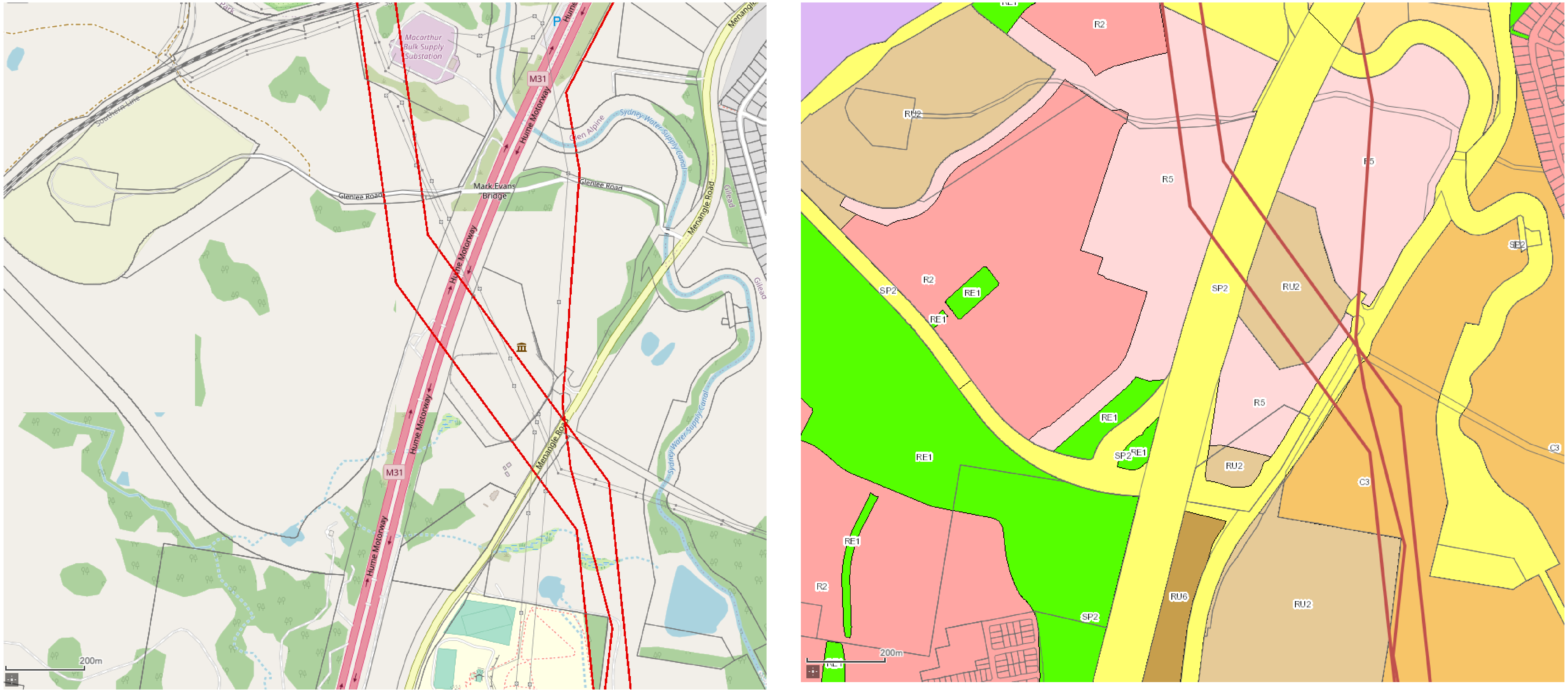

Figure 5: Examples of Energy Infrastructure pipelines within an urbanised environment – Glenfield

The Menangle park example has yet to be developed by Dahua, the current land holder, however, as can be seen from the above images, there is residential land zonings in and around the pipes.

Indicates Approximate position of major transmission pipelines

Source of Information - https://portal.spatial.nsw.gov.au/

3. Further review of Arriscar report.

In addition to the Key findings discussed previously, the following additional items are raised for consideration as part of the 3rd Party Review.

3.1 Arriscar Report Summary

As previously identified, the Arriscar findings have significantly limited potential development of the GMGA and are not consistent with the treatment of risk in the Australian pipeline industry. While the Arriscar Report identifies that NSW DPIE should consult with the pipeline operators (pg. 6), this is vital engagement should have been completed as the first activity, and as required under AS2885.

The QRA activity has created a distraction, while based on the HIPAP Guidelines which, whilst well considered for MHF's, are not crafted to properly represent a transmission pressure gas pipeline.

The Arriscar findings have significantly limited potential development of the GMGA and are not consistent with the treatment of risk in the Australian pipeline industry.

3.2 Arriscar Report Sections 4.2.4 & 7.1 & App C1.

The Arriscar Report identifies numerous mitigations and controls implemented by the various pipeline operators in Tables 5 & 6 however in Sections 4.2.4, 7.1 and App C1, the likelihood of failure is identified as being entirely based on overseas failure rates, totally unrelated to the actual design and management of the pipeline(s) in question.

3.3 Arriscar Report Section 5.4.7.

The stated escalations from the loss of containment of a single pipeline, where the second pipeline is situated within the blast crater of the first pipeline, would lead to the rupturing (loss of containment) of a second are a broad assumption.

The reference sited within the Arriscar Report (Ref 21 K Silva) recommends a minimum spacing between buried pipelines of 10m. However, not every rupture causes the maximum crater size and not every exposed adjacent pipeline will rupture or lose containment as evident by the 2004 Ghislenghien TP gas pipeline failure in Belgium.

In this example a second TP gas pipeline was exposed within the crater created by the loss of containment from the first TP gas pipeline, but, remained intact (refer to photos below). It should also be noted that, pipeline operators will continue to flow gas through the adjacent pipeline to keep the pipe wall cool during an incident when it is practical to do so.

The exact spacing of the pipelines in the GMGA is not known to the reviewer at the time of writing this Report apart from acknowledging that the Eastern Gas Pipeline (EGP) does cross the other pipelines at two locations as identified in the Arriscar Report. Given there are two locations where pipeline consequence escalation could occur in theory, the Arriscar Report does not speak to the highly effective controls implemented by the two pipeline licensees.

These controls are likely to include:-

- 3rd Party crossings of major pipelines will be clearly identified by signage alerting contractors to the presence of the pipeline(s) (multiple signage for multiple pipelines) and,
- Pipelines are often protected with concrete slabbing positioned over the top of the crossing point and/or with concrete slabbing positioned between the pipelines to prevent pipeline impact by contractors or third parties, and
- There are a range of procedural controls (DBYD, ground patrols, landholder engagement, In Line Inspection (ILI) etc..) that provide significant additional protection to the pipelines.
- It should also be noted that one pipeline will be buried significantly deeper than the other in order to cross making it far less likely to be exposed in the event of the other pipeline rupturing.

It is very important that a proper assessment of the actual “credible” threats and existing physical and procedural controls is made using the SMS process outlined in AS2885. Following this process will properly define the risk and identify if additional pipeline protections are required to lower the risk to an acceptable level.

Figure 6: Ghislenghien TP gas pipeline failure - 1

Figure 7: Ghislenghien TP gas pipeline failure - 2

Figure 8: Ghislenghien TP gas pipeline failure - 3

4. AS2885 SMS – Typical Approach and methodology

The following sections of the report detail the process and steps involved in a typical SMS.

Approach

The Australian Standard AS 2885.1–2018 & AS2885.6-2018 describes the requirements for a pipeline SMS including:

- Threat identification.
- Application of physical, procedural and design controls for each credible threat.
- Review of threat control; and
- Assessment of residual risk from failure threats.

The SMS process focuses on eliminating threats to pipeline integrity from location specific and non-location specific activities, present and future, and conditions foreseeable, including likely land use, during the pipeline operational phase. Where failures are assessed as possible after the application of control measures, risk assessment is undertaken for the relevant threat, and it must be demonstrated that the risks are 'as low as reasonably practicable' (ALARP).

Methodology

Prior to an SMS workshop being convened, the pipeline licensee and the developers team prepared a range of relevant information to be presented to the SMS workshop.

All threats developed prior to the SMS workshop are documented in a spreadsheet and added to during the workshop as they become known. Changes or additions to the threats and risk mitigations are recorded directly into the spreadsheet. Additional actions not related to particular threats are also recorded.

A copy of the proposed Development is made available to the workshop electronically along with any other relevant design documents where available.

The SMS study is based on the risk assessment process defined in AS 2885.6–2018 and in particular the Flowchart presented in the Standard and referenced below.

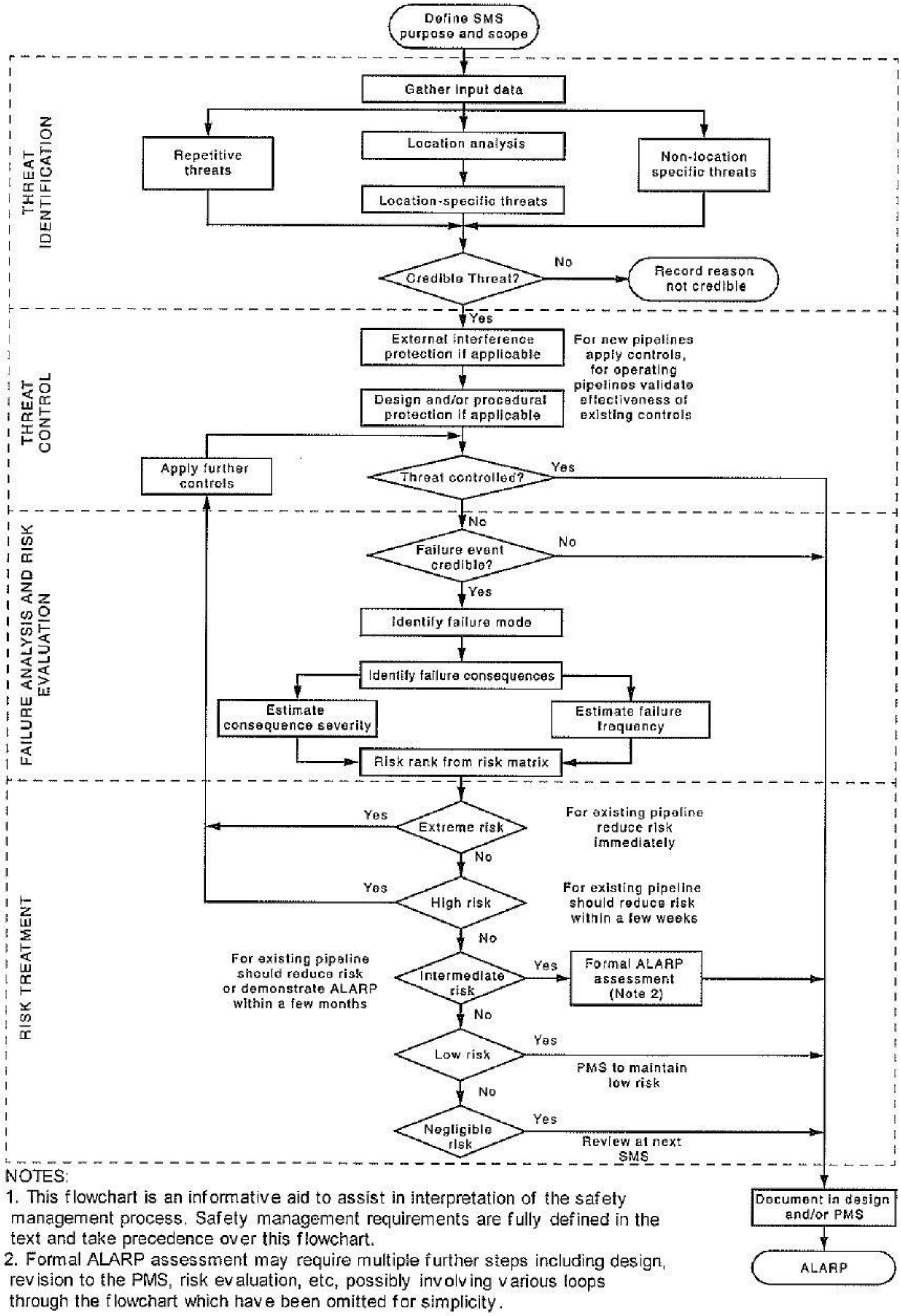

Figure 9: AS2885.6 Risk Assessment Process

Location Classification

The AS 2885.6 – 2018 definition of Location Class is “The classification of an area according to its general geographic and demographic characteristics, reflecting both the threats to the pipeline from the land usage and the consequences for the population, should the pipeline suffer a loss of containment”. For the selection of location class, the area along the pipeline route and the surrounding land uses are considered.

Classification of locations is defined in AS 2885.6-2018, Section 2.2.

The primary location class reflects the population density of the area. It is defined based on an analysis of the predominant land use in the broad area traversed by the pipeline/s. There are four primary location classes to select from, as described in, Appendix C. One or more secondary location classes, reflecting special uses, may also apply to an area, as described in, Appendix C. Changes in location class occur when there are changes in land use planning along the route of existing pipelines.

Where this occurs a safety assessment (SMS) shall be undertaken, and additional control measures implemented until it is demonstrated that the risk from loss of containment involving a rupture is As Low As Reasonably Practical “ALARP”.

The assessment shall include analysis of at least the alternatives of the following:

a. MAOP reduction.

b. Pipe replacement (with no rupture pipe).

c. Pipeline relocation.

d. Modification of land use; and

e. Implementing physical and procedural protection measures that are effective in controlling threats capable of causing rupture of the pipeline.

Threat Identification

The threat identification process seeks to list all location specific and non-location specific threats with the potential to:

- Damage any of the pipelines.
- Cause interruption to service for any of the pipelines.
- Cause release of fluid from any of the pipelines; or
- Cause harm to pipeline operators, the public or the environment.

Prompts are used to aid the team, drawn from the Standard, and include the most commonly identified threats for gas and liquid petroleum pipelines. The threat prompts are provided in Appendix D.

Threats determined to be non-credible are documented, along with the reasoning.

Threat Control

For each credible threat identified in the previous step, effective controls are listed. Controls are considered effective when failure as a result of that threat has been removed for all practical purposes.

For external interference threats, physical and procedural controls are required, and the minimum number of effective controls required for a threat depends on the location class, as shown in, Appendix C. The categories of physical and procedural are also displayed in Appendix D.

For all other threats, design and/or procedures are required.

To assist in the analysis and in determining if controls are effective (e.g., pipeline wall thickness), pipeline calculations can be completed. The pipeline calculations establish:

- The maximum excavator size and bucket teeth that can be used during construction to ensure the pipelines are not compromised; and

- Radiation contours (distances) of interest for full bore rupture and credible hole incidents

A radiation contour of 4.7 kW/m2 defines at what distance from an ignited release will cause injury (at least second-degree burns) after 30 seconds of exposure.

Residual Threats Risk Assessment

For threats where failure is still possible despite the control measures, and no further threat controls can be applied, an assessment of the residual risk is undertaken. This is completed by:

- Assessment of the severity of the consequence of a failure event
- Analysis of the frequency of occurrence of the failure event and
- Risk ranking

The results of the risk ranking determine the required treatment action for the threat. Refer to the Risk Matrix in Appendix E.

If the risk of a particular threat cannot be considered to be low or negligible according to the recognised industry risk matrix then further investigation of the threat will take place to confirm that the risk is “As Low As Reasonably Practical” (ALARP).

Actions noted in the minutes during the course of the SMS workshop will fall into two general categories, those requiring close out before the change in land use can proceed and those that will form part of the future Pipeline Integrity Management Plan (PIMP) or equivalent.

An SMS Report is produced following the workshop to capture proceedings of the workshop and highlight key decisions or issues. It will also contain all the threats and their associated mitigations and/or agreed actions.

Under AS2885, the pipeline(s) under consideration will have their own existing pipeline SMS database which covers the existing known threats and controls for the pipeline based on the existing land use for the development site.

The focus of the study is to ensure the safe operation and maintenance of the pipeline under AS2885 when considering the potential new threats or changes to existing threats resulting from construction of, and long-term presence of, the new Development proposed at the SMS Workshop.

5. AS 2885 LAND USE REQUIREMENTS

AS 2885.6 – Pipeline Safety Management

AS 2885.6 2018 is the Australian Standard that governs the management of safety & risk around and associated with petroleum pipelines, including transmission pressure (>1050kPag) natural gas pipelines. Within the Standard there are four Primary zones discussed, ranging from R1 – relatively remote, undeveloped land, through R2 (rural residential), and T1 (typical suburban development) to T2, which is intense multi-storey or CBD areas. There are also Secondary zones defined that categorise land use into heavy industrial (HI) or light industrial (I), common infrastructure corridor (CIC), crowds (C), or Sensitive (S) use. A copy of Section 2 of AS2885.6 is included in Appendix B of this document for reference.

A fundamental principle of AS2885.6 is that pipeline safety management and safe operation are on-going imperatives during the life of the pipeline and must be actively supported and documented by the pipeline licensee. This places on-going obligations on a pipeline licensee to operate and maintain robust systems, plans and procedures during the pipeline's operational phase.

A review of any transmission pressure gas pipeline is undertaken as a minimum every 5 years under AS2885 but is also triggered under the standard if there is a change in the design or operation of the pipeline or a change in land use within the Measurement Length of the pipeline that increases the likelihood or consequences of a failure event.

Measurement Length

The concept of Measurement Length (ML) is a key parameter in triggering assessments of land use changes for any Development within that ML.

The measurement length of a pipeline is defined in AS 2885.6 Appendix B1 as the radius of the 4.7 kW/m^2 radiation contour for a full-bore rupture. At this distance it is expected that an able bodied and clothed person is likely to sustain 2nd degree burns within 30 seconds if they were to remain in the area. This is derived from calculations of the heat radiation intensity if a full-bore rupture of the pipeline is ignited.

A related parameter is the radiation contour for a heat radiation intensity of 12.6 kW/m^2. At this distance it is expected that an able bodied and clothed person would sustain 3rd degree burns and life-threatening injuries within 30 seconds if they were to remain in the area.

These distances are calculated for each pipeline, and used in the assessment of land uses, both existing and planned for new and operational pipelines. AS2885.6 provides that the assessment of an existing pipeline's Location Class is based on land use within the measurement length.

The practical outcomes of the above are that for land use changes around an existing pipeline, the SMS Workshop assesses the population density and proposed activities of the land within the measurement length to determine what risks are present. The SMS Workshop assesses the level of existing (and possible new) protections required to protect against interference and other threats necessary to keep the pipeline and the people around the pipeline safe.

Sensitive use activities such as places where people congregate, and/or have limited means of escaping from a pipeline incident and fire (shopping centres, sports stadiums, schools, childcare, aged care facilities etc) within the measurement length impose the most stringent protection requirements on the pipeline, to the extent that significant measures are required to ensure that rupture of the pipe is not a credible event.

6. Physical and Procedural Protection Measures

AS 2885 Requirements

For pipeline Location Class T1, T1/S or T2 the design requirements against External Interference Threats within AS2885 seek to have a minimum of two physical protection measures and two procedural measures wherever possible.

Physical Protection

Physical protection measures comprise:

- Separation of external interference activities from the pipeline – exclusion of activities which may damage the pipeline. Typically, these are excavation activities by third parties, but can also include intensive vibration such as might be employed during the construction of roads and other infrastructure. Typical separation measures include burial, exclusion of the public or third parties from the pipeline alignment or barriers.
- Resistance to penetration, such as adequate wall thickness to resist the identified excavation equipment threats, or again a barrier to penetration.
- Concrete slabbing directly above pipelines is one barrier method that is accepted to provide adequate exclusion as a second physical barrier, particularly where a pipeline is at risk of holing or rupture due to the known threats. The concrete slab usually has a minimum width of the nominal pipeline diameter plus 600 mm either side and shall be placed a minimum of 300 mm above the pipeline. This solution is usually paired with marker tape installed above the concrete slab to warn of what is underneath the slab.
- A Concrete footpath or bike path over the pipeline or buried concrete or HDPE slabs are acceptable forms of physical protection when a pipeline is within a linear open space.

Procedural Measures

Procedural mitigation measures which are recognised by AS 2885 comprise:

- Pipeline Awareness activities, such as marker signs, dial-before-you dig service (DBYD), third party liaison programs to inform other parties of the presence of the pipeline and consequences of damage, and activity agreements with other entities.
- External interference detection measures such as pipeline patrolling, planning notification zones and remote intrusion detection. The most common for existing pipelines are the first two. Remote intrusion detection is usually only implemented at pipeline facilities such as valve or city gate stations. Pipeline licensees have a nominated patrol frequency for all their pipelines

7. Pipeline Technical Details for SMS

The SMS focuses on the section of pipeline within and adjacent to the subject land in in the GMGA. The pipeline's technical details and resistance to penetration data in the area will be identified prior to the SMS Workshop and can be summarised as follows:

Table 2, Typical Pipeline Technical Data Required for an SMS Workshop
Substance conveyed
Pipeline License No.
Measurement Length (ML) radiation contour 4.7kW/m^2
Measurement Length (ML) high consequence radiation contour 12.6kW/m^2
Length of pipeline affected
Pipeline section under review within PSP
Outside Diameter
Easement width
Wall Thickness
Depth of Cover
Pipeline Specification
Pipeline Coating
Max. Allowable Operating Pressure
Location Class - Primary
Location Class – Secondary
Pipeline Critical Defect Length (CDL)
Hole size & associated ML based on 10GJ/s release rate
Hole size & associated ML based on 1GJ/s release rate
Excavator "Credible" Hole size & associated ML
Auger Max Hole size (typically 50mm) & associated ML

The pipeline excavator risk will be determined as follows:

Table 4, Excavator Risk for Pipeline(s) Under Review
Max equipment sizes without risk of a leak: -
Excavator with std bucket
Excavator with Single Tiger Tooth
Excavator with Twin Tiger Tooth
Excavator with Penetration Tooth
Max equipment sizes without causing rupture: -
Excavator with std bucket
Excavator with Single Tiger Tooth
Excavator with Twin Tiger Tooth
Excavator with Penetration Tooth

8. Typical SMS Workshop Results

The SMS workshop team will review the Development proposed and confirm the Primary and Secondary Location Classes which are appropriate under AS2885 for the pipeline where the new development is located within the pipeline ML.

The workshop facilitator pre-populates an SMS Risk Register prior to the workshop using the threats listed in Appendix D as a guide when considering the Development. The threats considered at an SMS are usually summarised as follows:

Table 2, Risk Assessment Summary

Pipeline	Threats Considered	Threats		Threats Requiring Risk Assessment	Risk Assessment		
		Non-Credible	Credible		Negligible	Low	Intermediate

Where threats are found to have an “Intermediate” risk assessment they are then subjected to further analysis either through a LOPA and/or ALARP assessment to determine if any additional mitigations are required to render the risk ALARP.

Appendix A

Arriscar QRA Report

QRA for HP Pipelines in the Greater McArthur Growth Area

For NSW Department of Planning, Industry and Environment

26 March 2021

Doc. No.: J-000431-01

Revision: 0

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0	26-Mar-2021	JL	Incorporating client comments for final release	PS	JL

Summary

Arriscar Pty Ltd (Arriscar) has been engaged by the NSW Department of Planning, Industry and Environment (DPIE) to undertake a risk assessment from high pressure gas pipelines in the Greater McArthur Growth Area (GMGA) in NSW.

The main objectives of the study include:

(a) Estimation of the individual fatality risk and societal (fatality) risk for the HP pipelines in the GMGA;

(b) Assessment of the individual fatality risk and societal (fatality) risk against the existing criteria for fixed potential hazardous facilities described in Hazardous Industry Planning Advisory Papers No. 4 and 10 [1], [2].

(c) Generation of sufficient risk-based land use safety information to assist the Department in understanding the extent and magnitude of the potential risks from HP pipelines to the surrounding land uses in the GMCA.

Conclusions and recommendations

The pipelines in the GMGA generate risk levels that are above some of the individual risk criteria contained in HIPAP 10. More intensive development in the GMGA may also lead to excursions of the corresponding societal risk criteria. There is a need to develop a suitable strategic land use plan to ensure development within the GMGA near high pressure pipelines does not exceed NSW DPIE risk criteria. This study makes recommendations on development controls designed to ensure compliance with the risk criteria.

The recommendations are:

1. Implement a buffer zone between the pipelines and any residential use development;
    a. For the majority of the GMGA growth area, where all three pipelines run parallel in a common corridor in a North-South direction, there should be no residential development within 125m of the (Jemena) Central Trunk Main (CTM) so as to satisfy the DPIE residential land use criteria for individual risk.
    b. Where the path of the EGP diverges from the CTM and MSE in the northern and southern regions of the GMGA land release area, there should be no residential development between the pipelines and the 1.0E-06 LSIR contours shown in red in Figure 1 and Figure 2.
2. Implement a buffer zone between the pipelines and any sensitive use developments such as schools, childcare facilities, hospitals or aged-care facilities;
    a. For the majority of the GMGA growth area, where all three pipelines run parallel in a common corridor in a North-South direction, there should be no sensitive use development within 200m of the CTM.
    b. Where the path of the EGP diverges from the CTM and MSE in the northern and southern regions of the GMGA land release area, there should be no sensitive use development between the pipelines and the 0.5E-06 LSIR contours shown in orange in Figure 1 and Figure 2.
3. To satisfy the DPIE societal risk criteria, land use immediately either side of the pipeline corridor where the three pipelines run parallel should be restricted to uses where the

average population density is 0.0126 ppl/m^2. Based on the 2015 SGS Economic and Employment Analysis [3], this could include large format retail, local industry, subregional industry and footloose. Other non-commercial / industrial uses such as recreation would also be suitable provided the average density remains at or below 0.0126 ppl/m^2.

4. Consent should not be granted to any planning or development proposal within the measurement length of the respective pipelines that could increase population density above 0.0126 ppl/m^2 unless accompanied by a hazard analysis consistent with HIPAP 6 and HIPAP 10, demonstrating the DPIE individual and societal risk criteria are satisfied.

Figure 1: Location Specific Individual Risk Contours in the Northern Part of the Land Release Area

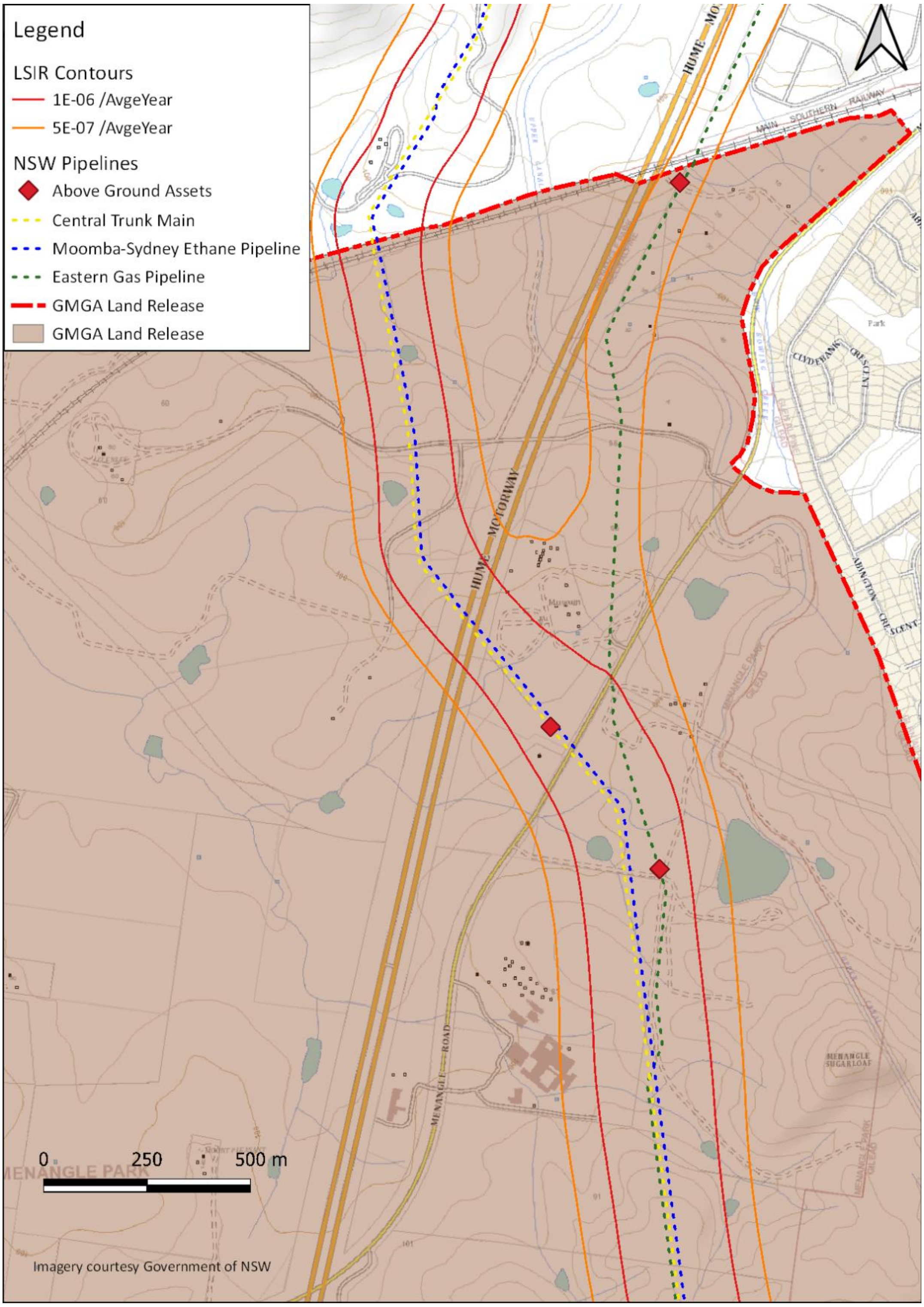
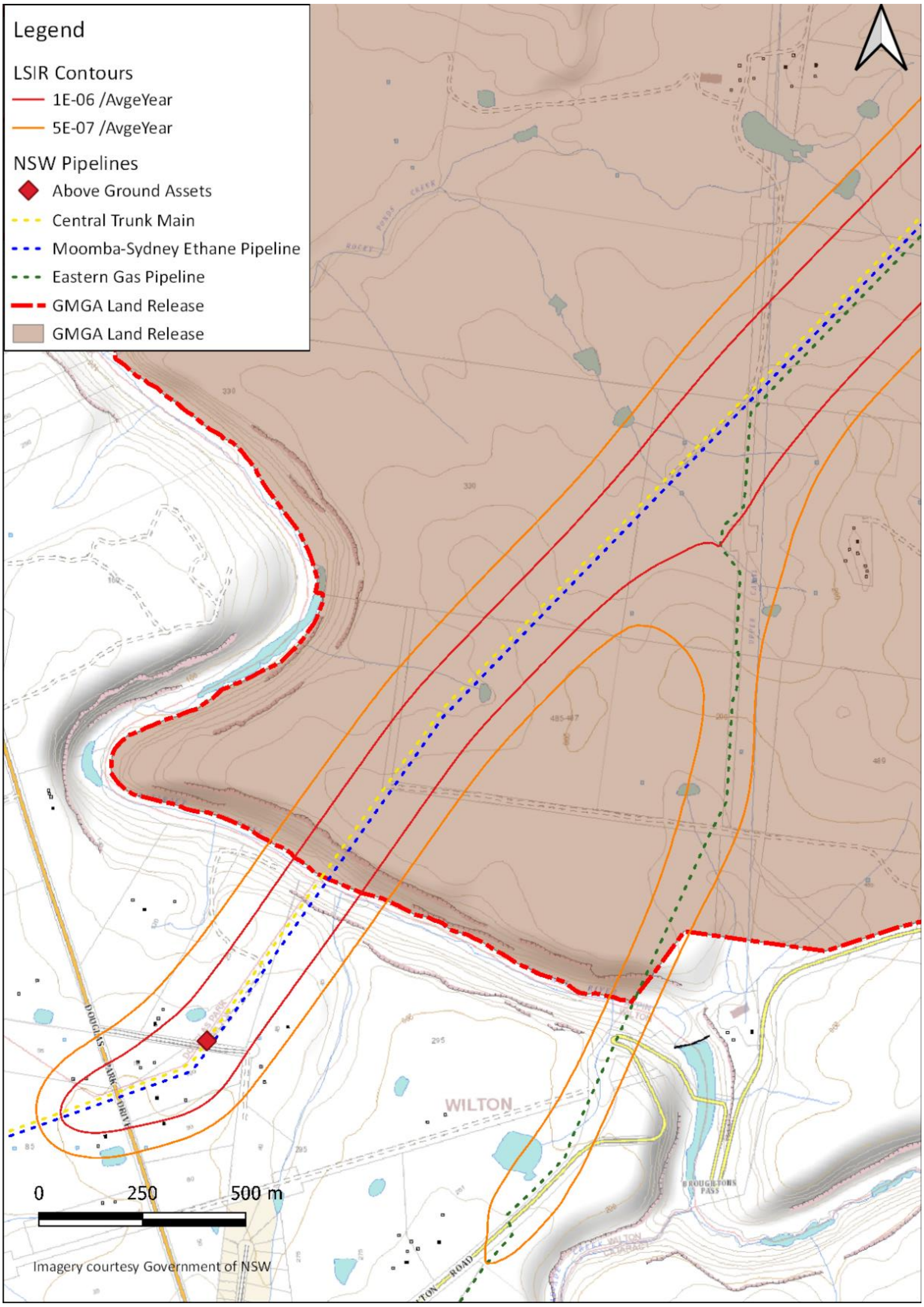


Figure 2: Location Specific Individual Risk Contours in the Southern Part of the Land Release Area



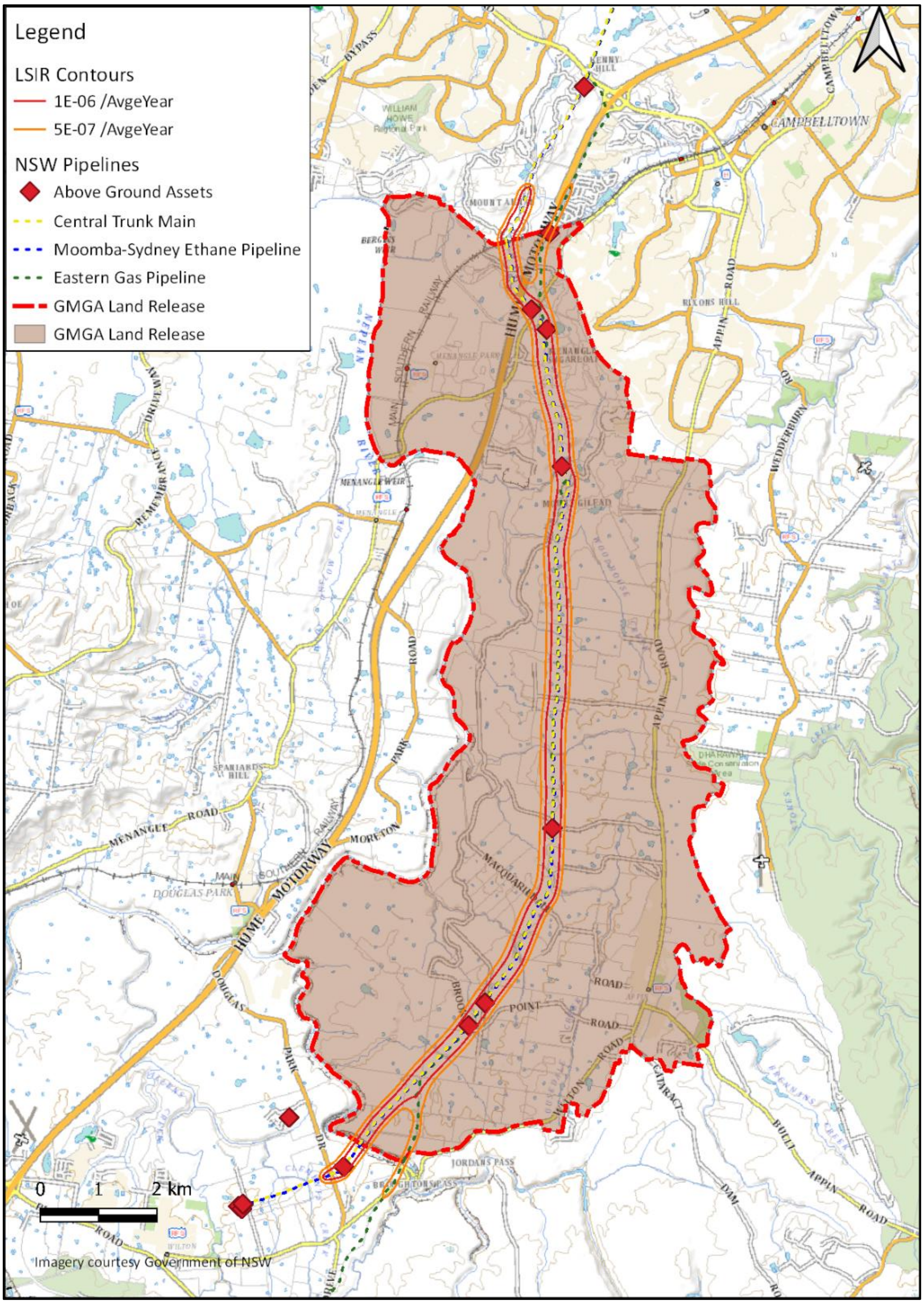
Additionally, the NSW DPIE should consult with pipeline operators on changes to the pipelines and pipeline protection that could further mitigate risk, such as:

- Additional protection against third party damage;
- Decreasing the interval between isolation valves such as automatic line break valves and main line valves;
- Preferred placement and type of roads within developments

- Advise development proponents to consult with pipeline owners and/or operators for individual development proposals so that Safety Management Studies, as required by AS 2885.6 when the land use changes, or there is an encroachment or activity on the easement, can effectively identify threats to the pipeline and implement appropriate mitigation measures.

For completeness, the cumulative 1.0 x 10^{-6} and 0.5 x 10^{-6} LSIR contours for all three pipelines within the entire GMGA land release area are shown in Figure 3.

Figure 3: Cumulative LSIR Contours for all Three Pipelines within the GMGA Land Release Area



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Notation

Abbreviation	Description
ALBV	Automatic Line Break Valve
Arriscar	Arriscar Pty Limited
BoM	Bureau of Meteorology
CTM	(Jemena) Central Trunk Main
DA	Development Application
DPIE	Department of Planning Industry and Environment
EGP	(Jemena) Eastern Gas Pipeline
GMGA	Greater Macarthur Growth Area
HIPAP	Hazardous industry Advisory Paper
kPa	kilo Pascal
kW / m^2	kilo Watts per square metre
LFL	Lower Flammable Limit
LGA	Local Government Area
LSIR	Location Specific Individual Risk
MLV	Main Line valve
MSE	Moomba-Sydney Ethane (pipeline)
QRA	Quantitative Risk Assessment
TPA	Third Party Activity
UFL	Upper Flammable Limit

1 INTRODUCTION

1.1 Background

Arriscar Pty Ltd (Arriscar) has been engaged by the NSW Department of Planning, Industry and Environment (DPIE) to undertake a risk assessment from high pressure gas pipelines in the Greater McArthur Growth Area (GMGA) in NSW.

1.2 Scope

1.3 Study Objectives

The main objectives of the study include:

(a) Estimation of the individual fatality risk and societal (fatality) risk for the HP pipelines in the GMGA;

(b) Assessment of the individual fatality risk and societal (fatality) risk against the existing criteria for fixed potential hazardous facilities described in Hazardous Industry Planning Advisory Papers No. 4 and 10 [1], [2].

(c) Generation of sufficient risk-based land use safety information to assist the Department in understanding the extent and magnitude of the potential risks from HP pipelines to the surrounding land uses in the GMCA.

1.4 Study Scope

The scope of work that has been undertaken by Arriscar includes the following:

1. Consultation with the pipeline operator/s (APA and Jemena) to: determine the locations of the HP pipelines in the GMGA; verify the relevant parameters required for the QRA (e.g. operating pressure, temperature, pipe wall thickness, burial depth, etc.); and, identify the safeguards installed for prevention, detection and isolation of leaks.
2. Preparation of an assumptions register listing the assumptions for the QRA, the justification for each assumption and how each assumption potentially affects the outcome of the results. The assumptions used in the analysis will be agreed with the Department's Hazard Team.
3. Estimation of the individual fatality risk and societal (fatality) risk using a QRA approach for a representative segment of the pipeline easement through a representative populated area in the GMGA (c. 45 dwellings per hectare at +/- 400 m from pipeline). This is to be based on a representative easement with two HP Natural Gas pipelines and one HP Ethane pipeline. :

   (a) Estimation of the individual fatality risk for a representative easement segment with two HP Natural Gas pipelines and one HP Ethane pipeline.

   (b) Estimation of the societal risk for a representative easement segment (with two HP Natural Gas pipelines and one HP Ethane pipeline) with the representative population density at an increased setback from the easement (i.e. to determine the minimum setback required to comply with the Department's societal risk criteria assuming no change in the maximum proposed population density).

   (c) Estimation of the societal risk for a representative easement segment (with two HP Natural Gas pipelines and one HP Ethane pipeline) with a 0 m setback and an increased or decreased representative population density (i.e. to determine the maximum population density that would comply with the Department's societal risk criteria assuming no setback limits).

Note: The calculations required for (b) and (c) will require iteration (i.e. re-running of the risk model to determine the required variable: set-back distance or population density limit).

All cases will be confirmed with the Department following consultation with the pipeline operators.

The methodology for risk estimation will be consistent with HIPAP No 6 [1].

- The individual fatality risk (Location specific individual risk or LSIR) will be estimated and presented as a risk transect (i.e. risk versus perpendicular distance from pipeline).
- The societal (fatality) risk will be presented as an F-N curve.

4. Additional risk calculations (as outlined in item 3 above) to address the following specific cases (if found to be applicable following consultation with the pipeline operators and the Department):
    - A representative segment of above-ground HP pipelines in the GMGA (e.g. due to a river crossing).
    - Representative coal seam gas pipelines or compression facilities that are close to the HP Pipelines. This would be undertaken semi-quantitively (i.e. not subject to full QRA).
5. Based on the findings of the QRA:
    (a) Determine if the proposed development near the HP Pipelines in the GMGA is appropriate from a strategic land use safety planning perspective (i.e. an assessment of compliance with relevant risk criteria).
    (b) Estimate the maximum distance from the HP pipeline easement in the GMGA, where hazards and risks should be considered during assessment of a Development Application (DA) introducing a significant population.
    (c) Determine the minimum setback required to comply with the Department's societal risk criteria assuming no change in the proposed maximum population density.
    (d) Determine the maximum population density that would comply with the Department's societal risk criteria assuming no setback limits.
    (e) Recommend measures to minimise risks from the HP pipelines in the GMGA.
6. Preparation and submission of a draft report.
7. Preparation and submission of a final report.

2 DESCRIPTION OF THE GREATER MACARTHUR GROWTH AREA

2.1 Overview

The vision for the Greater MacArthur Growth Area (GMGA) is set in the interim report Greater Macarthur 2040 [4], which is a land use and infrastructure implementation plan for the area as it develops and changes.

The GMGA is a region southwest of Sydney stretching from Appin in the Wollondily Local Government Area (LGA) to Glenfield in the Campbelltown LGA and is split into two development areas pivoting around Campbelltown-MacArthur: a land release area to the Southwest where development will involve changing land uses from predominantly rural to urban uses (Figure 4 and Figure 5); and an area to the Northeast of Campbelltown-MacArthur where development is predominantly characterised by urban renewal (Figure 6).

As the urban renewal area is already developed, the focus of this study is on the land release area.

Figure 4 Location of the GMGA Land Release Area with Respect to Sydney

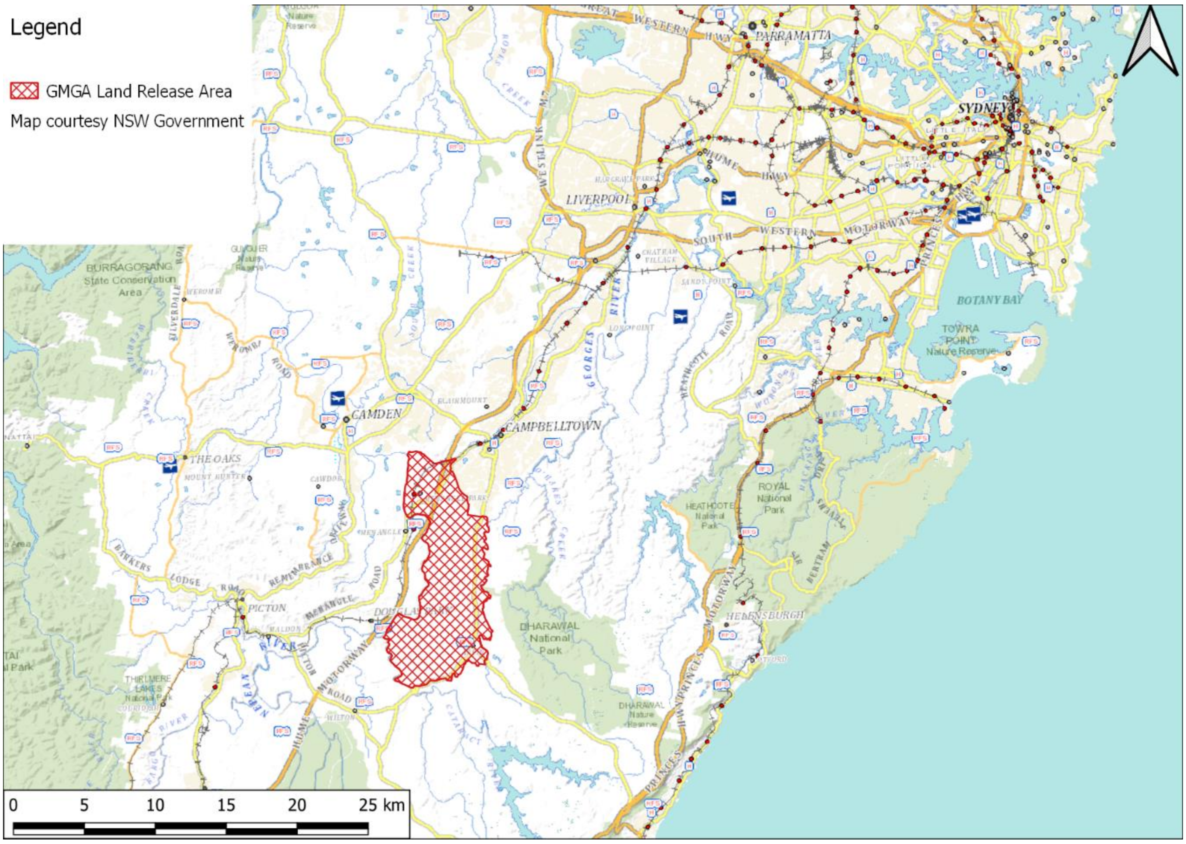


Figure 5 Greater Macarthur Structure Plan (land release areas) [4]

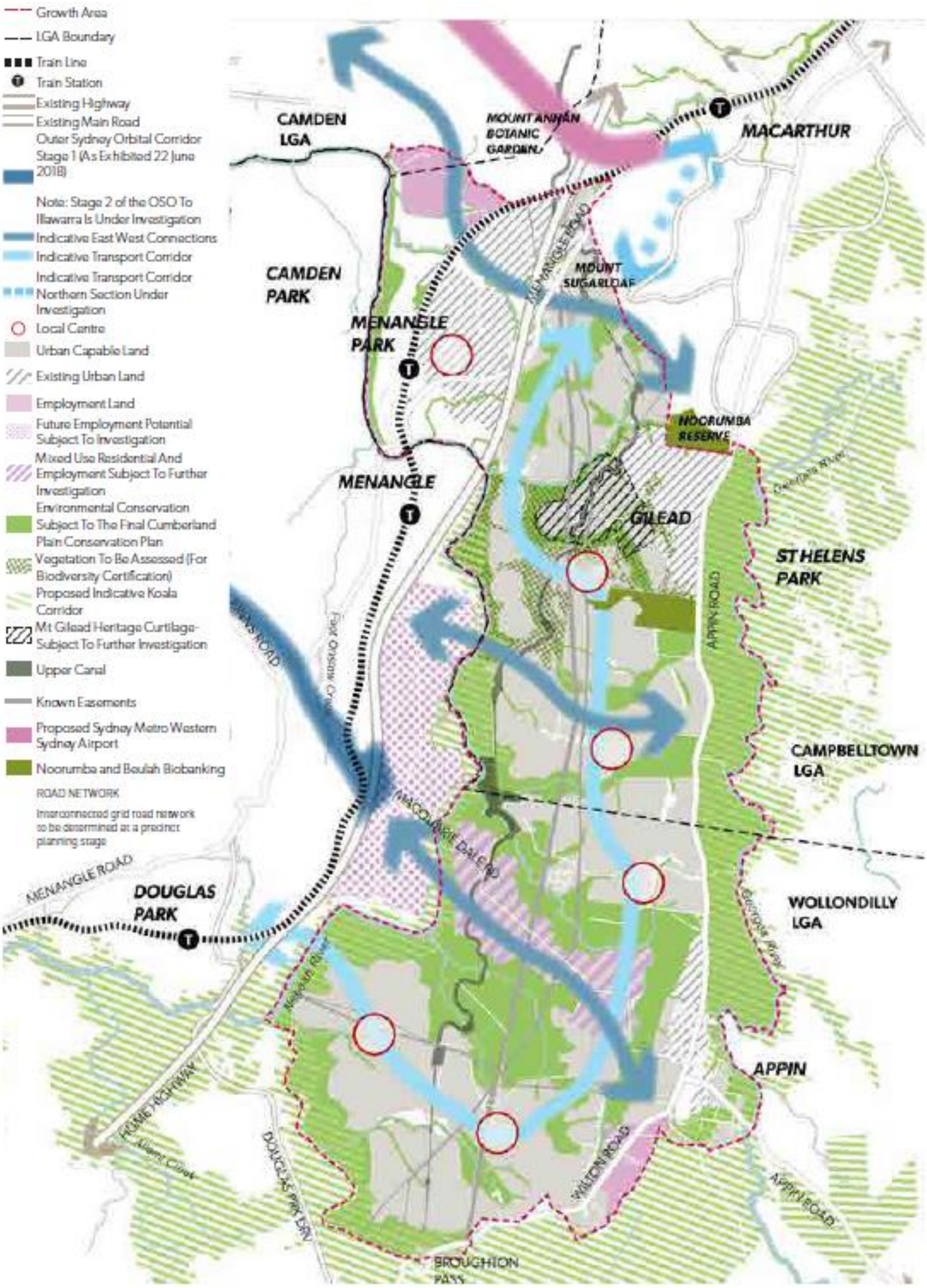
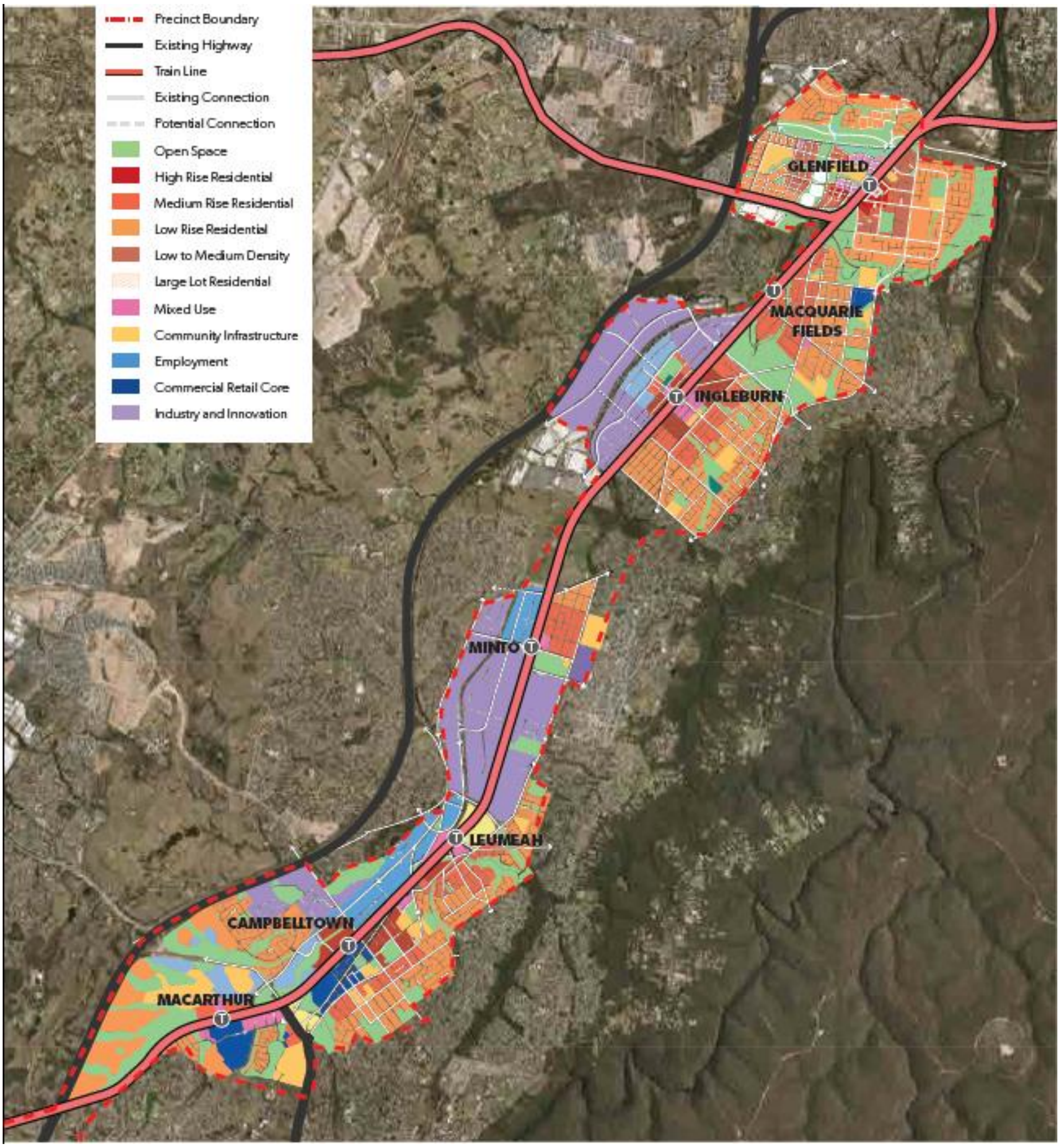


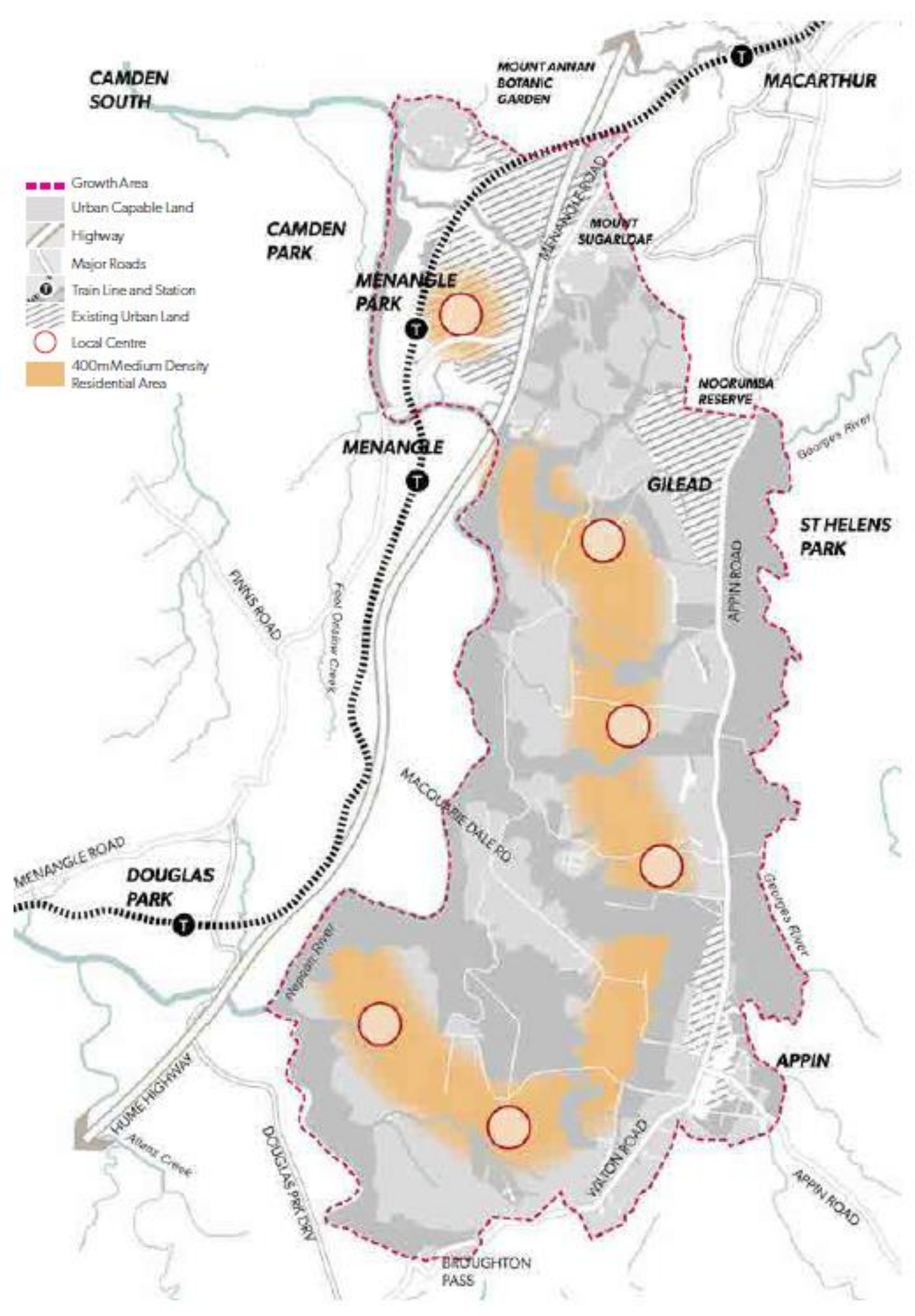
Figure 6 GMGA Urban Renewal Areas [4]



2.2 Population

The GMGA land release area is currently predominantly a rural population. As the area is developed, it is anticipated population density will increase. An indicative distribution of population density is shown in Figure 7, highlighting a corridor of medium density development.

Figure 7 Indicative Density Distribution [4]



Population density recommendations for the land release area are contained in the Density Study for Greater MacArthur [5] undertaken by Urbis. The recommended dwelling densities from [5] are provided in Table 1.

Table 1 Recommended Dwelling Densities per hectare [5]

Zone	Min Density	Mid Density	Max Density
Very Low Density	10	12.5	15
Low Density	15	20	25
Medium Density	25	30	35
Highest Density	35	40	45

An Economic and Employment Analysis [3] used an occupancy rate of 2.8 people per household. The same ratio has been assumed for this study, resulting in a maximum population density of 0.0126 ppl/m^2.

From the same study [3], estimates for employment density are presented in Table 2.

Table 2 Working Population Density

Category of Land Use	Required floorspace (m^2 / Job)	Floorspace to land area ratio	Land area per job (m^2/job)	Working Population (ppl / m^2)
Strategic centre retail and office	30	1	30	0.033
Other office and retail	35	0.75	47	0.021
Large format retail	70	0.3	233	0.0043
Local industry	100	0.3	333	0.0030
Subregional industry	140	0.3	467	0.0021
Footloose	150	0.3	500	0.002

The categoriesof land use are:

- **Strategic centre retail and office (SCRO)**: Located in identified major centres, taking the form of multi-level, mixed-use buildings with ground floor retail, high public transport accessibility and is often centred on a train station or major bus route interchange. SCRO requires an urban setting.
- **Other office and retail (OOR)**: Retail and commercial cluster servicing a local population. OOR is generally ground floor retail with office or shop-top residential above with on street parking or small carpark adjacent. OOR has good public transport connections and is often located proximate to civic buildings (town halls, libraries and so on). Examples: Town centres, corner shops, local shop cluster.

- **Large format retail (LFR)**: Large, warehouse-style retail buildings typically surrounded by or including a large amount of car parking. Situated on commercial centre periphery or in independent clusters.
- **Local industry (LI)**: Clustered in industrial areas, LI services a local area, typically small industrial lot sizes, workshop buildings with some possible office function. LI requires a large degree of functional hardstand for service delivery and operational space. Can be nearby surrounding residential and commercial community. Example: Car repairs; joinery and building supplies.
- **Subregional industry (SI)**: SI is found clustered in large industrial areas and its role is to service a broad catchment. It is characterised by larger lot sizes and often large warehouse buildings are common. SI requires a large degree of functional hardstand for service delivery and operational space. SI requires physical separation from residential development and often has a low degree of public transport accessibility due to its remoteness. Subregional Industry requires high levels of car and truck access, close proximity to arterial roads and motorway on/off ramps and possible access to freight rail. Example: Subregional warehousing, freight & logistics (such as food distribution).
- **Footloose (F)**: Footloose has little customer relation to its surrounding area as its primary function is to service a metropolitan or larger area. The land use is categorized by larger lot sizes and often with large warehouse buildings are common. Similar to SI, the Footloose CLU requires a large degree of functional hardstand for service delivery and operational space and requires physical separation from residential development. As per SI, Footloose needs high levels of car and truck access, close proximity to arterial roads and motorway on/off ramps and possible access to freight rail. Example: Manufacturing, major freight and logistics (such as DHL), regional distribution facilities.
- **Dispersed (D)**: Industries that do not fit into local, subregional or footloose categories. Dispersed uses are not tied to industrial precincts and vary in size, location (hence being dispersed), and often role.

2.3 Meteorology

The closest Bureau of Meteorology (BoM) weather station to the area is Camden Airport Automatic Weather Station, ID: 068192. Data from the weather station has been processed into six weather categories based on wind speed and Pasquill stability. Wind speed, temperature, relative humidity and solar radiation for each category is presented in Table 3, Each category is distributed amongst 16 wind directions for use in the consequence analysis (Table 4).

Table 3 Weather Categories and Selected Parameters

Category	Wind Speed (m/s)	Temperature (°C)	Relative Humidity	Solar Radiation (kW/m²)
1.8B	1.8	20.6	0.58	0.6
7.5D	7.5	21.7	0.42	0.4
3.9D	3.9	18.9	0.61	0.2
1.0D	1.0	13.1	0.84	0.0
2.6E	2.6	16.5	0.71	0.0
1.0F	1.0	12.1	0.87	0.0

Table 4 Distribution of Weather Categories by Stability Class and Wind Direction

Weather Category	Wind Direction																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
1.8B	0.017	0.015	0.008	0.007	0.004	0.005	0.005	0.008	0.004	0.003	0.003	0.006	0.002	0.004	0.009	0.025	0.125
7.5D	0.001	0.003	0.008	0.003	0.001	0.003	0.005	0.005	0.003	0.004	0.013	0.016	0.005	0.006	0.002	0.004	0.081
3.9D	0.016	0.014	0.026	0.026	0.015	0.019	0.026	0.040	0.029	0.021	0.019	0.018	0.005	0.006	0.008	0.021	0.310
1.0D	0.014	0.011	0.011	0.019	0.013	0.027	0.031	0.067	0.031	0.020	0.014	0.017	0.007	0.010	0.010	0.033	0.336
2.6E	0.002	0.002	0.004	0.007	0.004	0.004	0.005	0.006	0.003	0.004	0.002	0.002	0.001	0.001	0.001	0.002	0.048
1.0F	0.006	0.003	0.005	0.008	0.008	0.006	0.010	0.018	0.007	0.005	0.005	0.003	0.001	0.004	0.003	0.007	0.100
Total	0.056	0.048	0.061	0.069	0.045	0.063	0.082	0.145	0.077	0.058	0.057	0.062	0.020	0.032	0.033	0.093	1.000

3 OVERVIEW OF GAS FACILITIES IN THE GMGA

3.1 Introduction

Three high-pressure pipelines run through the GMGA. These are:

1. The Moomba-Sydney Ethane (MSE) pipeline, transporting ethane from Moomba in South Australia to Qenos in Port Botany. Flow in this pipeline is one direction only.
2. The Eastern Gas Pipeline (EGP) for transporting natural gas between Longford, Victoria, to Horsley Park, NSW. Predominantly the EGP transports gas from Victoria to NSW, however, it can be configured to flow in the opposite direction. For the purposes of this study, it is assumed flow is towards Sydney, as there is no major natural gas supply to the EGP north of the GMGA.
3. The Jemena Central Trunk Main (CTM). Not classified as a transmission pipeline, the CTM makes up part of the Jemena Gas Network servicing Sydney. The direction of flow in the CTM is based on supply and demand at various times. It is assumed for the purpose of the study that flow is towards Sydney. This is based on a review of publicly available information about gas supply and offtake from the CTM. The CTM feeds lower pressure parts of the gas network. The lower pressure segments of the gas network are typical of gas networks in urban areas and are not within the study scope.

Jemena and the APA Group provided relevant data for the pipeline (Refer to Section 3.2) and the risk at the proposed development from these pipelines was assessed against the risk criteria in HIPAP No. 10 (Refer to Section 8).

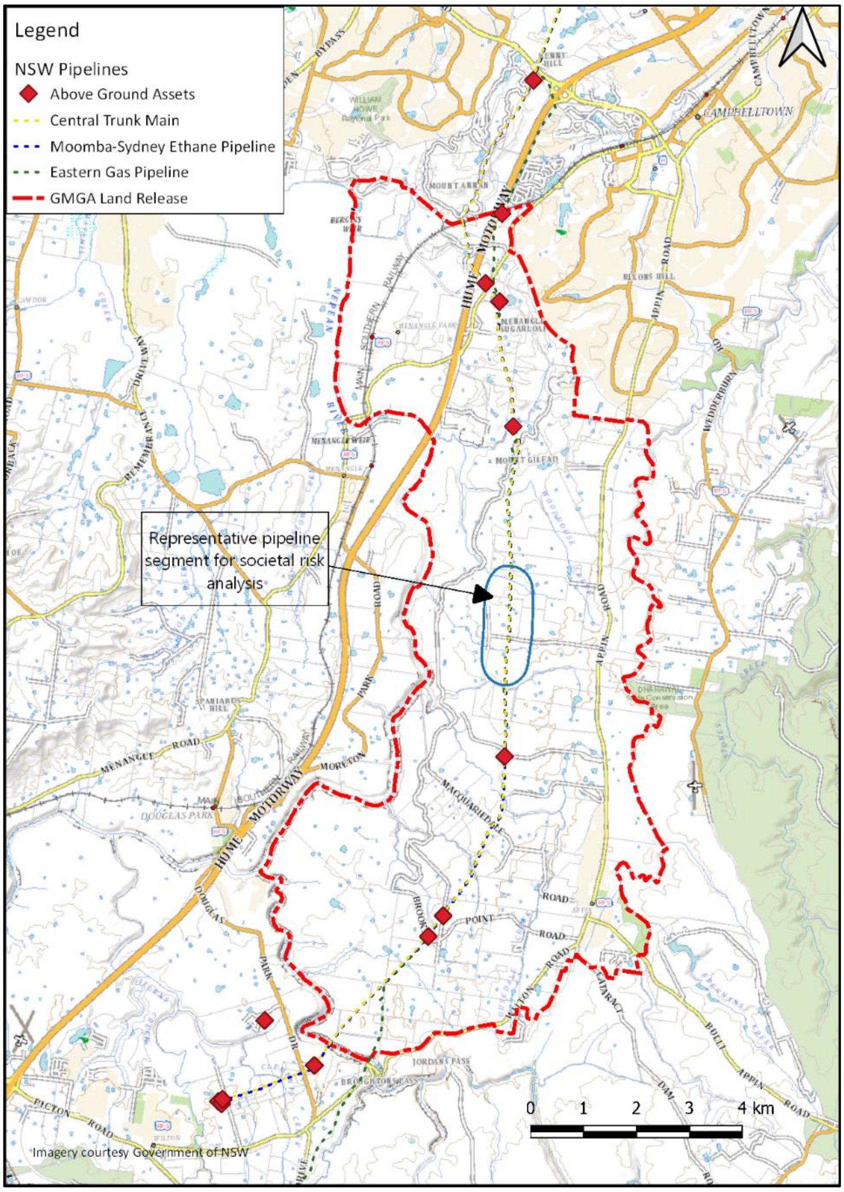
The route of the various pipelines is shown in Figure 8. Also shown in this picture is the segment of pipeline considered in the societal risk analysis.

Both the MSE and CTM enter the GMGA land release area from the Southwest, travelling Northeast until Appin, where they turn to the north, and continue to Gilead, where they divert to the Northwest and exit the GMGA land release area by crossing the Hume Motorway to the west.

The EGP enters the GMGA land release area from the south and continues north until it reaches the CTM and MSE travelling in a north-easterly direction. The EGP takes a north-easterly direction at this point before crossing both the CTM and MSE and turning north with the other two pipelines and continuing alongside those pipelines until after Gilead. Prior to the Menangle Park MLV, the EGP crosses the two other pipelines to exit the north of the GMGA land release area by running adjacent and to east of the Hume Motorway.

In addition to the three pipelines and gas network assets, AGL operate the Camden Gas Project, which includes the Rosalind Park Gas Plant in Menangle. In February 2016, AGL announced that it will progressively decommission wells and rehabilitate sites at the Camden Gas Project prior to ceasing production in 2023. As such, the Rosalind Park has been excluded from this study.

Figure 8 Routes of High Pressure Pipelines in the GMGA Land Release Area



3.2 Moomba to Sydney Ethane Pipeline

Information provided by the pipeline owner (APA) for the Ethane Pipeline is listed in Table 5 [6].

Table 5 Ethane Pipeline

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

Flowrate	Typical approx. 30 tonne per hour
Pipeline Material	API -5L grade X60
Pipeline Diameter	200mm NB
Wall Thickness	8.1 mm
Depth of Cover	>1200 mm
Cathodic Protection	Impressed Current Cathodic Protection applied
External Coating	HDPE (Yellowjacket)
Leak Detection	No . Loss of pressure detected at ALBVs (see below)
Locations of Automatic Line Break Valves (ALBVs)	Wilton (Southwest of GMGA), Menangle Park (in the Northeast of the GMGA), and Raby Road, Catherine Fields (North of the GMGA land release area)
Leak Detection Time	Line valves within the GMGA have Automatic Line Break systems (ALB) in place and each mainline valve would close the valve when the local pressure falls below the set pressure (approximately 4300 kPa). Local APA staff response time is estimated as 2 hrs from detection.
Leak Isolation Time	The pipeline section is isolated either automatically by ALB operation or by local staff.
Inspections	Ground Patrol Daily (Monday to Friday). Aerial Patrol Fortnightly.
Control Measures for 3rd Party Interference	8.1mm pipe wall thickness. > 1.2m depth of cover. 25mm Concrete Coating of pipeline (Rockjacket). Top slabbing (except through the riparian corridor area). Section of pipeline located within a Riparian Corridor (restricted access for excavation activities). Marker Posts. Dial before-you-dig (DBYD) provisions. Patrols Aerial patrol fortnightly. Daily ground patrol. Liaison with Councils, telecommunications companies, Electricity companies. Section of pipeline located within a Riparian Corridor (restricted access for excavation activities).
Pigging	Metal Loss intelligent pigging carried out on a risk basis program but is undertaken at 5 yearly presently
Current Condition of Pipeline	No wall thickness loss has been found in this section of pipeline

3.3 Natural Gas Pipelines

Information for the HP natural gas pipelines is listed in Table 6 [7].

Table 6 Natural Gas Pipelines

	Jemena Central Trunk Main (CTM)	Jemena Eastern Gas Pipeline (EGP)
Pipeline Owner	Jemena	Jemena
Pipeline Name	Central trunk: Wilton to Horsley Park	Eastern Gas Pipeline
Material/Product Transferred	Natural Gas	Natural Gas
Licence No.	Licence 1	PL 26
MAOP	6.895 MPa	14.895MPa
Normal Operating Pressure	4.5 – 5 MPa	14.895 MPa
Operating Temperature	15°C	15°C
Flowrate	NA	NA
Pipeline Material	API5LX65	Carbon Steel API 5LX 70
Pipeline Diameter	DN850	DN450
Wall Thickness	13.3 mm	11.8 mm
Depth of Cover	1200 mm	900 mm
Cathodic Protection	Impressed current	Impressed current
External Coating	Coal Tar Enamel	Fusion Bonded Epoxy
Leak Detection	None – but ALBVs located at Raby Road, Menangle Park and	NA
Locations of Nearest Isolation Valves	Catherine Fields ALBV (Raby Rd, North of the GMGA land release area), Menangle Park ALBV (in the Northwestern part of the GMGA land release area), Wilton (Southwest of the GMGA).	Main Line Valves (MLVs) located at Raby Road, Menangle Park (Northern part of GMGA land release area), Appin (Southern part of GMGA land release area), and O'Brien's Gap, near Wollongong outside the GMGA. Line pack is monitored by SCADA and MLVs may be closed remotely.
Leak Detection Time	NA	NA
Leak Isolation Time	NA	NA
Inspections	Weekly	Weekly, six weekly, annually
Control Measures for 3rd Party Interference	DOC, Wall thickness, Warning Signage, DBYD, patrols	DBYD, pipeline patrols
Pigging	Yes 2014, every 10 years	ILI every 10 years or as required

4 RISK ASSESSMENT METHODOLOGY

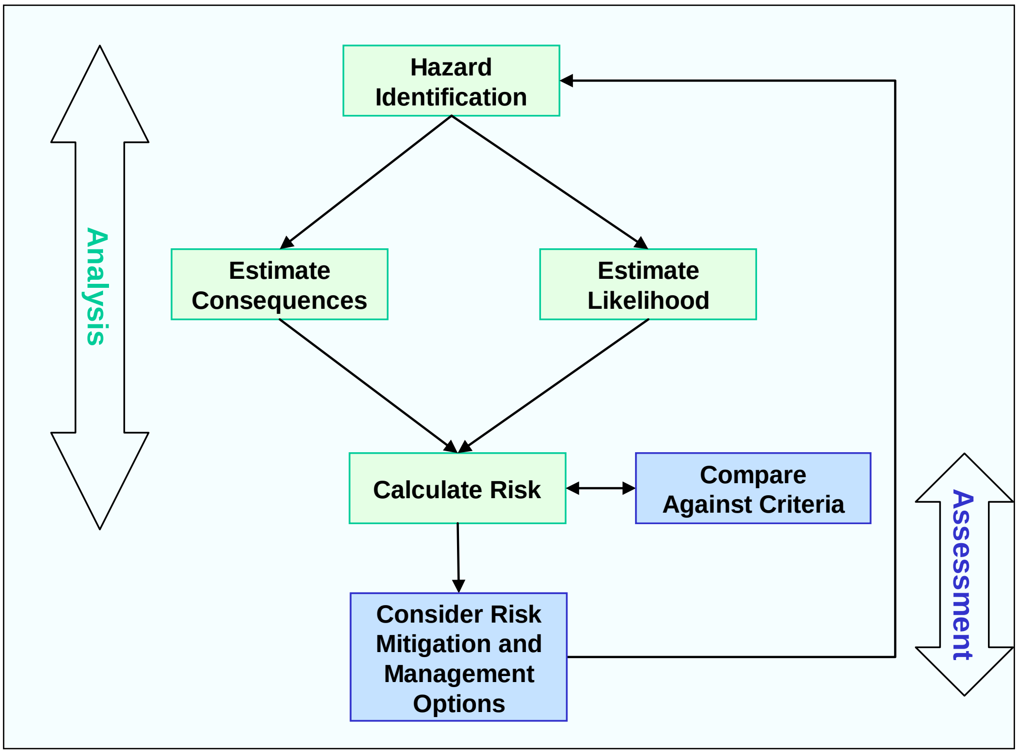
4.1 Introduction

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

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

Diagrammatically, the QRA process is as follows:

Figure 9 Overview of QRA Process [1]



4.2 Methodology Overview

4.2.1 Hazard Identification and Register of Major Accident Events

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

For example, the Hazard identification (or HAZID) step for a QRA of a potentially hazardous pipeline would identify representative events that could result in a release of the material from the pipeline with the potential to cause harm (e.g. due to a subsequent ignition and fire/explosion). The representative potentially hazard events are commonly described as 'Major Accident Events' (or MAEs). In the context of the QRA, an MAE is an event with the potential to cause: off-site fatality or injury; off-site property damage; or, long-term damage to the biophysical environment (i.e. any outcome for which DPIE has defined an acceptable risk criterion – Refer to Section 4.4).

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

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

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

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

4.2.2 Hazard Consequence Analysis

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

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

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

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

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

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

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

4.2.3 Impairment Criteria

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

Explosion

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

The impact of explosion overpressure on humans takes two forms:

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

The effects of exposure to explosion overpressure are summarised in Table 7 [1].

Table 7 Effects of Explosion Overpressure

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

Fire

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

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

Table 8 Effects of Thermal Radiation

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

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

4.2.4 Frequency and Likelihood Analysis

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

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

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

The frequency analysis data and results are summarised in Section 7 and Appendix C.1.

4.2.5 Risk Analysis and Assessment

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

Location-specific individual risk (LSIR) contours are usually used to represent off-site risk for a land-use safety QRA study. These iso-risk contours are superimposed on a plan view drawing of the site. Example risk levels that are typically shown as iso-risk contours include: 1 x 10^{-6} per year, 10 x 10^{-6} per year and 50 x 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 software package was used to generate the iso-risk contours / transects and societal risk results (Refer to Section 8).

4.3 Study Assumptions

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

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

4.4 Quantitative Risk Criteria

4.4.1 Individual Fatality Risk

The individual fatality risk imposed by a proposed (or existing) industrial activity should be low relative to the background risk. This forms the basis for the following individual fatality risk criteria adopted by the NSW DPIE [2] and [8].

Table 9 Individual Fatality Risk Criteria

Land Use	Risk Criterion [per million per year]
Hospitals, schools, childcare facilities and old age housing developments	0.5
Residential developments and places of continuous occupancy, such as hotels and tourist resorts	1
Commercial developments, including offices, retail centres, warehouses with showrooms, restaurants, and entertainment centres	5

Land Use	Risk Criterion [per million per year]
Sporting complexes and active open space areas	10
Industrial sites	50 *

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

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

4.4.2 Injury Risk

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

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

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

4.4.3 Risk of Property Damage and Accident Propagation

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

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

4.4.4 Societal Risk

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

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

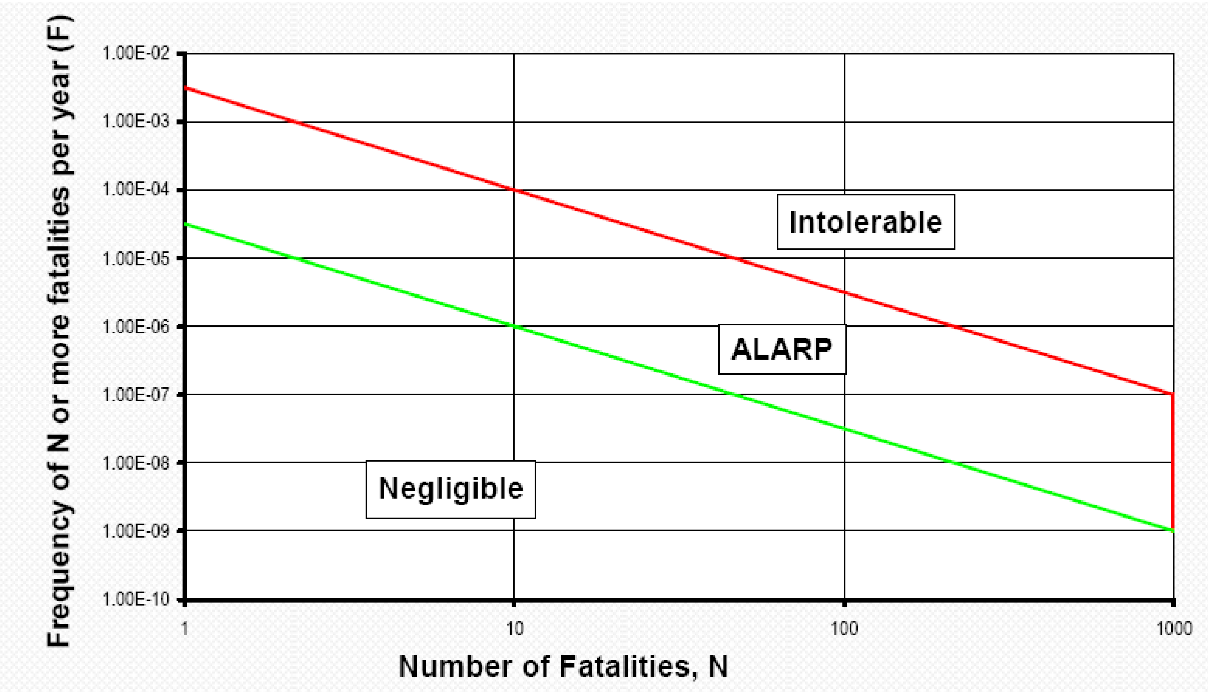
Two parameters are required to define societal risk: (a) Number of fatalities that may result from an incident; and (b) the frequency (likelihood) of occurrence of the incident.

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

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

The DPIE's suggested societal risk criteria (Refer to Figure 10), recognise that society is particularly intolerant of accidents, which though infrequent, have a potential to create multiple fatalities. Below the negligible line, provided other individual criteria are met, societal risk is not considered significant. Above the intolerable level, an activity is considered undesirable, even if individual risk criteria are met. Within the 'As Low As Reasonably Practicable' (ALARP) region, the emphasis is on reducing risks as far as possible towards the negligible line. Provided other quantitative and qualitative criteria of HIPAP 4 [8] are met, the risks from the activity would be considered tolerable in the ALARP region.

Figure 10 Indicative Societal Risk Criteria



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

HIPAP No.4 [8] also states that the criteria in Figure 10 are an indicative criteria and provisional only and do not represent a firm requirement in NSW.

4.5 Qualitative Risk Criteria

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

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

4.6 Approach to Achieving Study Objectives

To provide the Department with sufficient risk-based land use safety information to understand the extent and magnitude of the potential risks from HP pipelines to the surrounding land uses in the GMGA, and develop suitable approaches to development in recognition of those risks, the following approach has been taken:

1. Generate individual risk contours of representative sections of pipeline to identify any restrictions on land use based upon the individual risk criteria.
2. Using the results of step 1, postulate appropriate land uses and population densities surrounding the pipelines to generate societal risk results and compare against the DPIE criteria.
3. If necessary, adjust assumptions of land use and population density to satisfy the individual risk and societal risk criteria.

5 HAZARD IDENTIFICATION

5.1 Introduction

The hazard identification was based on a review of the: information on the Ethane and Natural Gas pipelines (Refer to Section 3.2); properties of Ethane and Natural Gas; and, potential failure modes and consequences if a leak were to occur from a pipeline. These findings are presented as follows:

Section 5.2 - Properties of Ethane and Natural Gas.

Section 5.3 - Pipeline Failure Modes.

Section 5.4 - Consequences.

Section 5.5 - Control Measures.

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

5.2 Properties of Ethane and Natural Gas

5.2.1 Ethane

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

Physical properties are listed in Table 10.

Table 10 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, odourless and non-toxic.

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

5.2.2 Natural Gas

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

Physical properties are listed in Table 11.

Table 11 Physical Properties of Methane

Boiling Point	-162 °C
Flash Point	-218 °C
Autoignition Temperature	540 °C
Relative Density (Air =1)	0.55
Lower Flammability Limit in air (vol. %)	4.4%
Upper Flammability Limit in air (vol. %)	16.5%

Methane is:

- A gas at ambient conditions;
- A gas at typical operating conditions for Natural Gas pipelines;
- Flammable;
- Lighter than air at ambient temperatures; and
- Colourless, odourless and non-toxic (Note: odorant is added to natural gas to alert people to leaks).

5.3 Pipeline Failure Modes

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

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

The relative likelihood of each failure mode is shown in Appendix C.1 for underground pipelines.

5.3.1 Mechanical Failure

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

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

5.3.2 Corrosion

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

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

This failure mode is credible for the three HP pipelines; however, historical incident data for other pipelines (Refer to Appendix C.1) indicates this is a low likelihood failure mode, particularly for pipelines with a higher wall thickness (i.e. > 10 mm) and more recently manufactured pipelines (i.e. post 1980).

5.3.3 Ground Movement and Other Failure Modes

Pipeline leaks may occur due to ground movement (e.g. following a landslide or earthquake). The potential also exists for ground movement in the vicinity of water crossings (water erosion) or as a result of construction activities (new road infrastructure and buildings). Notably, both the South Campbelltown and Appin mine subsidence districts are within the GMGA land release area. For this reason, no adjustment has been made to ground movement failure frequencies.

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

5.3.4 Third Party Activity

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

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

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

This failure mode is credible for the three HP pipelines.

5.4 Consequences of Gas Release

5.4.1 Asphyxiation

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

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

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

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

The potential for unconsciousness and fatality is only significant at less than 10% oxygen. However, to reduce the oxygen concentration to 10% requires a relatively high concentration (viz.

approximately 52% v/v, which equates to 641,000 mg/m^3 for Ethane and 342,000 mg/m^3 for Methane).

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

5.4.2 Jet Fire

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

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

5.4.3 Flash Fire

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

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

5.4.4 Vapour Cloud Explosion

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

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

5.4.5 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.

5.4.6 Toxic Smoke

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

5.4.7 Incident Escalation in Pipeline Easement

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

The potential for propagation and escalation was carried forward in the risk analysis where the distance between pipelines was within the radius of a crater created by a full-bore rupture. This was restricted to the points where the EGP crosses both the MSE and CTM.

5.5 Control Measures

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

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

5.5.1 Prevention of Mechanical Failure

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

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

The three HP pipelines are inspected using 'intelligent pigging' (Refer to Section 3.2) and no loss of wall thickness has been reported [13].

5.5.2 Corrosion Prevention

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

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

The Moomba to Sydney Ethane Pipeline is inspected using 'intelligent pigging' (Refer to Section 3.2) and has a significant wall thickness (8.1 mm). It is equipped with a cathodic protection system and a double layered HDPE coating (Refer to Section 3.2).

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

5.5.3 Prevention of Damage due to Ground Movement and Other Failures

Normal loads (e.g. due to the internal and external pressure, weight of soil, traffic loads, etc.) and occasional loads (e.g. due to flood, earthquake, transient pressures in liquid lines and land movement due to other causes) are considered during design of a pipeline (as per AS2885.1:2012). To comply with AS2885.1:2012 [14], additional depth of cover may also be required where the minimum depth of cover cannot be attained because of the action of nature (e.g. soil erosion, scour).

The Campbelltown South and Appin Mining Subsidence Areas are within the GMGA land release area. Ground movement cannot be discounted.

5.5.4 Prevention of Damage due to Third Party Activity

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to undertake a Safety Management Study (as per Section 11 of AS 2885.3:2012) to assess the risks associated with threats to the pipeline and to instigate appropriate measures to manage the identified threats. The safety management study is reported in Ref. [13].

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 [15].

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

5.5.5 Mitigation Control Measures

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

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

Leaks may be detected during visual inspections, incident notifications and/or by instrumented monitoring systems. If a leak is detected, then the HP pipelines can be isolated by closing automated and/or manual valves (Refer to Section 3.2 for locations of upstream and downstream isolation valves).

5.6 MAEs for Risk Analysis

The list of MAEs included in the risk analysis is provided in Table 12.

Table 12 List of MAEs

MAE	Potential Consequences
Release of High Pressure Ethane from the MSE	Jet Fire, Flash Fire or Explosion
Release of High Pressure Natural Gas (Methane) from the EGP	Jet Fire, Flash Fire or Explosion
Release of High Pressure Natural Gas (Methane) from the CTM	Jet Fire, Flash Fire or Explosion

6 CONSEQUENCE ANALYSIS

6.1 Release of Flammable Liquid / Gas

6.1.1 Representative Hole Diameter

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

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

Table 13 Representative Hole Diameters Selected for Consequence Analysis

Pipeline	Internal Diameter (mm)	Representative Hole Diameter (mm)			
		Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)
MSE	202.9	10 or 25*	75	110	Full bore
EGP	433.6	10 or 25*	75	110	Full bore
CTM	836.8	10 or 25*	75	110	Full bore

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

6.1.2 Rate of Release

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

6.1.3 Height and Orientation of Release

The release of high pressure gas or liquefied gas from a buried pipeline would result a crater and gas would be released vertically from the crater [16]. Where above ground assets have been modelled (ALBVs and MLVs), the release has been assumed to be horizontal in the same direction as the wind, from a distance 1m above ground level.

6.1.4 Duration of Release

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

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

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

6.2 Fire Modelling

The latest SAFETI software package (Version 8.23) was used to model all the representative fire events included in the risk analysis.

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

6.2.1 Jet Fire

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

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

6.2.2 Flash Fire

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

6.3 Vapour Cloud Explosion

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

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

The 3-D obstruction model in SAFETI was used to estimate the overpressure for a VCE. Target points on each of the buildings were selected and the overpressures were estimated for each pipeline scenario. Results are provided in Section B.2.3.

7 FREQUENCY AND LIKELIHOOD ANALYSIS

7.1 Likelihood of Gas Release

The likelihood of a gas release (i.e. leak) from each of the HP pipelines is tabulated in Appendix C.1 and was estimated based on a review of relevant data sources. The primary data sources included:

- Department of Industry, Resources and Energy, New South Wales, *2017-18 Licensed Pipelines Performance Report* [17]. This includes data for all licensed pipelines in NSW for the 5-year period: 2013/14 to 2017/18.
- UK Health and Safety Executive (HSE), Research Report (RR) 1035 [9].
- British Standards Institute (2013) [18].
- US Department of Transportation (DoT) (2018) [19].

7.2 Probability of Ignition

The ignition probabilities adopted in the risk analysis are based on Scenario 3 “Pipe Gas LPG Industrial” described in the International Association of Offshore Oil & Gas Producers Risk Assessment Data Directory – Ignition Probabilities [20] after a review of relevant ignition probability data and ignition probability correlations (Refer to Appendix C.1.3).

7.3 Likelihood of Escalation in Pipeline Easement

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

The likelihood of propagation and escalation was estimated based on a review of historical incidents by Silva et al. [21]. The EGP crosses each of the MSE and CTM in two locations within the GMGA. Estimated crater dimensions from SAFETI and have been used to estimate the likelihood of escalation to a second pipeline. The points at which the EGP crosses other pipelines are the only points where escalation potential has been identified. The potential for escalation where the pipelines run parallel is extremely unlikely as the distance between the pipelines as determined from the pipelines database appears to be greater than the crater dimensions.

7.4 Likelihood of Representative MAEs

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

8 RISK ANALYSIS

8.1 Individual Risk of Fatality

The combined individual risk of fatality contours for a representative segment of the three pipelines in the central part of the GMGA land release area is shown in Figure 11. A more focused view of the pipeline segment for which the societal risk analysis was performed is shown in Figure 12. Both figures demonstrate that all three pipelines combined generate individual risk levels greater than of the risk criteria for sensitive land uses and residential land use as described in HIPAP No.10 [2].

Figure 11: Cumulative LSIR Contours for All three Pipelines Combined

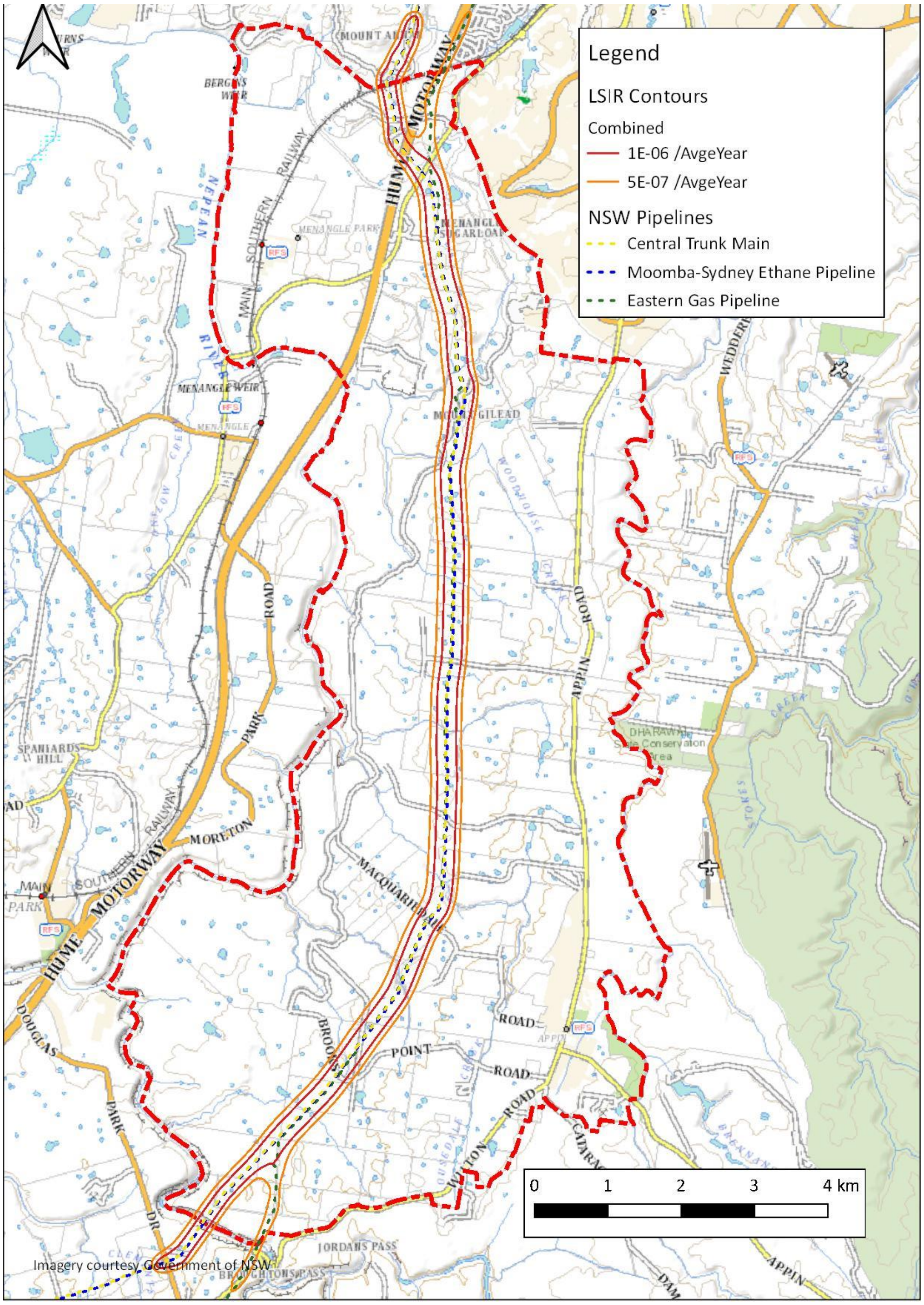
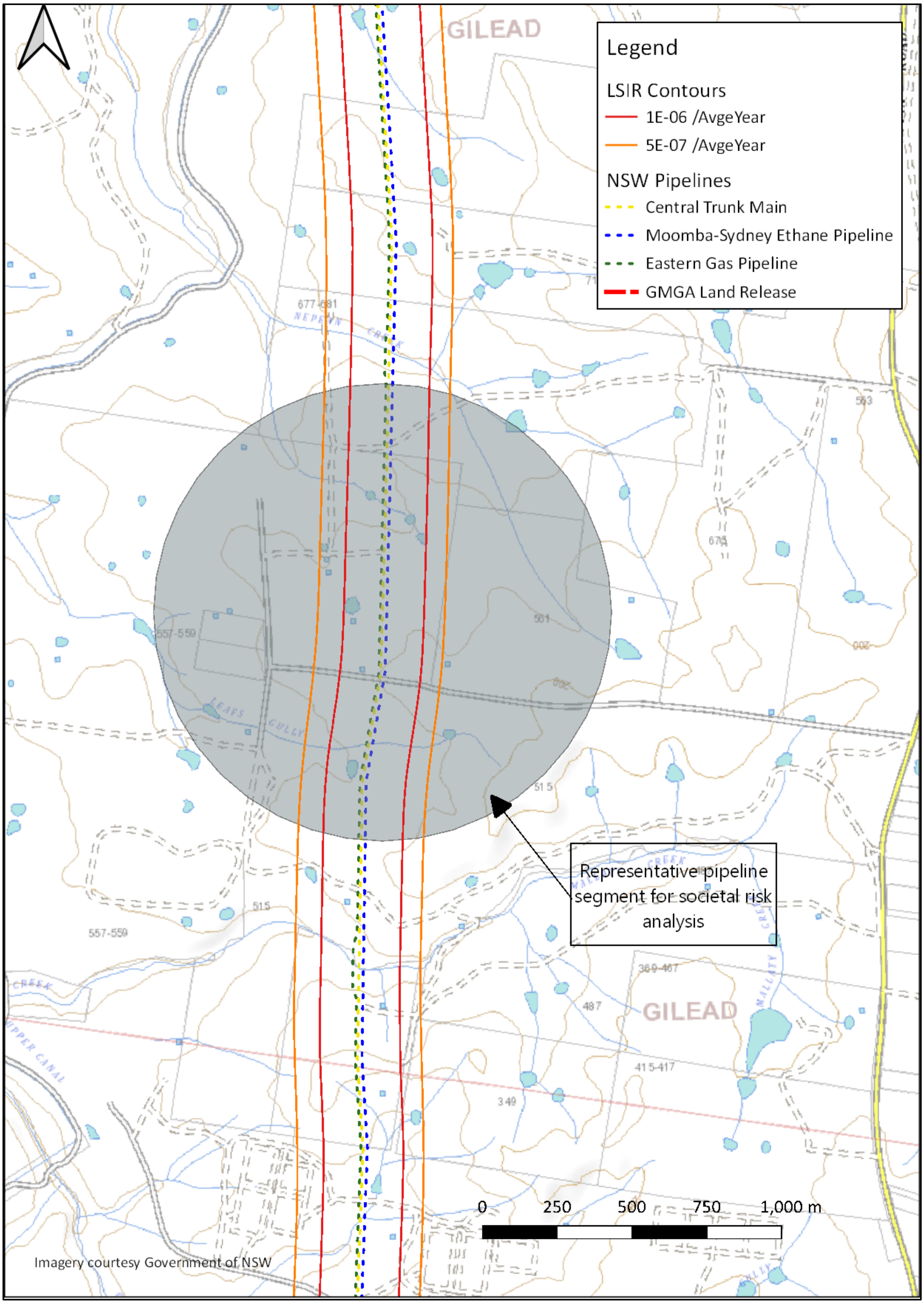


Figure 12 Combined LSIR Contours for MSE, CTM and EGP in the Central Part of the GMGA Land Release Area



The maximum cumulative individual risk of fatality for the three pipelines combined is less than 3.0E-06 p.a. This is below the NSW DPIE individual risk criteria for commercial developments, sporting complexes and active open space, and industrial developments.

As an indication of the relative contribution of each of the individual pipelines, individual risk contours for each of the pipelines alone are presented in Figure 13, Figure 14, Figure 15. These figures indicate that:

1. Only the MSE generates a 1.0 x 10^{-6} p.a. contour for the length of the pipeline. The EGP also generates small 1.0 x 10^{-6} p.a contours (around 30 m radius) from above ground assets such as MLVs. The EGP has MLVs at MenanglePark and Appin, and a TRAD at the very northern end of the GMGA land release area next to the Hume motorway.
2. As all pipelines have a 0.5 x 10^{-6} p.a contour, all three combined (and in fact, any two) contribute the extent of the 1.0 x 10^{-6} p.a contour.
3. The extent of the 0.5 x 10^{-6} p.a contour is driven by the CTM. This pipeline has the lowest decay of individual risk with distance away from the pipeline centreline.

As the EGP diverges from the path taken by the CTM and MSE in the northern and southern extents of the land release area, the risk profile of the EGP alone, and the combined risk of the MSE and CTM has also been prepared. These are shown in Figure 13 and Figure 14 respectively, which replicate Figure 1 and Figure 2 of the Summary.

For completeness, individual risk contours for sections of the three pipelines combined at the northern extent and southern extent of the land release area are presented in Figure 16 and Figure respectively. As expected, the distance to specified risk levels increases as the pipelines diverge until the pipelines are separated enough to start reducing the cumulative effect of the risk.

Figure 13 LSIR Contours for the EGP in the Central Part of the GMGA Land Release Area

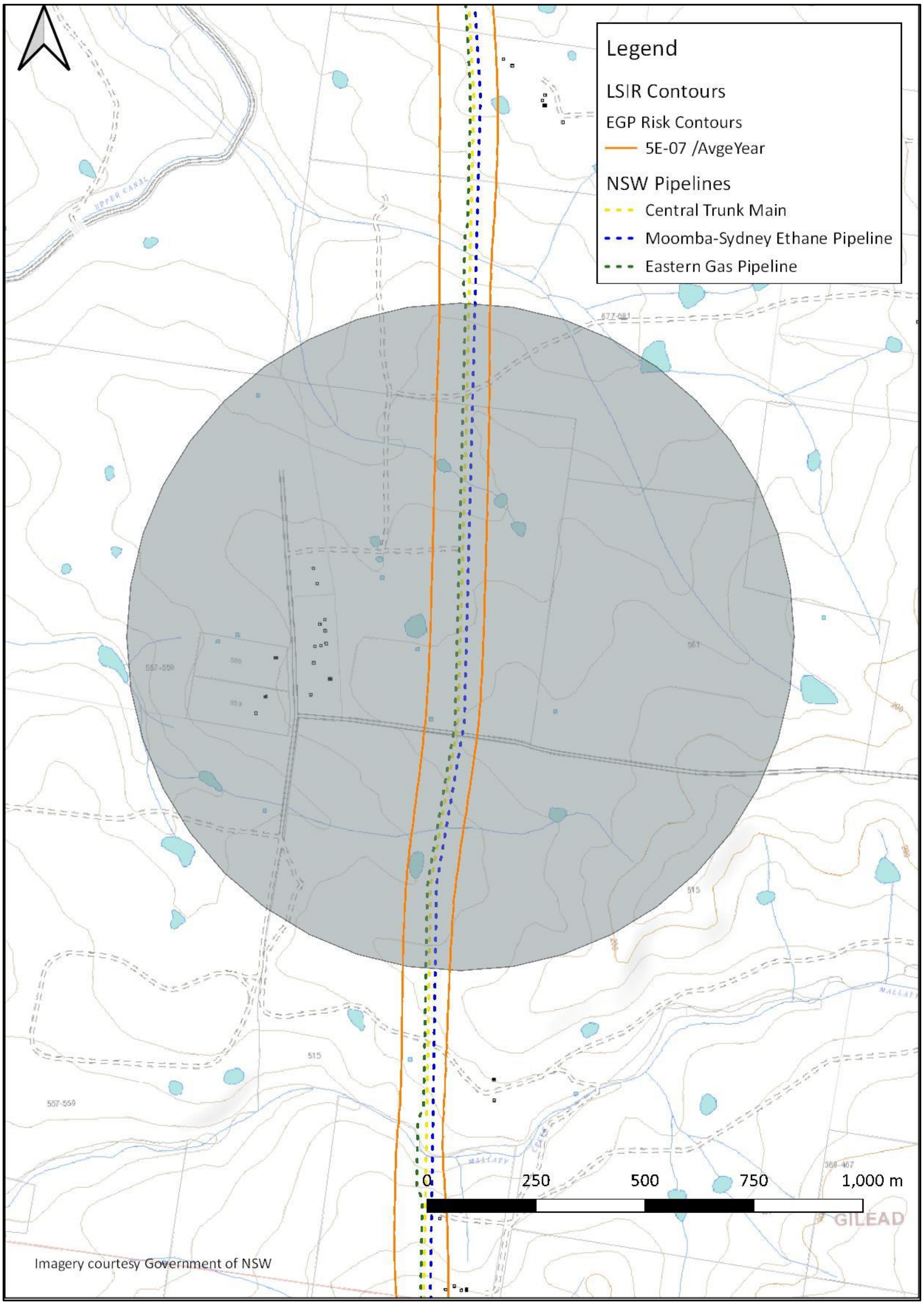


Figure 14 LSIR Contours CTM in the Central Part of the GMGA Land Release Area

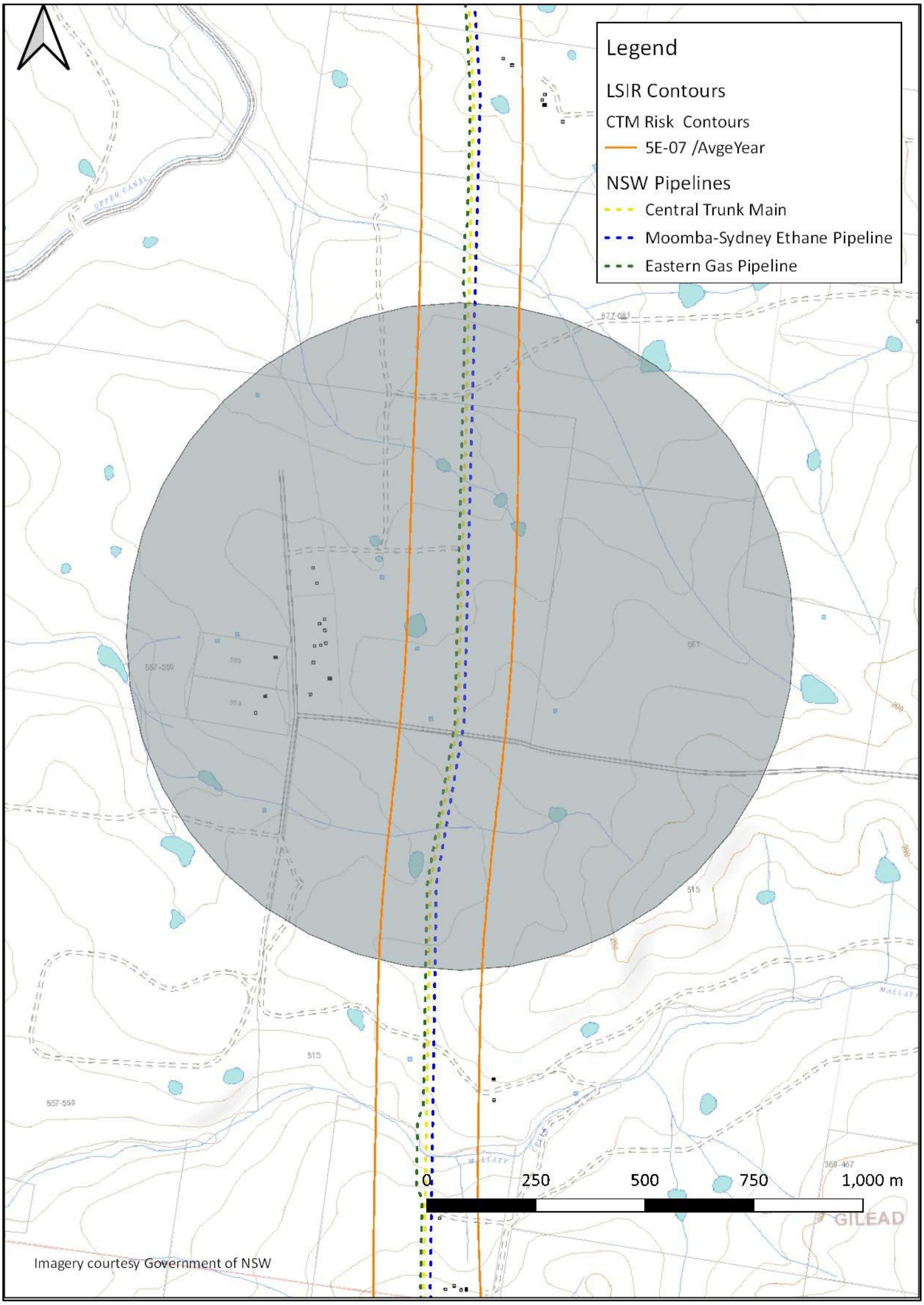


Figure 15: LSIR Contours MSE in the Central Part of the GMGA Land Release Area

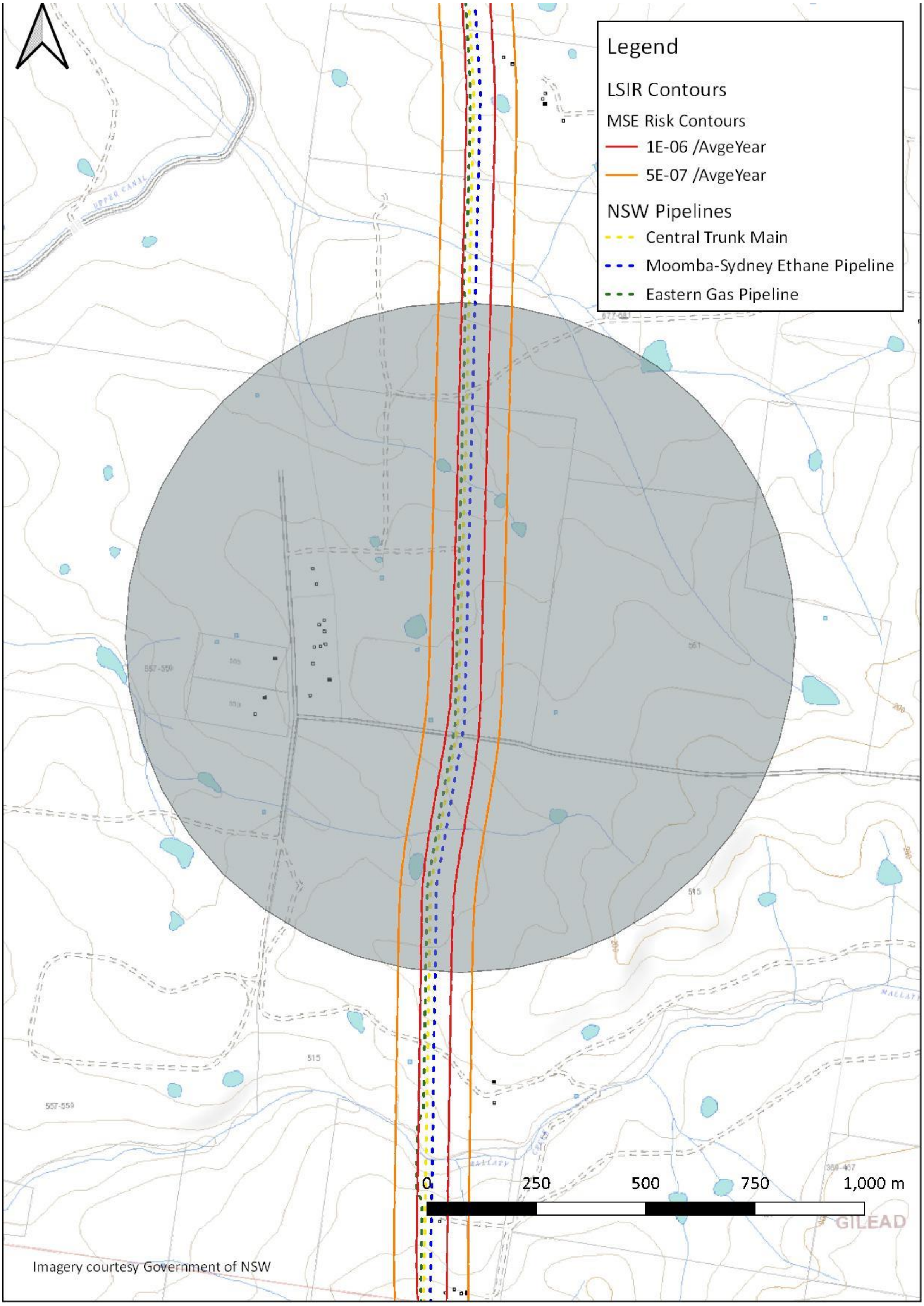


Figure 16 LSIR Contours for MSE, CTM and EGP in the Northern Part of the GMGA Land Release Area

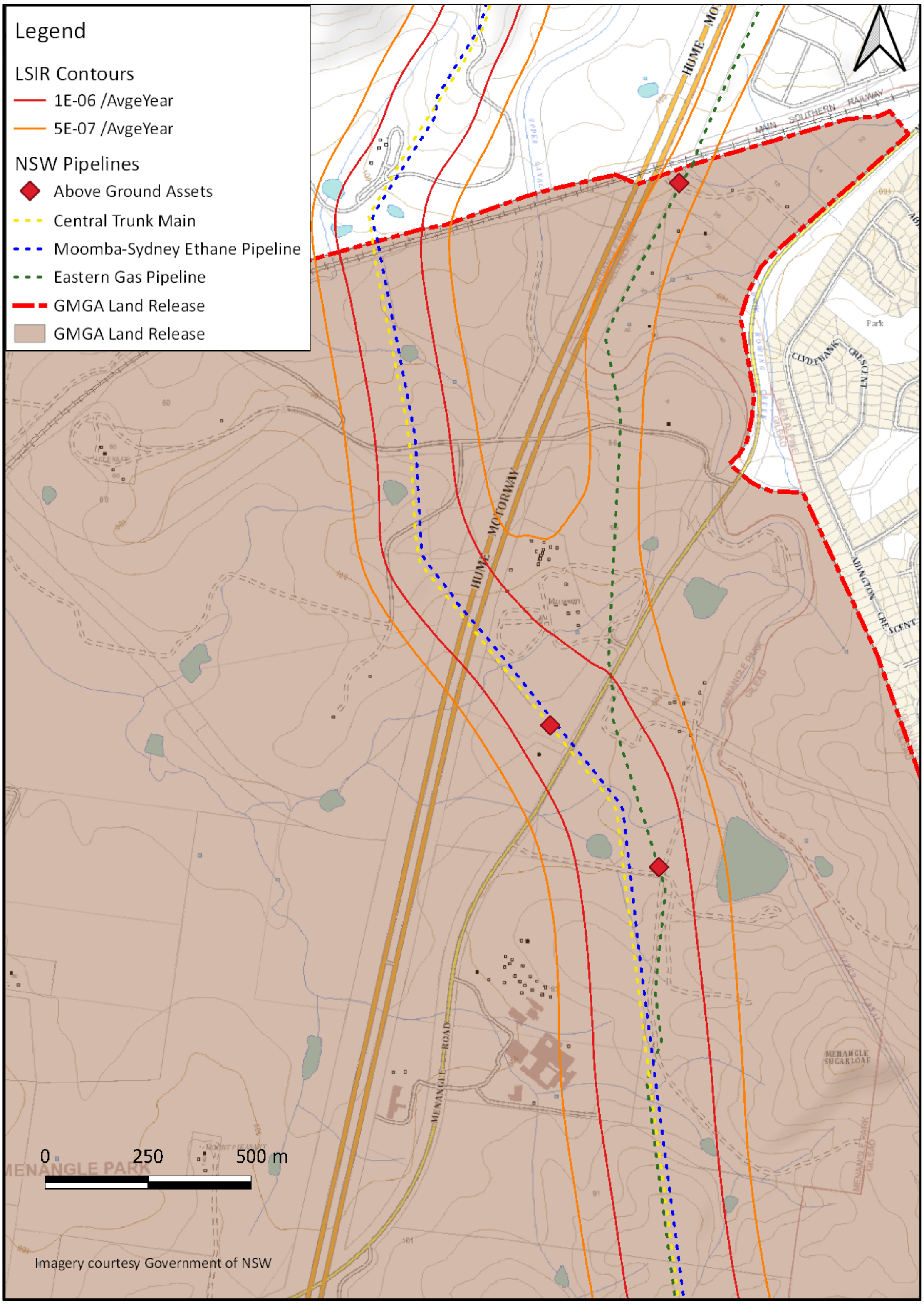
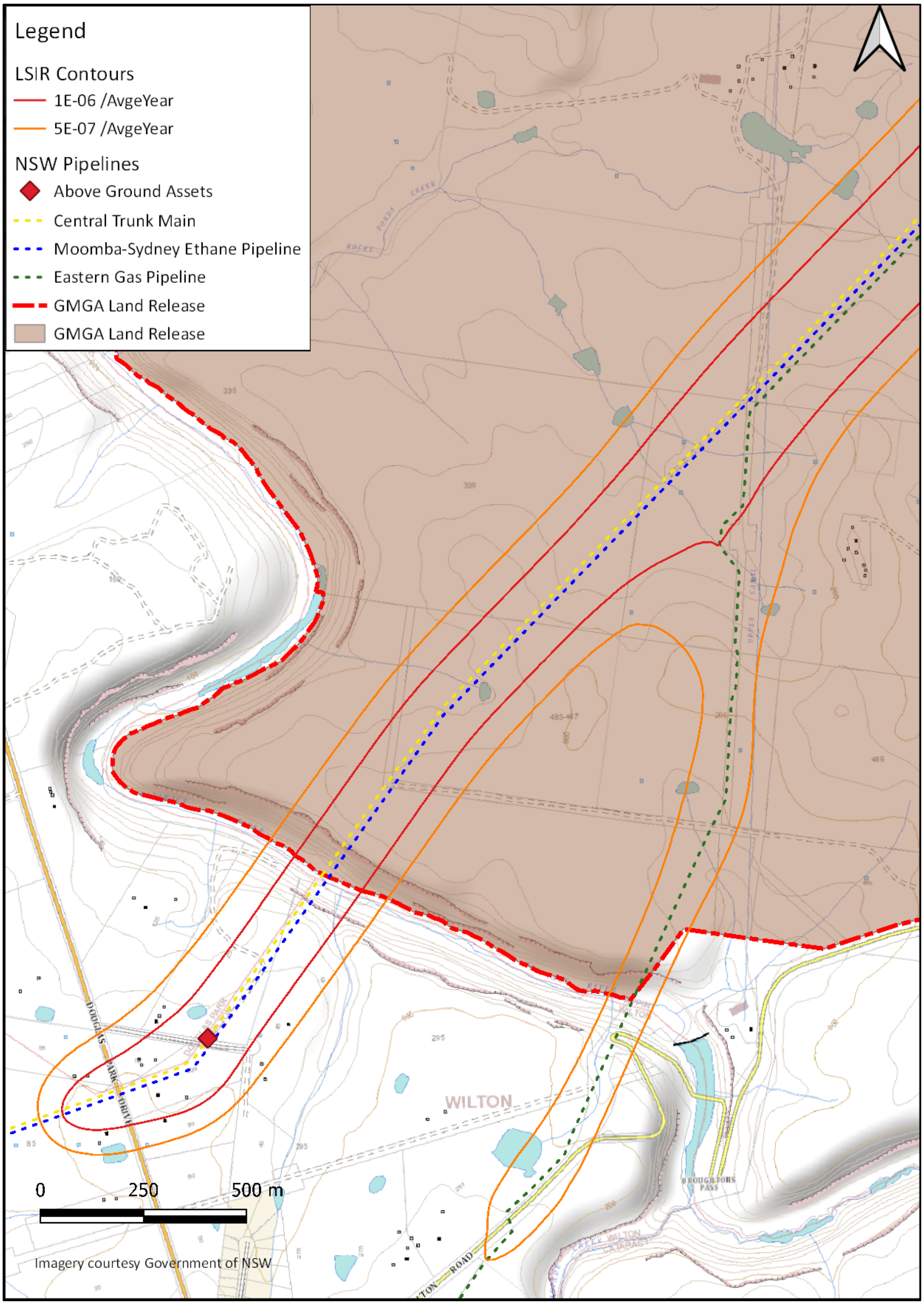


Figure 17 LSIR Contours for MSE, CTM and EGP in the Southern Part of the GMGA Land Release Area



8.2 Risk of Acute Toxic Injury or Irritation

No events with the potential to cause acute toxic injury or irritation were identified for inclusion in the risk analysis (Also refer to Section 5.4.6); therefore any future proposed development will comply with the relevant DPIE toxic injury risk and irritation criteria with respect to the high pressure transmission pipelines (Refer to Section 4.4.2).

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

The cumulative risk of property damage and accident propagation (Overpressure exceeding 14 kPa) does not reach 50 x 10^{-6} per annum; therefore, any future proposed development will comply with the DPIE property damage and accident propagation criteria with respect to the high pressure transmission pipelines (Refer to Section 4.4.3).

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

The cumulative risk of property damage and accident propagation (Heat radiation exceeding 23 kW/m^2) does not reach 50 x 10^{-6} per annum; therefore, any future proposed development will comply with the DPIE property damage and accident propagation criteria with respect to the high pressure transmission pipelines (Refer to Section 4.4.3).

8.5 Risk of Injury (Exceeding 7 kPa)

The cumulative risk of injury (Overpressure exceeding 7 kPa) does not reach 50 x 10^{-6} per annum; therefore, any future proposed development will comply with the relevant DPIE risk criterion (Refer to Section 4.4.2) with respect to the high pressure gas transmission pipelines.

8.6 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, any future proposed development will comply with the relevant DPI&E risk criterion (Refer to Section 4.4.2) with respect to the high pressure gas transmission pipelines.

8.7 Qualitative Risk Criteria

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

- Avoidance of all 'avoidable' risks – The pipelines are existing facilities and cannot be relocated to avoid risk exposure.
- Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low – Some risk reduction measures are discussed in Section 8.9.
- Containment, wherever possible, within the site boundary of the effects (consequences) of the more likely hazardous events – The pipelines carry gases and liquefied gases that will vaporize upon release. Containment is not a practicable solution.
- Recognition that if the risk from an existing installation is already high, further development should not be permitted if it significantly increases that existing risk – This study has identified areas where certain land uses must be avoided to comply with the NSW DPIE risk criteria, and also potential limitations on the intensity of other land uses.

8.8 Societal Risk

Societal risk was analysed for a segment of pipeline indicated in Figure 8. This segment of pipeline is approximately twice the measurement length of the CTM long, and hence every part of the segment could potentially be impacted by another event in the segment. Conducting societal risk for an entire transport route (including pipelines) is problematic, because the societal risk would increase with the length of the route, despite no increase in individual risk transects.

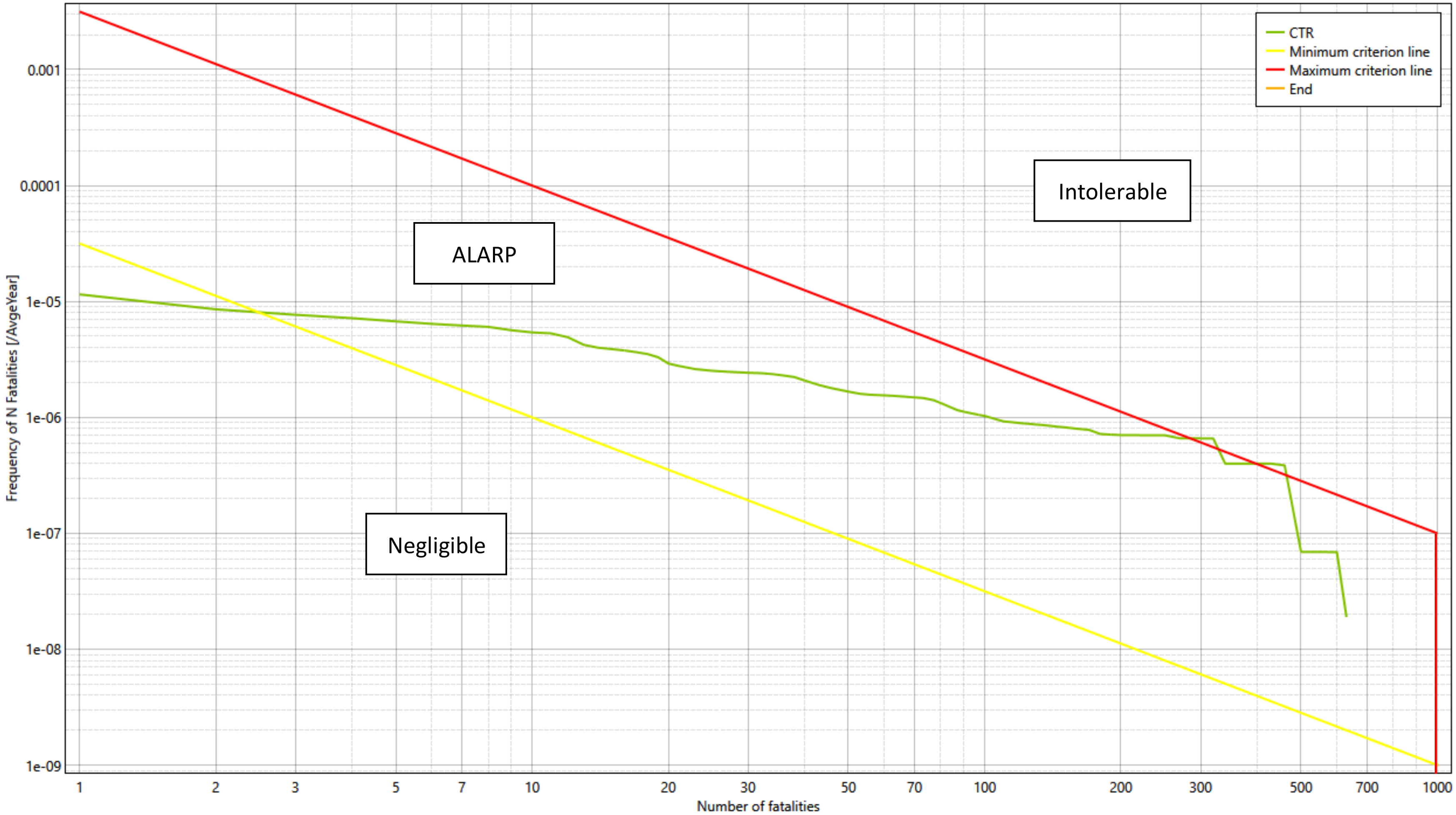
The societal risk analysis assumed residential development up to the proposed maximum density of 45 dwellings per hectare located outside the 1.0×10^{-6} p.a individual risk contour (refer Section 8.1) on either side of the pipeline corridor , supplemented with an infill of the buffer zone with other land uses such as industrial or commercial, populated to the same density of 0.0126 ppl/m^2, but only occupied for ten hours per day...

In HIPAP 10 [2], the following is reported in regard to 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 4 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].*

The results of the societal risk analysis are shown in Figure 18 as an F-N Curve. There are minor excursions of the intolerable line between N=300 and N=500. Given the level of conservatism in the assumptions of population (maximum predicted population density for the entire area in regions where the individual risk criteria is satisfied), the graph reasonably portrays an acceptable level of population and employment density in the GMGA land release area. It was found that the main contributor to exceeding the societal risk is the thermal radiation effects from a full-bore rupture of the CTM.

Figure 18 Societal Risk



8.9 Risk Reduction Measures

Developing a planning scheme that recognises the risks arising from the high pressure pipelines, and manages development consistent with the DPIE risk criteria, is a risk reduction activity and recommendations on such are included in 9.2

Qualitative risk reduction measures not easily highlighted in this generic QRA may need to be undertaken by the pipeline owners and operators as the zoning in the measurement length changes from rural to urban zoning, including residential zones. The changes of land use will trigger a safety management study by the operators.

Additional engineering measures that could be included are increasing the number of ALBV's and MLVs in the GMGA. For example, the EGP has two MLVs within the GMGA land release area, whereas the CTM and MSE have only one ALBV. The closest MLV in the EGP upstream of Appin is at O'Brien's Gap, approximately 29 km upstream of the GMGA. This presents a considerable inventory that will be released if a major accident occurs. This is compared to around a 11 km interval in MLVs further downstream (Appin, Menangle Park, Raby Road and Austral). While additional isolation points will not necessarily reduce the risk as calculated by this QRA (focus on the 30 seconds of release for jet fires), isolation will be necessary to allow emergency services early access to the area.

9 FINDINGS AND RECOMMENDATIONS

9.1 Findings

The following findings were made from the risk assessment:

- When running in parallel with each other, the three pipelines generate location specific individual risk of fatality greater than 0.5×10^{-6} and 1.0×10^{-6} p.a., which limits the sensitive use and residential development in the vicinity of the pipelines. For the majority of the GMGA land release area, the LSIR is above 0.5×10^{-6} p.a. for up to 200 m from the CTM. The LSIR is above 1.0×10^{-6} p.a. for up to 125 m either side of the CTM. As the pipelines diverge in the north and south of the GMGA land release area, the distance to specified risk levels increases until the diverging pipelines are separated sufficiently to minimise the interaction with each other.
- Residential development in areas where the residential individual risk criterion is satisfied can be up to the proposed maximum dwelling density for the GMGA of 45 dwellings per hectare without exceeding the societal risk criteria.
- Non-residential and development either side of the pipeline corridor up to an average population density of 0.0126 ppl/m^2 may be undertaken without exceeding the societal risk criteria.

9.2 Recommendations

1. Implement a buffer zone between the pipelines and any residential development;
   a. For the majority of the GMGA growth area where all three pipelines run parallel in a common corridor in a North-South direction, there should be no residential development within 125m of the CTM.
   b. Where the path of the EGP diverges from the CTM and MSE in the northern and southern regions of the GMGA land release area, there should be no residential development between the pipelines and the 1.0×10^{-6} p.a LSIR contours shown in red in Figure 1 and Figure 2.
2. Implement a buffer zone between the pipelines and any sensitive use developments such as schools, childcare facilities, hospitals or aged-care facilities;
   a. For the majority of the GMGA growth area where all three pipelines run parallel in a common corridor in a North-South direction, there should be no sensitive use development within 200m of the CTM.
   b. Where the path of the EGP diverges from the CTM and MSE in the northern and southern regions of the GMGA land release area, there should be no sensitive use development between the pipelines and the 0.5×10^{-6} p.a LSIR contours shown in orange in Figure 1 and Figure 2
3. To satisfy the DPIE societal risk criteria, land use immediately either side of the pipeline corridor where the three pipelines run parallel should be restricted to uses where the average population density is 0.0126 ppl/m^2. Based on the 2015 SGS Economic and Employment Analysis [3], this could include large format retail, local industry, subregional industry and footloose. Other non-commercial / industrial uses such as recreation would also be suitable provided the average density remains at or below 0.0126 ppl/m^2.
4. Consent should not be granted to any planning or development proposal within the measurement length of the respective pipelines that could increase population density

above 0.0126 ppl/m^2 unless accompanied by a hazard analysis consistent with HIPAP 6 and HIPAP 10, demonstrating the DPIE individual and societal risk criteria are satisfied.

10 REFERENCES

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[21] 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 Major Accident Events (MAEs) potentially affected. Key references are also listed for each assumption, where relevant.

It is important that the assumptions be supported by:

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

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

List of Assumptions

A.1 Operational Data

Assumption No. 1 Pipeline Operating Conditions
Subject: Operational Data
Assumption/s: • All pipeline operating conditions (pressure, temperature, etc.) are as reported in Sections 3.2 and 3.3.
Justification and Impact/s of Assumption/s: • All operational data for the Ethane pipeline was provided by the pipeline owner (APA Group). • All operational data for the Natural Gas pipelines (CTM and EGP) was provided by the pipeline operator, Jemena Limited. • Operating conditions (particularly operating pressure) are required to undertake the release and dispersion modelling.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group • Data provided by Jemena Limited

Assumption No. 2 Pipeline Utilisation
Subject: Operational Data
Assumption/s: • The Ethane pipeline is utilised 100% of the time. • The Natural Gas pipelines (CTM and EGP) are utilised 100% of the time.
Justification and Impact/s of Assumption/s: • Utilisation data is required to undertake the release and dispersion modelling and to estimate the release frequency.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group • Data provided by Jemena Limited).

A.2 Locational Data

Assumption No. 3: Representative Wind Speeds, Wind Directions and Stability Classes
Subject: Locational Data
Assumption/s: • The probabilistic distribution of wind speed and wind direction for the representative stability classes is provided in Section 2.3. • Night-time is considered the period from 1 hour before sunset, to one hour after sunrise. This approximates to 10 hours daytime and 14 hours night-time. • The distribution of stability classes is presented in Section 2.3.
Justification and Impact/s of Assumption/s: • Meteorological data (mean cloud cover, temperature, wind speeds) is collected by the Bureau of Meteorology (BoM) for the Camden Automatic Weather Station weather station for the period 1995-2014. This raw data was rationalised into a set of wind speed/weather stability classes for dispersion calculations. The Camden Airport weather station was selected as being the closest to the GMGA with sufficient data and most representative. • Wind will cause flames to tilt downwind. The higher the wind speed, the greater the tilt. The net effect of the tilt is to increase the heat radiation in the downwind direction. This is much more pronounced for pool fires than jet fires because jet fires have much greater momentum. An allowance for flame tilt is included in the SAFETI models for pool fires and vertical jet fires. The SAFETI model assumes horizontal jet fires are directed in the same direction as the wind. • The downwind gas concentrations, and hence the hazard ranges for dispersion of flammable gas or vapour, vary with wind speed and weather stability class. Therefore, multiple representative wind speed and stability class categories are included in accordance with standard practice for undertaking a quantitative risk assessment (QRA). • 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 Camden Airport weather station, ID: 068192.

Assumption No. 4: Ambient Conditions
Subject: Locational Data
Assumption/s: • The typical ambient conditions (temperature, atmospheric pressure, solar radiation and relative humidity) are provided in Section 2.3.
Justification and Impact/s of Assumption/s: • The average ambient temperature is a required input for the SAFETI model. The temperature of the material in each pipeline is similar; therefore, the average ambient temperature does not have a significant impact on the consequence calculations. • The average relative humidity is a required input for the SAFETI model. This is used in thermal radiation calculations to attenuate the heat radiation. • The average solar radiation is a required input for the SAFETI model.
MAE/s Affected: • All.
Reference/s: • BoM meteorological data for Camden AWS.

Assumption No. 5: Surface Roughness Length

Subject: Locational Data

Assumption/s:

- The roughness length for different surface types, as listed in the SAFETI user manual, is shown below in Table 14.

Table 14 Surface Roughness Length

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

- A conservative roughness length of 1.0 m is applicable for the regular large obstacle coverage expected in suburban areas within the GMGA when fully developed.

Justification and Impact/s of Assumption/s:

- The surface roughness affects the dispersion analysis. As the surface roughness increases, a release of gas or vapour will disperse more quickly with increasing distance from the source. Therefore, it is necessary in SAFETI to select a surface roughness length that is representative of the types of terrain and obstacles near the source of release.
- 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.
- The purpose of the analysis is to determine the level of risk once the GMGA is developed into a suburban environment.

MAE/s Affected:

- Dispersion modelling for all relevant MAEs.

Reference/s:

- SAFETI software documentation.

Assumption No. 6: Location of High Pressure Gas Pipelines
Subject: Locational Data
Assumption/s: • The location of all three pipelines is sourced from the APGA Australian Pipeline Database

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

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

Assumption No. 7: Residential Population (Day and Night)

Subject: Locational Data

Assumption/s:

- The average number of residents per household used for the base case is 2.8.
- The average number of residents per dwelling may be as high as 3.2.
- The local night-time residential population is derived from multiplying the number of people per household by the dwelling density in the proposed development. Dwelling densities range between 10 and 45 dwellings per hectare.
- The daytime population is 61% of the night-time population.

Justification and Impact/s of Assumption/s:

- The average number of residents per dwelling is based on the 2015 report "Greater Macarthur Investigation Area Economic and Employment Analysis".
- The total number of people in the Campbelltown and Camden LGAs as at the 2016 census was 235,221, while the total number of dwellings was 81,524 producing an average number of people per dwelling if 2.9. Of the total number of dwellings, 7,467 were listed as "Not Applicable". People per dwelling for all "Applicable" dwellings is 3.2.
- Dwelling density range is based on the 2019 draft report "Density Study, Greater Macarthur".
- Daytime population is assumed to be the night-time population less the number of persons travelling more than 1 km from home for the day. This has been inferred from the following observations from the 2016 census results in the Camden and Campbelltown LGAs:
  - 35% of persons reported working more than 25 hours per week.
  - 94% of persons reporting a distance other than "Not Applicable" in the census quoted the distance to their workplace was more than 1 km. It is assumed if people travel less than 1 km to work, they may still be impacted by pipeline events.
  - 6% of persons reported attending a TAFE or Tertiary educational institution either part time or full time. Implicit in this is that TAFE and Tertiary educational institutions are not typically found in residential areas.
  - People leaving the area impacted by pipeline events during the day are therefore 35% x 94% + 6% = 39%.

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:

- SGS Economics and Planning, "Greater Macarthur Investigation Area Economic and Employment Analysis", NSW Department of Planning and Environment, 2015.
- Urbis, "Density Study, Greater Macarthur", NSW Department of Planning and Environment, Draft for Review, July 2019.
- Census of Population and Housing, 2016, TableBuilder.

Assumption No. 8: Indoor / Outdoor distribution of people
Subject: Locational Data
Assumption/s: • 99% of the night time population will be located indoors. • 90% of the daytime population will be located indoors. • All population is located at ground level.
Justification and Impact/s of Assumption/s: • The default values recommended by the TNO [‘Purple Book’] for residential and industrial areas are tabulated below.

Table 15 Proportion of Population Indoor and Outdoor During Day and Night [TNO]

Location	Day Time (8am to 6:00pm)	Night Time (6:00pm to 8am)
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 DPIE). It is reported in these analyses that the % of people indoors and outdoors is 90% indoors and 10% outdoors during the day, which differs slightly from the TNO data, but is typically justified as being more applicable for Australian environmental conditions. Similarly, it is reported in these analyses that the % of people indoors and outdoors is 95 to 99% indoors and 1 to 5% outdoors during the night.
MAE/s Affected: • All societal risk calculations.
Reference/s: • • TNO, VROM, Guidelines for Quantitative Risk Assessment, 'Purple Book', CPR18E, 3rd Edition.

A.3 Risk Analysis Methodology

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

A.4 Consequence Analysis

Assumption No. 10: Representative Materials
Subject: Consequence Analysis
Assumption/s: • Ethane is modelled as 100% Ethane. • Natural gas is modelled as 100% Methane.
Justification and Impact/s of Assumption/s: • The composition and materials used affect the magnitude of the consequences. Materials containing multiple components are simplified for modelling purposes by choosing a representative component to best approximate the variable composition. Modelling a representative material rather than a multi-component material reduces complexity, limits the potential for inconsistencies and ultimately has a minimal effect on the results. • The natural gas in the pipelines has been processed for domestic and industrial consumption. As part of the processing, valuable by products such as ethane, propane and butane have been removed at several major producers such as Moomba and Longford. Heavier hydrocarbons are also typically removed to prevent condensation. • Natural gas typically contains 85 to 95% methane. In 1996-97, the composition of natural gas used in Melbourne was 91.2% methane. • The ethane pipeline carries ethane which has been processed to serve as a petrochemical feed stock.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group. • Natural Gas: Energy for the New Millennium, Research Paper 5 1998-99, Mike Roarty, Science, Technology, Environment and Resources Group' December 1998.

Assumption No. 11: Pressure and Flow for Release Modelling
Subject: Consequence Analysis
Assumption/s: • A release of Ethane from the Moomba to Sydney Ethane Pipeline is modelled at 8.2 MPag (Operating pressure), compared to an MAOP of 10 MPag. • A release of Natural Gas from the Jemena Eastern Gas pipeline (EGP) is modelled at 14.895 MPag, which is also the MAOP for the pipeline. • A release of Natural Gas from the (CTM) is modelled at 5 MPag (operating pressure is between 4.5 and 5 MPag), compared to an MAOP of 6.895 MPag. • Release events are modelled using the 'Long Pipeline' model in SAFETI and may be based on a time varying release rate (depending on hole size). • All pipelines have assumed zero flow.
Justification and Impact/s of Assumption/s: • The release rate is dependent on the pressure and the MAOP is the maximum pressure permitted under an existing licence. • The pressure used to model the release rates was based on the pipeline pressure near the proposed development, as advised by the pipeline owner (Refer to Sections 3.2 and 3.3). • The long pipeline model assumes the input pressure is reduced by frictional losses along the pipeline length until the breach point. This results in a lower initial release rate. • Providing a flow will slow the rate of pressure reduction calculated by the long pipeline model, but this is insignificant for the initial 30 second release, the basis of which the impact for jet fire has been assumed. • A flow will increase the residual pressure the long pipeline model calculates, but as it will take much longer than 30 seconds to reach residual pressure, this is not relevant.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group. • Data provided by Jemena Limited.

Assumption No. 12: Representative Hole Diameters for Release Modelling

Subject: Consequence Analysis

Assumption/s:

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

Table 16 Representative Hole Diameters Selected for Consequence Analysis

Pipeline/s	Material	Internal Pipeline Diameter (mm)	Representative Hole Diameter (mm)			
			Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)
APA Ethane Pipeline	Ethane	202.9	10 or 25*	75	110	Full bore
Jemena Eastern Gas Pipeline (EGP)	Natural Gas	433.6	10 or 25*	75	110	Full bore
Jemena Gas Network CTM	Natural Gas	836.8	10 or 25*	75	110	Full bore

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

Justification and Impact/s of Assumption/s:

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

MAE/s Affected:

- All.

Reference/s:

- Refer to Appendix B.1.

Assumption No. 13: Location of Release for Transmission Pipelines
Subject: Consequence Analysis
Assumption/s: • High pressure gas releases would create a crater on the ground. The direction of release for underground pipeline failures from the crater is always vertical. • The location of failure on the pipe can be taken as: - Top of the pipe (unobstructed releases); or - Middle of the pipe (on the side – obstructed releases) • The release frequency is distributed between the two locations (37% from middle of pipe and 63% from top of pipe for all release cases except non-TPA events with a hole size less than or equal to 25mm, which are modelled as 100% from middle of pipe).
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. 14: Maximum Extent of Flash Fire

Subject: Consequence Analysis

Assumption/s:

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

Justification and Impact/s of Assumption/s:

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

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

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

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

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

  Hanna claims that experimentally:

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

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

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

  t = 18.75 s.

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

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

Assumption No. 16: Shielding by Intervening Structures
Subject: Consequence Analysis
Assumption/s: • The presence of intervening structures (e.g. buildings) does not shield other receptors from the heat radiation from a jet fire.
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. 22).
MAE/s Affected: • All MAEs with a pool fire or jet fire as a potential outcome.
Reference/s: • SAFETI software documentation.

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

Assumption No. 18: Escalation due to Propagation Between Adjacent Pipelines
Subject: Consequence Analysis
Assumption/s: • Escalation between pipelines will only occur if the radius of the crater created by a pipeline failure is larger than the distance between the failed pipeline and the pipeline subject to escalation. • Propagation is non-credible to/from underground pipelines in different corridors. • Escalation only occurs when there is propagation before sufficient mitigation of the initial fire.
Justification and Impact/s of Assumption/s: • Escalation MAEs are generally lower likelihood and higher consequence events, which may affect the cumulative risk (Particularly the societal risk). • The likelihood of propagation and escalation was estimated based on a review of historical incidents, primarily from Ref. [21], estimated crater dimensions from SAFETI, and the separation distance between the CTM and the MSE in the common easement. Based on this review, propagation and escalation was not considered a credible event for inclusion in the risk assessment. • In a review of buried pipeline rupture incidents, it was found that there was 1 escalation in 8 cases of rupture when an adjacent pipeline was exposed [21].
MAE/s Affected: • Escalation MAEs only.
Reference/s: • E.P. Silva, M. Nele, P. F.Frutuoso e Melo, and L. Könözsy, *Underground parallel pipelines domino effect: An analysis based on pipeline crater models and historical accidents*, Journal of Loss Prevention in the Process Industries, June 2016.

A.5 Likelihood Analysis

Assumption No. 19: Likelihood of Release (Loss of Containment)
Subject: Likelihood Analysis
Assumption/s: • The likelihood of each representative release is provided in Appendix C.1.3. • The UK HSE pipeline failure rate data is the primary data used for the risk assessment. • The contribution to pipeline failure from ground movement has been adjusted down to allow for local conditions.
Justification and Impact/s of Assumption/s: • The estimated likelihood of release (or loss of containment) is a critical and significant input for the risk analysis. The risk results are directly proportional to this input. • Generic failure rate data for cross-country pipelines from the UK, USA and Europe were reviewed. The UK data incorporates the European data. There are two sources of data from the UK: (a) HSE recommended data for land use safety planning (RR 1035); and (b) British Standards Institute PD 8010-3:2009+A1:2013. The HSE data is primarily used in this study, which is consistent with the NSW performance data. • The HSE data identifies four contributors to pipeline failure: (a) mechanical failure; (b) corrosion; (c) ground movement/other; and (d) Third Party Activity (TPA). Of these, mechanical, corrosion and TPA are similar to conditions in Australia and hence no frequency adjustments due to local conditions are justified. • The justification for the data used in this risk analysis is provided in Appendix C.1.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.1.

Assumption No. 20: Ignition Probability
Subject: Likelihood Analysis
Assumption/s: • The probability of ignition for each representative release is provided in Appendix C.1.3.
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.1.3.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.1.3.

Assumption No. 21: 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. 22: 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 17 Probability of Fatality for Exposure to Heat Radiation (Outdoor)

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

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

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

Assumption No. 22: 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 18 Effects of Thermal Radiation

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

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

MAE/s Affected:

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

Reference/s:

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

Assumption No. 23: 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. 24: 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 19 (Person located outdoors) and Table 20 (Person located indoors).

Table 19 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 20 Probability of Fatality from Exposure to Peak Side on-Overpressure (Indoor)

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

Justification and Impact/s of Assumption/s:

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

Incidents Affected:

- All incidents with a VCE as a potential outcome.

Reference/s:

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

Appendix B Consequence Analysis – Example Data and Results

B.1 Representative Hole Diameters

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

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

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

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

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

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

Table 21 Dimensions of Leaks for Above Ground or Underground Cross-Country Natural Gas or Propylene Pipelines (UKOPA - Reported Values Only)

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

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

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

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

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

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

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

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

Table 23 Dimensions of Puncture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)

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

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

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

B.2 Consequence Analysis Results for Representative Release Scenarios

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

AAA-CTR-XXX-BBB Release Scenario Y

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

CTR – Location of the scenario. All results presented are for the analysis of the centre section.

XXX – Hole size, in mm.

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

Y – The number of the rationalised discharge scenario used for the analysis, determined by SAFETI.

B.2.1 Auto-Sectioning Results

SAFETI 8.23 sections the pipeline based on pressures and the location of valves. Items in **bold** indicate the section that was used in the risk analysis of the central GMGA land release area.

Table 24 Sub-Section Distances for the MSE

Sub-section name	Sub-section type	Sub-section start distance from upstream end [m]	Sub-section end distance from upstream end [m]	Sub-section midpoint distance from upstream end [m]	Sub-section lengths [m]
Section 0 -> Sub-section 0	Automatic	0	3	1.5	3
Section 1 -> Sub-section 0	Automatic	3	1.073E+04	5366	1.073E+04
Section 2 -> Sub-section 0	**User-defined**	**1.073E+04**	**1.226E+04**	**1.149E+04**	**1530**
Section 3 -> Sub-section 0	Automatic	1.226E+04	1.813E+04	1.519E+04	5868
Section 4 -> Sub-section 0	Automatic	1.813E+04	3.337E+04	2.575E+04	1.524E+04

Sub-section name	Sub-section type	Sub-section start distance from upstream end [m]	Sub-section end distance from upstream end [m]	Sub-section midpoint distance from upstream end [m]	Sub-section lengths [m]
Section 4 -> Sub-section 1	Automatic	3.337E+04	4.862E+04	4.099E+04	1.524E+04
Section 4 -> Sub-section 2	Automatic	4.862E+04	6.386E+04	5.624E+04	1.524E+04
Section 4 -> Sub-section 3	Automatic	6.386E+04	7.622E+04	7.004E+04	1.236E+04

Table 25 Sub-section Pressures for the MSE

Sub-section name	Pressure at sub-section start [bar]	Pressure at sub-section end [bar]	Pressure at sub-section mid-point [bar]
Section 0 -> Sub-section 0	83.01	83.01	83.01
Section 1 -> Sub-section 0	83.01	82.39	82.7
Section 2 -> Sub-section 0	**82.39**	**82.3**	**82.34**
Section 3 -> Sub-section 0	82.3	81.95	82.13
Section 4 -> Sub-section 0	81.95	81.06	81.51
Section 4 -> Sub-section 1	81.06	80.17	80.62
Section 4 -> Sub-section 2	80.17	79.28	79.73
Section 4 -> Sub-section 3	79.28	78.56	78.92

Table 26 Sub-section Distances for the CTM

Sub-section name	Sub-section type	Sub-section start distances from upstream end [m]	Sub-section end distances from upstream end [m]	Sub-section midpoint distances from upstream end [m]	Sub-section lengths [m]
Section 0 -> Sub-section 0	Automatic	0	5309	2655	5309
Section 0 -> Sub-section 1	Automatic	5309	1.062E+04	7964	5309
Section 1 -> Sub-section 0	**User-defined**	**1.062E+04**	**1.215E+04**	**1.138E+04**	**1531**
Section 2 -> Sub-section 0	Automatic	1.215E+04	2.232E+04	1.723E+04	1.017E+04
Section 2 -> Sub-section 1	Automatic	2.232E+04	3.248E+04	2.74E+04	1.017E+04
Section 2 -> Sub-section 2	Automatic	3.248E+04	4.265E+04	3.757E+04	1.017E+04
Section 2 -> Sub-section 3	Automatic	4.265E+04	5.084E+04	4.674E+04	8186

Table 27 Sub-section Pressures for the CTM

Sub-section name	Pressure at sub-section start [bar]	Pressure at sub-section end [bar]	Pressure at sub-section mid-point [bar]

Section 0 -> Sub-section 0	51.01	50.97	50.99
Section 0 -> Sub-section 1	50.97	50.93	50.95
Section 1 -> Sub-section 0	**50.93**	**50.92**	**50.92**
Section 2 -> Sub-section 0	50.92	50.83	50.87
Section 2 -> Sub-section 1	50.83	50.75	50.79
Section 2 -> Sub-section 2	50.75	50.67	50.71
Section 2 -> Sub-section 3	50.67	50.6	50.63

Table 28 Sub-section Distances for the EGP

Sub-section name	Sub-section type	Sub-section start distances from upstream end [m]	Sub-section end distances from upstream end [m]	Sub-section midpoint distances from upstream end [m]	Sub-section lengths [m]
Section 0 -> Sub-section 0	Automatic	0	1.564E+04	7820	1.564E+04
Section 0 -> Sub-section 1	Automatic	1.564E+04	3.128E+04	2.346E+04	1.564E+04
Section 0 -> Sub-section 2	Automatic	3.128E+04	3.721E+04	3.424E+04	5924
Section 1 -> Sub-section 0	**User-defined**	**3.721E+04**	**3.874E+04**	**3.797E+04**	**1531**
Section 2 -> Sub-section 0	Automatic	3.874E+04	5.438E+04	4.656E+04	1.564E+04
Section 2 -> Sub-section 1	Automatic	5.438E+04	7.002E+04	6.22E+04	1.564E+04
Section 2 -> Sub-section 2	Automatic	7.002E+04	7.82E+04	7.411E+04	8186

Table 29 Sub-section pressures for the EGP

Sub-section name	Pressure at sub-section start [bar]	Pressure at sub-section end [bar]	Pressure at sub-section mid-point [bar]
Section 0 -> Sub-section 0	150	149.8	149.9
Section 0 -> Sub-section 1	149.8	149.6	149.7
Section 0 -> Sub-section 2	149.6	149.5	149.6
Section 1 -> Sub-section 0	149.5	149.5	149.5
Section 2 -> Sub-section 0	149.5	149.3	149.4
Section 2 -> Sub-section 1	149.3	149.1	149.2
Section 2 -> Sub-section 2	149.1	149	149.1

B.2.2 Section Breach Discharge Results

Peak discharge rates are shown in the flash fire and jet fire results. It should be noted that for the larger hole sizes (full bore rupture for the natural gas pipelines, and 75 mm or greater for the MSE), the dispersion calculations used multiple release rates to represent the reduction of flowrate over time as the pipelines depressurise.

B.2.3 Flash Fire Results

Results for distances to LFL concentrations are tabulated in Table 30, Table 31, and Table 32 for release from the MSE, CTM and EGP respectively.

Table 30 Distances to LFL for MSE Releases

Model	Weather Category	Peak flowrate (kg/s)	Distance to LFL (m)	Maximum width to LFL (m)
MSE-CTR-010-MID Rationalised Scenario 01	1.0D	3.477	0.3678	0.5292
	1.0F	3.477	0.3477	0.5224
	1.8B	3.477	0.3909	0.5529
	2.6E	3.477	0.3805	0.552
	3.9D	3.477	0.4175	0.5994
	7.5D	3.477	0.4955	0.7054
MSE-CTR-025-MID Rationalised Scenario 01	1.0D	21.73	n/a	n/a
	1.0F	21.73	n/a	n/a
	1.8B	21.73	0.8917	1.201
	2.6E	21.73	0.8416	1.205
	3.9D	21.73	0.8775	1.233
	7.5D	21.73	0.9281	1.293
MSE-CTR-075-MID Rationalised Scenario 05	1.0D	96.78	n/a	n/a
	1.0F	96.78	1.898	1.69
	1.8B	96.78	1.33	1.716
	2.6E	96.78	1.472	1.725
	3.9D	96.78	1.355	1.76
	7.5D	96.78	1.409	1.836
MSE-CTR-075-TOP Rationalised Scenario 05	1.0D	96.78	0.6604	0.6998
	1.0F	96.78	0.6676	0.6986
	1.8B	96.78	0.6489	0.7005
	2.6E	96.78	0.6217	0.7036
	3.9D	96.78	0.7114	0.7093
	7.5D	96.78	0.6415	0.7231
MSE-CTR-110-MID Rationalised Scenario 05	1.0D	208.2	n/a	n/a
	1.0F	208.2	1.74	1.854
	1.8B	208.2	1.526	1.879
	2.6E	208.2	1.698	1.889
	3.9D	208.2	1.563	1.923
	7.5D	208.2	1.618	1.996
MSE-CTR-110-TOP Rationalised Scenario 05	1.0D	208.2	0.8215	0.8695
	1.0F	208.2	0.9504	0.8687
	1.8B	208.2	0.8828	0.8679
	2.6E	208.2	0.902	0.8717
	3.9D	208.2	0.9806	0.8752
	7.5D	208.2	0.7892	0.8872
	1.0D	709	265.6	204.9

Model	Weather Category	Peak flowrate (kg/s)	Distance to LFL (m)	Maximum width to LFL (m)
MSE-CTR-203-FBR Rationalised Scenario 05	1.0F	709	291.1	138.5
	1.8B	709	64.07	43.37
	2.6E	709	7.368	7.739
	3.9D	709	5.67	7.797
	7.5D	709	5.53	7.824

Table 31 Distances to LFL for CTM Releases

Model	Weather	Peak observer rate (kg/s)	Distance to LFL (m)	Maximum width to LFL (m)
CTM-CTR-010-MID Rationalised Scenario 01	1.0D	0.6415	0.2252	0.4412
	1.0F	0.6415	0.2066	0.4321
	1.8B	0.6415	0.2441	0.4699
	2.6E	0.6415	0.2343	0.4699
	3.9D	0.6415	0.273	0.5106
	7.5D	0.6415	0.3566	0.6009
CTM-CTR-025-MID Rationalised Scenario 01	1.0D	4.01	0.4455	0.8793
	1.0F	4.01	0.408	0.8703
	1.8B	4.01	0.4635	0.9098
	2.6E	4.01	0.4394	0.909
	3.9D	4.01	0.4853	0.9469
	7.5D	4.01	0.5467	1.028
CTM-CTR-075-MID Rationalised Scenario 01	1.0D	36.09	1.062	2.063
	1.0F	36.09	1.279	2.055
	1.8B	36.09	1.102	2.095
	2.6E	36.09	1.132	2.093
	3.9D	36.09	1.109	2.123
	7.5D	36.09	1.163	2.181
CTM-CTR-075-TOP Rationalised Scenario 01	1.0D	36.09	0.4266	0.8832
	1.0F	36.09	0.4677	0.8808
	1.8B	36.09	0.4568	0.889
	2.6E	36.09	0.4522	0.8912
	3.9D	36.09	0.4596	0.8998
	7.5D	36.09	0.4846	0.9179
CTM-CTR-110-MID Rationalised Scenario 01	1.0D	77.63	1.319	2.55
	1.0F	77.63	1.462	2.543
	1.8B	77.63	1.342	2.58
	2.6E	77.63	1.35	2.578
	3.9D	77.63	1.356	2.602
	7.5D	77.63	1.363	2.647
CTM-CTR-110-TOP Rationalised Scenario 01	1.0D	77.63	0.5357	1.034
	1.0F	77.63	0.5089	1.032
	1.8B	77.63	0.5385	1.036

Model	Weather	Peak observer rate (kg/s)	Distance to LFL (m)	Maximum width to LFL (m)
	2.6E	77.63	0.5406	1.04
	3.9D	77.63	0.5538	1.045
	7.5D	77.63	0.5469	1.059
CTM-CTR-837-FBR Rationalised Scenario 02	1.0D	3050	6.247	11.99
	1.0F	3050	n/a	n/a
	1.8B	3050	6.645	12.02
	2.6E	3050	6.253	12.04
	3.9D	3050	6.246	12.07
	7.5D	3050	6.257	12.08

Table 32 Distances to LFL for EGP Releases

Model	Weather	Peak flow rate (kg/s)	Distance to LFL (m)	Maximum width (at height of interest) to LFL (m)
EGP-CTR-010-MID Rationalised Scenario 01	1.0D	2.111	0.3413	0.6701
	1.0F	2.111	0.3118	0.6604
	1.8B	2.111	0.3631	0.7013
	2.6E	2.111	0.3462	0.7011
	3.9D	2.111	0.3885	0.7423
	7.5D	2.111	0.4546	0.8316
EGP-CTR-025-MID Rationalised Scenario 01	1.0D	13.19	0.6796	1.327
	1.0F	13.19	0.649	1.318
	1.8B	13.19	0.7003	1.356
	2.6E	13.19	0.6608	1.356
	3.9D	13.19	0.7112	1.389
	7.5D	13.19	0.7623	1.453
EGP-CTR-075-MID Rationalised Scenario 01	1.0D	118.7	1.057	1.924
	1.0F	118.7	1.328	1.921
	1.8B	118.7	1.072	1.929
	2.6E	118.7	1.019	1.936
	3.9D	118.7	1.086	1.946
	7.5D	118.7	1.1	1.961
EGP-CTR-075-TOP Rationalised Scenario 01	1.0D	118.7	0.5156	0.9258
	1.0F	118.7	0.528	0.9269
	1.8B	118.7	0.551	0.9109
	2.6E	118.7	0.5308	0.9217
	3.9D	118.7	0.5634	0.9209
	7.5D	118.7	0.5912	0.9251
EGP-CTR-110-MID Rationalised Scenario 01	1.0D	255.4	1.226	2.202
	1.0F	255.4	1.37	2.2
	1.8B	255.4	1.271	2.195
	2.6E	255.4	1.253	2.206

Model	Weather	Peak flow rate (kg/s)	Distance to LFL (m)	Maximum width (at height of interest) to LFL (m)
	3.9D	255.4	1.222	2.21
	7.5D	255.4	1.299	2.215
EGP-CTR-110-TOP Rationalised Scenario 01	1.0D	255.4	0.7155	1.282
	1.0F	255.4	1.1	1.284
	1.8B	255.4	0.7292	1.259
	2.6E	255.4	0.8538	1.274
	3.9D	255.4	0.7782	1.27
	7.5D	255.4	0.8236	1.27
EGP-CTR-434-FBR Rationalised Scenario 03	1.0D	2117	5.51	10.67
	1.0F	2117	n/a	
	1.8B	2117	5.821	10.71
	2.6E	2117	5.615	10.72
	3.9D	2117	5.585	10.74
	7.5D	2117	5.576	10.77

B.2.4 Jet Fire Results

Results for jet fire scenarios are tabulated in Table 33, Table 34, and Table 35 for releases from the MSE, CTM and EGP respectively.

Table 33 Distances (m) Downwind to Selected Radiation Intensity for MSE Releases

Model	Weather Category	Jet fire mass rate (kg/s)	Flame length (m)	4.7 kW/m^2 (m)	12.5 kW/m^2 (m)	23 kW/m^2 (m)	35 kW/m^2 (m)
MSE-CTR-010-MID Rationalised Scenario 01	1.8B	3.477	22.07	32.75	19.97	10.1	4.67
	7.5D	3.477	15.41	36.44	25.9	20.91	17.41
	3.9D	3.477	17.85	35.06	22.85	18.23	14.51
	1.0D	3.477	24.87	30.34	12.75	3.936	2.132
	2.6E	3.477	20.04	33.1	22.16	15.28	8.745
	1.0F	3.477	24.87	30.37	12.76	3.943	2.134
MSE-CTR-025-MID Rationalised Scenario 01	1.8B	21.73	47.27	76.4	46.63	26.33	12.84
	7.5D	21.73	33	61.69	32.33	18.73	11.32
	3.9D	21.73	38.24	80.07	51.88	40.46	31.77
	1.0D	21.73	53.27	72.18	33.82	11.62	5.646
	2.6E	21.73	42.92	77.06	50.61	35.17	21.99
	1.0F	21.73	53.27	72.27	33.9	11.65	5.658
MSE-CTR-075-MID Rationalised Scenario 05	1.8B	91.97	82.82	144.5	85.33	48.33	23.68
	7.5D	91.97	57.82	142.8	93.65	72.15	62.09
	3.9D	91.97	67	149.9	97.46	74.54	58.23
	1.0D	91.97	93.33	136.4	65.17	22.04	9.26
	2.6E	91.97	75.2	146.7	94.62	65.54	42.58
	1.0F	91.97	93.33	136.6	65.34	22.13	9.288

Model	Weather Category	Jet fire mass rate (kg/s)	Flame length (m)	4.7 kW/m² (m)	12.5 kW/m² (m)	23 kW/m² (m)	35 kW/m² (m)
MSE-CTR-075-TOP Rationalised Scenario 05	1.8B	91.97	75.15	125.4	66.13	27.17	8.797
	7.5D	91.97	52.47	121.8	78.32	61.76	51.12
	3.9D	91.97	60.79	118.9	75.01	49.91	29.95
	1.0D	91.97	84.68	121.7	52.48	10.76	3.297
	2.6E	91.97	68.23	123.3	71.09	38.74	15.67
	1.0F	91.97	84.68	121.9	52.64	10.82	3.307
MSE-CTR-110-MID Rationalised Scenario 05	1.8B	173.8	105.9	190.3	110.7	62.35	29.35
	7.5D	173.8	73.94	178.5	115	90.42	76.33
	3.9D	173.8	85.67	183.5	120.6	89.96	67.44
	1.0D	173.8	119.3	180.5	87.34	29.85	11.51
	2.6E	173.8	96.15	192.1	122	82.85	52.8
	1.0F	173.8	119.3	180.8	87.57	30	11.55
MSE-CTR-110-TOP Rationalised Scenario 05	1.8B	173.8	97.9	159	81.79	30.89	10.02
	7.5D	173.8	68.35	154.3	99.68	77.93	62.94
	3.9D	173.8	79.2	151.7	94.05	60.4	33.2
	1.0D	173.8	110.3	161	70.81	15.3	4.661
	2.6E	173.8	88.89	156.6	88.46	45.47	17.54
	1.0F	173.8	110.3	161.3	71.04	15.39	4.675
MSE-CTR-203-FBR Rationalised Scenario 05	1.8B	286.1	140.9	255	159.5	103.5	63.77
	7.5D	286.1	98.35	225.1	146.5	115.8	97.49
	3.9D	286.1	114	255.5	166.4	127.5	37.86
	1.0D	286.1	158.7	250.3	138.9	71.22	37.72
	2.6E	286.1	127.9	256.6	167.7	120.4	85.61
	1.0F	286.1	158.7	250.7	139.2	71.46	37.83

Table 34 Distances (m) Downwind to Selected Radiation Intensity for CTM Releases

Model	Weather Category	Jet fire mass rate (kg/s)	Flame length (m)	4.7 kW/m² (m)	12.5 kW/m² (m)	23 kW/m² (m)	35 kW/m² (m)
CTM-CTR-010-MID Rationalised Scenario 01	1.8B	0.6415	13.44	12.35	3.209	0.333	n/a
	7.5D	0.6415	9.39	16.89	12.2	9.769	8.942
	3.9D	0.6415	10.84	14.68	10.03	5.105	1.655
	1.0D	0.6415	14.97	8.384	n/a	n/a	n/a
	2.6E	0.6415	12.12	14.07	6.908	1.958	0.4879
	1.0F	0.6415	14.95	8.427	n/a	n/a	n/a
CTM-CTR-025-MID Rationalised Scenario 01	1.8B	4.01	29	29.24	9.03	1.547	n/a
	7.5D	4.01	20.27	37.63	24.8	20.51	17.02
	3.9D	4.01	23.4	33.57	21.83	11.29	3.895
	1.0D	4.01	32.32	22.2	3.463	n/a	n/a
	2.6E	4.01	26.18	32.45	16.47	5.401	1.59
	1.0F	4.01	32.27	22.29	3.558	n/a	n/a

Model	Weather Category	Jet fire mass rate (kg/s)	Flame length (m)	4.7 kW/m² (m)	12.5 kW/m² (m)	23 kW/m² (m)	35 kW/m² (m)
CTM-CTR-075-MID Rationalised Scenario 01	1.8B	36.09	70.99	79.5	28.39	9.567	n/a
	7.5D	36.09	49.61	97.54	63.41	50.09	39.03
	3.9D	36.09	57.28	89.59	56.37	32.92	15.54
	1.0D	36.09	79.12	66.43	17.89	n/a	n/a
	2.6E	36.09	64.07	86.83	45.16	17.85	7.481
	1.0F	36.09	79	66.66	18.19	n/a	n/a
CTM-CTR-075-TOP Rationalised Scenario 01	1.8B	36.09	59.87	58.13	14.56	n/a	n/a
	7.5D	36.09	41.84	74.92	47.38	30.96	16.78
	3.9D	36.09	48.3	70.17	34.39	11.7	n/a
	1.0D	36.09	66.7	49.57	n/a	n/a	n/a
	2.6E	36.09	54.03	64.79	22.81	n/a	n/a
	1.0F	36.09	66.6	49.77	n/a	n/a	n/a
CTM-CTR-110-MID Rationalised Scenario 01	1.8B	77.63	95.39	109.6	39.33	13.81	n/a
	7.5D	77.63	66.67	133.8	86.74	67.31	51.35
	3.9D	77.63	76.97	124.8	76.76	45.83	23.83
	1.0D	77.63	106.3	94.25	27.75	n/a	n/a
	2.6E	77.63	86.09	119.2	60.08	21	10.55
	1.0F	77.63	106.1	94.58	27.97	n/a	n/a
CTM-CTR-110-TOP Rationalised Scenario 01	1.8B	77.63	79.66	78.01	19.91	n/a	n/a
	7.5D	77.63	55.67	100.5	61.03	37.26	15.08
	3.9D	77.63	64.27	93.41	43.96	15.79	n/a
	1.0D	77.63	88.74	67.95	n/a	n/a	n/a
	2.6E	77.63	71.88	86.4	31.28	n/a	n/a
	1.0F	77.63	88.61	68.23	n/a	n/a	n/a
CTM-CTR-837-FBR Rationalised Scenario 02	1.8B	3050	424.6	582.3	275.5	137.4	58.82
	7.5D	3050	296.7	611.7	400.7	291.3	213.3
	3.9D	3050	342.6	639.8	381.6	239.1	139.8
	1.0D	3050	473.2	541.4	232.1	84.86	n/a
	2.6E	3050	383.2	615.2	329.2	171.6	101.9
	1.0F	3050	472.5	543.3	233.5	86.38	n/a

Table 35 Distances (m) Downwind to Selected Radiation Intensity for EGP Releases

Model	Weather Category	Jet fire mass rate (kg/s)	Flame length (m)	4.7 kW/m² (m)	12.5 kW/m² (m)	23 kW/m² (m)	35 kW/m² (m)
EGP-CTR-010-MID Rationalised Scenario 01	1.0D	2.111	24.91	16.11	1.025	n/a	n/a
	1.0F	2.111	24.88	16.18	1.095	n/a	n/a
	1.8B	2.111	22.36	22.02	6.733	1.182	n/a
	2.6E	2.111	20.18	24.41	12.24	3.608	0.9457
	3.9D	2.111	18.04	25.29	16.74	8.587	2.992
	7.5D	2.111	15.62	28.58	19.46	15.95	13.68

Model	Weather Category	Jet fire mass rate (kg/s)	Flame length (m)	4.7 kW/m² (m)	12.5 kW/m² (m)	23 kW/m² (m)	35 kW/m² (m)
EGP-CTR-025-MID Rationalised Scenario 01	1.0D	13.19	52.71	40.58	9.262	n/a	n/a
	1.0F	13.19	52.63	40.73	9.347	n/a	n/a
	1.8B	13.19	47.3	50.55	17.2	4.947	n/a
	2.6E	13.19	42.69	55.68	29.06	11.13	3.882
	3.9D	13.19	38.16	57.29	36.57	20.17	7.93
	7.5D	13.19	33.06	63.17	41.31	33.25	26.48
EGP-CTR-075-MID Rationalised Scenario 01	1.0D	118.7	120	106.1	28.52	n/a	n/a
	1.0F	118.7	119.8	106.5	28.89	n/a	n/a
	1.8B	118.7	107.7	121.4	43.49	n/a	n/a
	2.6E	118.7	97.17	132.1	59.81	22.75	n/a
	3.9D	118.7	86.87	140	78.98	39.99	17
	7.5D	118.7	75.25	149.4	97.13	72.18	52.26
EGP-CTR-075-TOP Rationalised Scenario 01	1.0D	118.7	105.7	83.42	n/a	n/a	n/a
	1.0F	118.7	105.5	83.76	n/a	n/a	n/a
	1.8B	118.7	94.88	94.78	25.84	n/a	n/a
	2.6E	118.7	85.61	104.5	39.06	n/a	n/a
	3.9D	118.7	76.54	112.6	53.31	19.92	n/a
	7.5D	118.7	66.31	121.1	73.01	44.33	18.12
EGP-CTR-110-MID Rationalised Scenario 01	1.0D	255.4	160.2	147.7	40.7	n/a	n/a
	1.0F	255.4	159.9	148.2	41.21	n/a	n/a
	1.8B	255.4	143.7	165	61.78	n/a	n/a
	2.6E	255.4	129.7	178.3	79.48	31.99	n/a
	3.9D	255.4	116	189	103.3	48.59	23.8
	7.5D	255.4	100.4	198.6	128.4	90.82	62.4
EGP-CTR-110-TOP Rationalised Scenario 01	1.0D	255.4	146.8	123.7	n/a	n/a	n/a
	1.0F	255.4	146.6	124.2	n/a	n/a	n/a
	1.8B	255.4	131.8	138.2	43.63	n/a	n/a
	2.6E	255.4	118.9	150.8	60.39	n/a	n/a
	3.9D	255.4	106.3	161.3	78.76	33.04	n/a
	7.5D	255.4	92.09	173.1	104.3	64.47	30.66
EGP-CTR-434-FBR Rationalised Scenario 03	1.0D	2117	411.4	464.1	196.1	71.29	n/a
	1.0F	2117	410.8	465.7	197.2	72.56	n/a
	1.8B	2117	369.1	502.3	233.9	116.1	51.63
	2.6E	2117	333.1	531.4	286.4	144.6	86.11
	3.9D	2117	297.8	552.4	333	212	128.1
	7.5D	2117	258	535.1	352.6	259.8	192.4

B.2.5 Explosion Results

Explosion results are tabulated in Table 36, Table 37, and Table 38 for releases from the MSE, CTM and EGP, respectively. The maximum calculated overpressure was less than 14 kPa, so only distances for 7 kPa are shown.

Table 36 Explosion Distances for MSE Releases

Model	Weather Category	Distance downwind to 7 kPa (m)	Max diameter (m)	Explosion centre (m)
MSE-CTR-025-MID Rationalised Scenario 01	1.0D	31.56	53.25	4.932
	1.0F	30.33	50.61	5.026
	2.6E	23.93	39.8	4.032
	3.9D	22.57	37.3	3.917
MSE-CTR-075-MID Rationalised Scenario 05	1.0D	56.31	95.06	8.778
	1.0F	54.22	89.13	9.657
	1.8B	29.59	53.08	3.055
	2.6E	46.36	75.74	8.487
	3.9D	43.34	70.74	7.972
	7.5D	35.61	59.13	6.042
MSE-CTR-075-TOP Rationalised Scenario 05	1.0D	26.76	47.19	3.169
	1.0F	29.8	51.42	4.091
	1.8B	26.54	46.13	3.481
	2.6E	27.62	47.52	3.853
	3.9D	29.35	49.6	4.552
	7.5D	31.13	50.69	5.783
MSE-CTR-110-MID Rationalised Scenario 05	1.0D	80.02	134	13.04
	1.0F	74.28	120.5	14.04
	1.8B	58.22	98.4	9.019
	2.6E	55.1	92.38	8.911
	3.9D	50.66	85.18	8.067
	7.5D	50.34	82.42	9.129
MSE-CTR-110-TOP Rationalised Scenario 05	1.0D	28.84	52.8	2.438
	1.0F	28.86	52.29	2.714
	1.8B	24.48	44.75	2.1
	2.6E	34.66	60.69	4.314
	3.9D	37.65	64.82	5.239
	7.5D	43.71	71.69	7.863
MSE-CTR-203-FBR Rationalised Scenario 05	1.0D	339.1	401	138.6
	1.0F	323.2	378.7	133.9
	1.8B	134.5	239.1	14.95
	2.6E	159.7	256.6	31.36
	3.9D	148.7	241.7	27.79
	7.5D	107	177.8	18.14

Table 37 Explosion Distances for CTM Releases

Model	Weather Category	Distance downwind to 7 kPa (m)	Max diameter (m)	Explosion centre (m)
CTM-CTR-110-MID Rationalised Scenario 01	1.0D	25.05	43.66	3.221
	2.6E	26.17	44.84	3.747
	3.9D	26.76	45.41	4.054
	7.5D	27.91	46.02	4.896
CTM-CTR-837-FBR Rationalised Scenario 01	1.0D	123	216.3	14.86
	1.0F	1298	718.5	938.8
	1.8B	96.26	174.3	9.123
	2.6E	154.1	255.5	26.33
	3.9D	161.2	264.2	29.07
	7.5D	155	251.4	29.32
CTM-CTR-837-FBR Rationalised Scenario 02	1.0D	122.9	216.2	14.84
	1.0F	1308	698	959.4
	1.8B	96.16	174.1	9.111
	2.6E	154	255.4	26.33
	3.9D	161.2	264.2	29.06
	7.5D	154.9	251.3	29.26

Table 38 Explosion Distances for EGP Releases

Model	Weather Category	Distance downwind to 7 kPa (m)	Max diameter (m)	Explosion centre (m)
EGP-CTR-075-MID Rationalised Scenario 01	1.0D	24.9	44.09	2.858
	1.0F	29.65	50.86	4.218
	1.8B	25.33	44.17	3.25
	2.6E	26.92	46.6	3.622
	3.9D	29.63	50.01	4.632
	7.5D	31.3	51.22	5.685
EGP-CTR-110-MID Rationalised Scenario 01	1.0D	22.52	41.69	1.673
	1.0F	25.27	46.24	2.152
	1.8B	25.77	46.8	2.368
	2.6E	33.6	58.77	4.212
	3.9D	36.67	62.88	5.235
	7.5D	42.09	69.06	7.559
EGP-CTR-434-FBR Rationalised Scenario 03	1.0D	91.9	165.8	8.981
	1.0F	1320	722.9	958.6
	1.8B	100.2	177.1	11.63
	2.6E	130.6	218.2	21.49
	3.9D	141.3	231.4	25.61
	7.5D	134.5	218.3	25.4

Appendix C Likelihood Analysis - Data and Results

C.1 Likelihood of Release from Underground Pipelines

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

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

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

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

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

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

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

C.1.1 Ethane

NSW Performance Report

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

UK HSE (RR1035)

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

The total leak frequency data reported in Section 7.6 of RR1035 for underground LPG pipelines is slightly more conservative (e.g. 2.1E-04 per km per year for a pipeline with wall thickness ≥ 5 mm to < 10 mm) and was adopted in the QRA for the underground HP Ethane pipeline (Refer to Table 39).

Table 39 Leak Frequencies for Underground LPG Pipelines

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

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

The data and approach included in Annex B of PD 8010-3:2009+A1:2013 was used to estimate the leak frequencies for the Moomba to Sydney Ethane Pipeline (Refer to Table 40). The data applicable for a pipeline with a wall thickness of 8.1 mm, manufactured after 1980, was used.

Leak frequency data is not reported for internal corrosion; therefore, the total leak frequencies reported in Table 40 may be underestimated.

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

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

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

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

Table 40 Approx. Leak Frequencies for Underground Ethane Pipeline

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

US Department of Transportation (DoT)

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

To enable a comparison with the UK data, the data for all Highly Volatile Liquids (Except Ammonia) was analysed and the leaks categorised using the same representative hole sizes as reported in the UK (i.e. RR1035 and PD8010). The results are reported in Table 41.

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

Table 41 Leak Frequencies for Underground HVL Pipelines (Excluding Ammonia)

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

C.1.2 Natural Gas

NSW Performance Report

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

UK HSE (RR1035)

The total leak frequency data reported in Section 7.1 of RR1035 for underground natural gas pipelines (e.g. 5.1E-05 per km per year for a ≥ 305 mm diameter pipeline with wall thickness ≥ 10 mm) is very comparable the average leak frequency from the 2018 NSW Performance Report and was adopted in the risk analysis for the HP Natural Gas pipelines (Refer to Table 42).

Table 42 Leak Frequencies for Underground Natural Gas Pipelines

Failure Mode	Pipeline Diameter (mm)	Wall Thickness (mm)	Leak Frequency (per km per yr)				
			Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	< 115	All	4.5E-04	1.0E-08	1.0E-08	1.0E-08	4.5E-04
	127 to < 273		1.5E-04	1.0E-08	1.0E-08	1.0E-08	1.5E-04
	≥ 305		8.7E-06	1.0E-08	1.0E-08	1.0E-08	8.7E-06
Corrosion	All	< 5	3.1E-04	1.0E-08	1.0E-08	1.0E-08	3.1E-04
		5 to < 10	3.3E-05	1.0E-08	1.0E-08	1.0E-08	3.3E-05
		≥ 10	1.0E-07	1.0E-08	1.0E-08	1.0E-08	1.3E-07
Ground Movement / Other	All	All	1.2E-05	2.5E-06	1.5E-07	2.5E-06	1.7E-05

Failure Mode	Pipeline Diameter (mm)	Wall Thickness (mm)	Leak Frequency (per km per yr)				
			Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
TPA	All	All	2.2E-05	2.4E-06	1.0E-07	1.0E-07	2.5E-05
Total Leak Frequency =	≥ 305	≥ 10	4.3E-05	4.9E-06	2.7E-07	2.6E-06	**5.1E-05**
% =			84.6	9.7	0.5	5.2	

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

The data and approach included in Annex B of PD 8010-3:2009+A1:2013 was used to estimate the leak frequencies for the HP Natural Gas Pipelines (Refer to Table 43 and Table 44). The data applicable for pipelines with a wall thickness > 10 mm to ≤ 15 mm was used.

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

The leak frequency for external corrosion is reported to be 0 for pipelines with a wall thickness > 10 mm to ≤ 15 mm. Leak frequency data is not reported for internal corrosion; therefore, the total leak frequencies reported in Table 43 and Table 44 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 pipelines (i.e. location, design factor, wall thickness and depth of cover).

Table 43 Approx. Leak Frequencies for Jemena Eastern Gas Pipeline (EGP)

Failure Mode	Approx. Leak Frequency (per km per yr)				
	Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	1.7E-05	0.0E+00	0.0E+00	0.0E+00	1.7E-05
Corrosion	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ground Movement / Other	2.8E-07	2.8E-07	2.8E-07	2.2E-08	8.7E-07
TPA	3.8E-05	2.5E-05	1.3E-05	8.6E-05	1.6E-04

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
Total Leak Freq. =	5.5E-05	2.6E-05	1.3E-05	8.6E-05	**1.8E-04**
% =	30.8	14.3	7.2	47.8	

Table 44 Approx. Leak Frequencies for Jemena Gas Network (CTM) Trunk Pipeline

Failure Mode	Approx. Leak Frequency (per km per yr)				
	Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	1.7E-05	0.0E+00	0.0E+00	0.0E+00	1.7E-05
Corrosion	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ground Movement / Other	2.3E-07	2.3E-07	2.3E-07	6.8E-08	7.5E-07
TPA	1.3E-05	8.8E-06	4.4E-06	1.8E-05	4.4E-05
Total Leak Freq. =	3.0E-05	9.0E-06	4.6E-06	1.8E-05	**6.2E-05**
% =	49.3	14.6	7.5	28.6	

US Department of Transportation (DoT)

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

To enable a comparison with the UK data, the data for underground transmission pipelines was analysed and the leaks categorised using the same representative hole sizes as reported in the UK (i.e. RR1035 and PD8010). The results are reported in Table 45.

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

Table 45 Leak Frequencies for Underground Natural Gas Transmission Pipelines

Failure Mode	Approx. Leak Frequency (per km per yr)				
	Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	2.2E-06	5.4E-07	2.7E-07	0.0E+00	3.0E-06
Corrosion	9.7E-06	0.0E+00	2.7E-07	0.0E+00	9.9E-06
Ground Movement / Other	4.0E-06	1.1E-06	0.0E+00	2.7E-07	5.4E-06
TPA	3.2E-06	7.0E-06	4.0E-06	4.0E-06	1.8E-05
Total Leak Freq. =	1.9E-05	8.6E-06	4.6E-06	4.3E-06	**3.7E-05**
% =	52.2	23.5	12.5	11.8	

C.1.3 Likelihood of Representative Release Scenarios

The estimated likelihood of each representative release scenario is listed in Table 46, Table 47 and Table 48.

Table 46 Release Frequency – Ethane Pipeline

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

Table 47 Release Frequency – Jemena Eastern Gas Pipeline (EGP)

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

Table 48 Release Frequency – Jemena Gas Network Central Trunk Main (CTM)

Leak Scenario	Release Frequency (per km per year)			
	TPA	All Other Failure Modes	Total Release Frequency	
10mm MID		2.08E-05	2.08E-05	0.4110
10mm TOP		0.00E+00	0.00E+00	0.0000
25mm MID	2.20E-05		2.20E-05	0.4347

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

C.2 Ignition Probability

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

Ethane

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

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

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

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

Natural Gas

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

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

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

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

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

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

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

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

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

Table 49 Ignition Probability - UKOPA

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

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

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

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

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

Table 50 Ignition Probability – OGP Scenario 3

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

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

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

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

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

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

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

(1) Not otherwise reportable under this section;

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

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

(4) Cleaned up promptly;

(c) Death of any person;

(d) Personal injury necessitating hospitalisation;

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

Table 51 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 52 Ignition Probability – UK HSE (RR 1034)

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

(1) For example: ethylene

(2) For example: butane, ethane and propane

(3) For example: ammonia, carbon monoxide

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

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

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

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

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

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

P_{ign} = probability of ignition

p = pipeline operating pressure (bar)

d = pipeline diameter for ruptures (m)

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

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

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

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

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

Table 53 Ignition Probability – Acton & Baldwin

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

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

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

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

Table 54 Ignition Probability – EGIG

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

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

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

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

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

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

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

Table 55 Ignition Probability – UK HSE (RR 1034)

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

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

Table 56 Ignition Probability – Data Cited by UK HSE (RR 1034)

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

	All sizes	0.03

Appendix B

Indicative SMS Attendance List

Indicative SMS Attendance List

Below is a listing of the typical participants that would be present in a SMS. The list is not exhaustive, and can be added to, as required.

Position	Organisation
SMS Facilitator	Independent Consultant
Project Manager	Developer
Principal Planner/Designer	Developer
Construction Manager (Detailed Design SMS only)	Developers Constructor
Senior Strategic Planner	Council
Coordinator Development Infrastructure	Council
Precinct Structure Planning Coordinator	Utility Provider
Risk Engineer	Pipeline Licensee
Lands Office	Pipeline Licensee
Project Development Engineer	Pipeline Licensee
Senior Urban Planner	Pipeline Licensee

Appendix C

AS2885 - Classification of Locations

Classification of Locations

In order to determine the location class, the Standard AS2885 requires that the population, activities, and environment be assessed within a distance described as the "measurement length (ML)" from the centre of the pipeline. For gas pipelines in particular, where the most serious outcome is either injury or fatality due to radiation from an ignited gas leak, the measurement length is deliberately and conservatively defined in AS 2885.1, Cls 4.3.2 as the radius of the 4.7 kW/m2 radiation contour for an ignited full-bore rupture calculated in accordance with Clause 4.10. Clause 4.10 states that the calculation is to assume that the pipeline is at Maximum Allowable Operating Pressure (MAOP) at the time of release. A full-bore rupture is a hole which is equivalent to the diameter of the pipeline.

It is important to understand that the measurement length is used to define the corridor around the pipeline that must be considered to determine location classification, regardless of whether a full-bore rupture at MAOP is credible or not.

As is required by the Standard, consideration has been given to future development along the pipeline route both within and outside the pipeline measurement length when assessing the pipeline classification.

For any given location classification, AS 2885 defines minimum compliance requirements. As the consequence of a pipeline failure increases and location classification changes, the requirements of AS 2885 become more stringent. The various Location Classes under the Standard are outlined below

AS2885.1-2012 gives four primary location classes:

Location Class	Description
R1 - Rural	Land that is unused, undeveloped or is used for rural activities such as grazing, agriculture and horticulture.
R2 - Rural Residential	Land that is occupied by single residence blocks typically in the range 1 to 5 ha.
T1 - Residential	Residential applied where multiple dwellings exist in proximity of other dwellings and are surveyed by common public utilities.
T2 - High Density	Multi storey dwellings where a large number of people congregate

In addition, AS2885.1-2018 gives five secondary location classes:

Location Class	Description
S – Sensitive Use	where consequences of a failure may be increased due to use by a community unable to protect themselves from consequences of pipeline failure. Schools, hospitals, aged care facilities and prisons within the pipeline measured length are examples of this classification. The requirements are as for T2.
I – Industrial	Manufacturing, processing, maintenance, storage, or similar activities. These are assigned to any portion of land immediately adjoining the pipeline. The requirements are for T1.
HI – Heavy Industrial	Heavy industry or toxic industrial use. Require assessment of any threats to the pipeline or may cause pipeline failure to escalate. Depending on assessment R2, T1 or T2 may apply.
CIC – Common Infrastructure Corridor	Multiple infrastructure development within a common easement or reserve or in easements which are in close proximity. A CIC secondary classification places the following requirements on the pipeline owner/operator - To control the activities that take place in the CIC easement some form of agreement should be in place.

Appendix D

Threats & Controls

Threats & Controls

Threat Identification Prompts	
Category	**Threat**
External Interference	Excavation - related to construction
	Excavation - without consent
	Excavation - private landowners post construction (e.g., ploughing, ripping, or trenching)
	Power augers and drilling
	Cable installation ripping & ploughing
	Pipeline access for maintenance activities
	Installation of posts or poles
	Land use development - pavement works, road surfacing &/or grading
	Land use development - landscaping
	Deep ploughing or drilling around pipeline (horizontal)
	Vehicle or vessel impact - during construction
	Vehicle or vessel impact - during ongoing use of the road
	Vehicle or vessel impact - rail
	Vehicle or vessel impact - aircraft crash
	Damage from bogged vehicles or plant
	External loads from backfill or traffic
	Blasting
	Blasting - seismic survey for mining using explosives
	Anchor dropping & dragging
	Other - soil testing with penetrometer
	Other - methane from contaminated land ignited by site works (e.g., welding)
	Other - creeping movement of slope (geotechnical risk)
	Other - loading from the buildings
	Other - Vibration due to piling
Corrosion	External corrosion or erosion due to environmental factors
	Internal corrosion due to contaminants
	Internal erosion
	Environmentally assisted cracking / stress corrosion cracking
	Bacterial corrosion
	Other - stray current corrosion
	Other - CP testing performed incorrectly and potential for corrosion.
	Other - low frequency induction from parallel HV power lines or earthing bed

Category	Threat
Natural Events	Earthquake
	Ground movement - land subsidence, soil expansion / contraction
	Ground movement - land subsidence causing breakage of water
	pipelines in region of gas pipe
	Wind and cyclone
	Bushfires
	Lightning
	Flooding or inundation
	Erosion of cover or support
	Other – tsunami or volcanic eruption
Operations & Maintenance	Exceeding MAOP of pipeline
	Incorrect operation of pigging
	Incorrect valve operating sequence
	Incorrect operation of control & protective equipment
	Bypass of logic, control or protection equipment followed by incorrect
	manual operation
	Fatigue from pressure cycling
	Inadequate or incomplete maintenance procedures
	Maintenance actions contrary to procedures
	Incident due to inadequate, incorrect, or out of date operating or
	maintenance procedures
	Inadequate servicing of equipment
	Other - inaccurate test equipment, leading to incorrect settings
	Other - overpressure control system failure
	Other - pipe vibration (e.g., underground due to road works)
	Other - failure to adequately manage and implement changes to assets
	Other - incident caused due to project records, as built records and
	installed material records being lost, ignored, or not maintained
	Other - inaccurate measurement equipment or equipment not calibrated
	Other - inadequate emergency management
	Other - live welding
Design Defects	Incorrect material, component, and equipment characteristics
	Incorrect design or engineering analysis
	Failure to define correct range of operating conditions
	Failure of design configuration and equipment features to allow for safe
	operations & maintenance
	Other - design for corrosion
	Other - stresses in places that are not earth anchored areas

Category	Threat
Material Defects	Incorrectly identified components
	Incorrect specification, supply, handling, storage, installation, or testing
	Under-strength pipe
	Manufacturing defect
	Lack of adequate inspection & test procedures
Construction Defects	Undetected of unreported damage to the pipe, coating, or equipment
	Undetected or unreported critical weld defects
	Failure to install the specified materials or equipment
	Failure to install equipment using the correct procedures or materials
	Failure to install equipment in accordance with the design
	Failure to install the pipeline in the specified location or manner
	Inadequate testing of materials for defects prior to handover
Intentional Damage	Sabotage / Terrorism / Malicious Damage / Vandalism
Other - environmental	Soil excavation
	Ground water and soil contamination from fuel and other chemicals used
	on site during construction
	Escape of liquid fuel to ground water and soil contamination

External Interference Protection – Physical Controls		
Control	Methods	Examples
Separation	Burial	
	Exclusion	Fencing
	Barrier	Bridge crash barriers
Resistance to penetration	Wall thickness -	
	Barrier to penetration	Concrete slabs Concrete encasement Concrete coating

External Interference Protection – Procedural Controls		
CONTROL	**METHODS**	**EXAMPLES**
PIPELINE AWARENESS -	LANDOWNER	
	THIRD PARTY LIAISON	LIAISON PROGRAM INCLUDING ALL RELEVANT PARTIES
	COMMUNITY AWARENESS PROGRAM	
	ONE-CALL SERVICE	
	MARKING	SIGNAGE / BURIED MARKER TAPE
	ACTIVITY AGREEMENTS WITH OTHER ENTITIES	
EXTERNAL INTERFERENCE DETECTION	PLANNING NOTIFICATION ZONES	PLANNING NOTIFICATION REQUIRE BY LAW

	PATROLLING	SYSTEMATIC PATROLLING OF THE PIPELINE
	REMOTE INTRUSION MONITORING	DETECTION AND ALARM BEFORE THE PIPELINE IS DAMAGED

Appendix E

AS2885 Part6 Risk Assessment

AS2885 Part6 Risk Assessment

The AS2885 Risk Assessment we used to undertake any risk assessments is provided below

TABLE 3.1

SEVERITY CLASSES

Dimension	Severity class				
	Catastrophic	Major	Severe	Minor	Trivial
	Measures of severity				
People	Multiple fatalities result	One or two fatalities; or several people with life-threatening injuries	Injury or illness requiring hospital treatment	Injuries requiring first aid treatment	Minimal impact on health and safety
Supply (see Note)	Widespread or significant societal impact, such as complete loss of supply to a major city for an extended time (more than a few days)	Widespread societal impact such as loss of supply to a major city for a short time (hours to days) or to a localized area for a longer time	Localized societal impact or short-term supply interruption (hours)	Interruption or restriction of supply but shortfall met from other sources	No loss or restriction of pipeline supply
Environment	Impact widespread; viability of ecosystems or species affected; or permanent major changes	Major impact well outside PIPELINE CORRIDOR or site; or long-term severe effects; or rectification difficult	Localized impact, substantially rectified within a year or so	Impact very localized and very short-term (weeks), minimal rectification	No effect; or minor impact rectified rapidly (days) with negligible residual effect

NOTE: Appendix G provides guidance on assessment of consequence severities.

3.5.3 Frequency analysis

A frequency class shall be assigned to each FAILURE SCENARIO. The frequency class shall be selected from Table 3.2.

The contribution of existing controls to the prevention of failure shall be considered in assigning the frequency class.

NOTE: Appendix F provides guidance on estimating frequencies.

TABLE 3.2

FREQUENCY CLASSES

Frequency class	Frequency description
Frequent	Expected to occur once per year or more
Occasional	May occur occasionally in the life of the pipeline
Unlikely	Unlikely to occur within the life of the pipeline, but possible
Remote	Not anticipated for this pipeline at this location
Hypothetical	Theoretically possible but would only occur under extraordinary circumstances

3.5.4 Risk ranking

Table 3.3 shall be used to combine the results of the consequence analysis and the frequency analysis to determine the risk rank.

Use of the risk matrix in Table 3.3 is mandatory for SAFETY MANAGEMENT STUDIES in accordance with this Standard. Other methods such as a corporate risk matrix may be used only in parallel with Table 3.3 or as part of a separate corporate RISK ASSESSMENT.

TABLE 3.3

RISK MATRIX

	Catastrophic	Major	Severe	Minor	Trivial
Frequent	Extreme	Extreme	High	Intermediate	Low
Occasional	Extreme	High	Intermediate	Low	Low
Unlikely	High	High	Intermediate	Low	Negligible
Remote	High	Intermediate	Low	Negligible	Negligible
Hypothetical	Intermediate	Low	Negligible	Negligible	Negligible

NOTE: Comparative studies sponsored by the Energy Pipelines Cooperative Research Centre have shown that for risks ranked as Intermediate, Table 3.3 produces results consistent with both reliability-based analysis (in accordance with Annex O of CSA Z662-07) and quantitative risk assessment. Use of a different risk matrix or method that has not been similarly calibrated may produce invalid results.

3.6 RISK TREATMENT

3.6.1 General

Action to reduce risk shall be taken in accordance with Table 3.4, based on the risk rank determined from Table 3.3.

The action(s) taken and the planned effect on risk shall be documented.

3.6.2 Risk treatment during design

Risk treatment actions at design stage may include the following:

(a) Relocation of the pipeline route.

(b) Modification of the design for any one or more of the following:

  (i) PIPELINE SYSTEM isolation.

  (ii) PHYSICAL CONTROLS for prevention of external interference.

  (iii) PROCEDURAL CONTROLS for prevention of external interference.

  (iv) Corrosion prevention.

  (v) Operational controls.

TABLE 3.4

RISK TREATMENT ACTIONS

Risk rank	Required action
Extreme	Modify the THREAT, the frequency or the consequences so that the risk rank is reduced to Intermediate or lower. For an in-service pipeline, the risk shall be reduced immediately.
High	Modify the THREAT, the frequency or the consequences so that the risk rank is reduced to Intermediate or lower. For an in-service pipeline, the risk shall be reduced as soon as possible. Risk reduction should be completed within a timescale of not more than a few weeks.
Intermediate	Repeat THREAT identification and risk evaluation processes to verify the risk estimation; determine the accuracy and uncertainty of the estimation. Where the risk rank is confirmed to be "intermediate", where reasonably practicable modify the THREAT, the frequency or the consequence to reduce the risk rank to "low" or "negligible". Where it is not reasonably practicable to reduce the risk rank to "low" or "negligible", action shall be taken to— (a) remove THREATS, reduce frequencies and/or reduce severity of consequences to the extent practicable; and (b) formally demonstrate ALARP (see Section 4). For an in-service pipeline, the reduction to "low" or "negligible" or demonstration of ALARP shall be completed as soon as possible. Risk reduction or demonstration of ALARP should be completed within a few months.
Low	Determine the management plan for the THREAT to prevent occurrence and to monitor changes that could affect the classification.
Negligible	Review at the next relevant SMS (for periodic operational review, LAND USE CHANGE, ENCROACHMENT, or change of operating conditions).

3.6.3 Risk treatment during operation and maintenance

Risk treatment actions at operating pipeline stage may include one or more of the following:

(a) Installation of additional or modified PHYSICAL CONTROLS.

(b) Additional or modified PROCEDURAL CONTROLS.

(c) Specific actions in relation to identified activities (e.g. presence of operating personnel during activities on the easement).

(d) Modification to pipeline marking.

(e) Changes to the isolation plan.

(f) Changes to the PIPELINE SYSTEM design or operation to satisfy the requirements of this Standard when there is a change to the LOCATION CLASS of the pipeline.

(g) Specific operational or maintenance procedures.

(h) Repair, remediation or removal of a condition or DEFECT that presents a THREAT.

THREAT treatment for operating PIPELINE SYSTEMS should consider interim control measures (e.g. reduction in operating pressure, access restrictions) to allow time for the implementation of permanent control measures (e.g. repair).

Appendix F

Mark Harris – Relevant Experience

Background of 3rd Party Reviewer – Mark Harris

Mark Harris is a process safety and risk assessment professional with 33+ years of process design experience in the Oil & Gas Industry and 22+ years of process safety leadership and facilitation experience.

Mark has been facilitating AS2885 pipeline safety management studies for the likes of APA, Jemena, Santos, AGL, Esso, Beach Energy, BHP, Epic Energy, Senex, DBNGP, SEAGas, QGC, APLNG, GLNG and has been consulting to industry, developers, councils and government authorities on the application of AS2885 in the planning and development process.

Summary List of Relevant Project Experience:-

Expert Advice and Witness - West Australian Planning Commission (WAPC), Perth WA:

Mark has provided independent expert advice to the WAPC in an encroachment dispute between a Developer and a Pipeline Licensee. Services included interviewing all parties and providing considered opinions on matters relating to the application of the Australian Pipeline Standard AS2885.

As part of his independent role, Mark was later invited to lead the Safety Management Study associated with this project on behalf of the WAPC and State Administrative Tribunal.

AS2885 Advisory Support to the Victorian Planning Authority

Mark has facilitated multiple Pipeline SMS's for various VPA future land developments including most recently the Arden Structure Plan and continues to provide advisory support on the application of AS2885 with respect to pipeline encroachment and planning permits in Victoria.

SMS 5 yearly Review of Victorian Onshore Assets – ESSO, Victoria

Mark prepared and facilitated a portfolio of 5 yearly SMS studies for all of ESSO's onshore pipelines (16 in total). Mark undertook a detailed review of existing data and past assessments along with changes in land use in preparation for an AS2885 5 yearly review Workshop of the pipeline assets as part of Esso's wider Safety Case requirements.

Principal Risk Reviewer, Western Sydney Green Gas Project (WSGGP), (Jemena), NSW

Mark undertook multiple independent risk reviews of the Jemena Western Sydney Green Gas Project reviewing the Company Risk Management Plan, the Project Risk Management Plan and the Project Risk Register to ensure all risks are being addressed to plan and actions are being addressed by competent, experienced engineers in a discoverable way. Mark was engaged to undertake a second round of reviews for detailed design including a process design review of the proposed design as well as the application of NSW HIPAPs Guidelines on Construction Safety.

Principal Risk Reviewer, Malabar Biomethane Injection Project (MBIP), (Jemena), NSW

Mark has been engaged to undertake multiple independent risk reviews of the Jemena Malabar Biomethane Injection Project reviewing the Company Risk Management Plan, the Project Risk Management Plan and the Project Risk Register to ensure all risks are being addressed to plan and actions are being addressed by competent, experienced engineers in a discoverable way.

Project Risk Facilitator – BIPS Gas Pipeline Connection Project (AGL), SA:

Mark was engaged to facilitate several project risk workshops associated with connection of a new gas supply line from the existing Torrens Island Facility to the new Barker Inlet Power Station (BIPS).

SMS Study Walla Walla Solar Farm Development (FRV/SMEC/Transgrid/APA), NSW:

Mark led the SMS for the Solar Farm Development encroachment on the existing APA Pipeline.

SMS Study Pakenham East PSP Development (Cardinia Council/APA), Vic:

Mark led the SMS for the Pakenham East PSP encroachment on the existing APA and Origin Pipelines.

SMS Study Wallan East PSP Development (Mitchell Shire Council/APA/VPA), Vic:

Mark led the SMS for the Wallan East PSP encroachment on the existing Pipeline.

SMS Study Clyde North PSP Development (City of Casey Council/APA/VSBA/DET), Vic:

Mark led the SMS for the Clyde North PSP encroachment on the existing APA Pipeline.

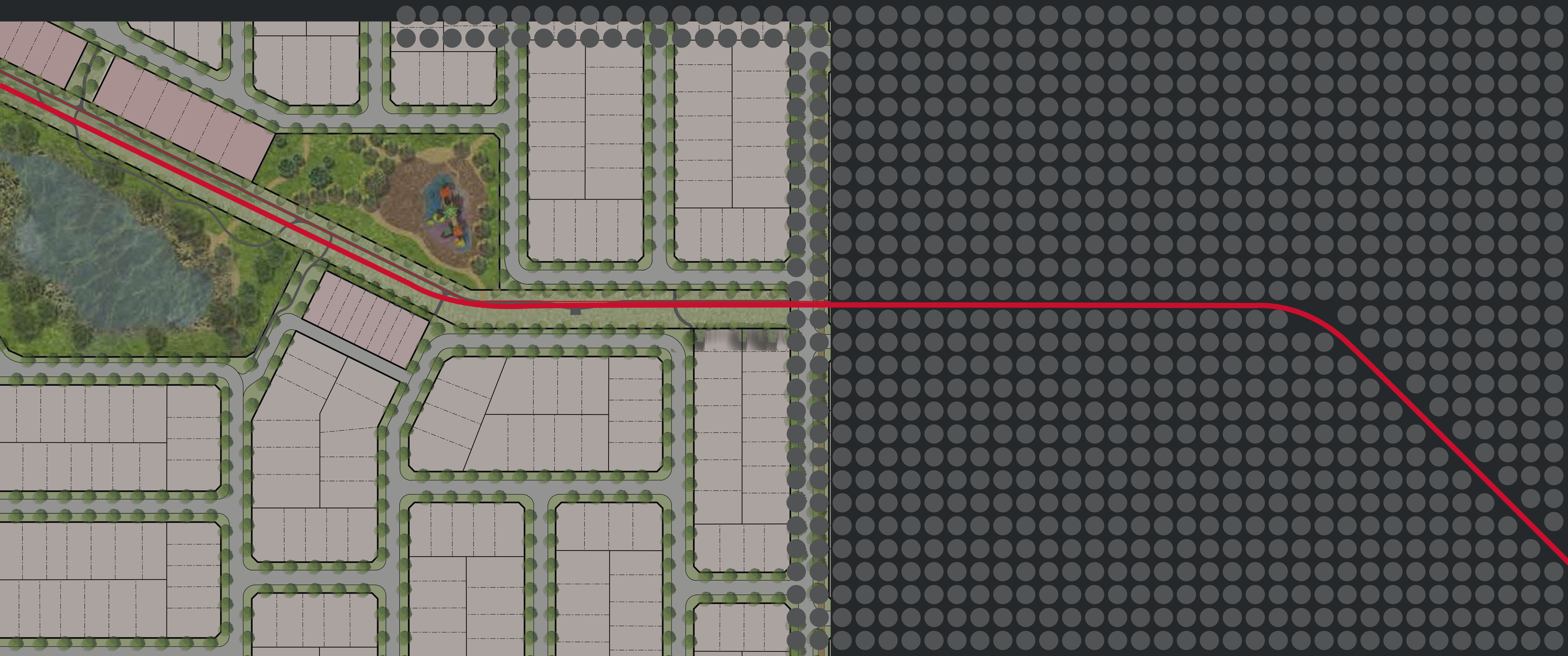
SMS Study Ballan South PSP Development (Moorabool Shire Council/APA/VPA), Vic:

Mark led the SMS for the Ballan South PSP encroachment on the existing APA Pipeline.

Appendix G

APA Site Planning and Landscape National Guidelines

site planning + landscape
national guidelines



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energy. connected.

Member of the Surbana Jurong Group

contents

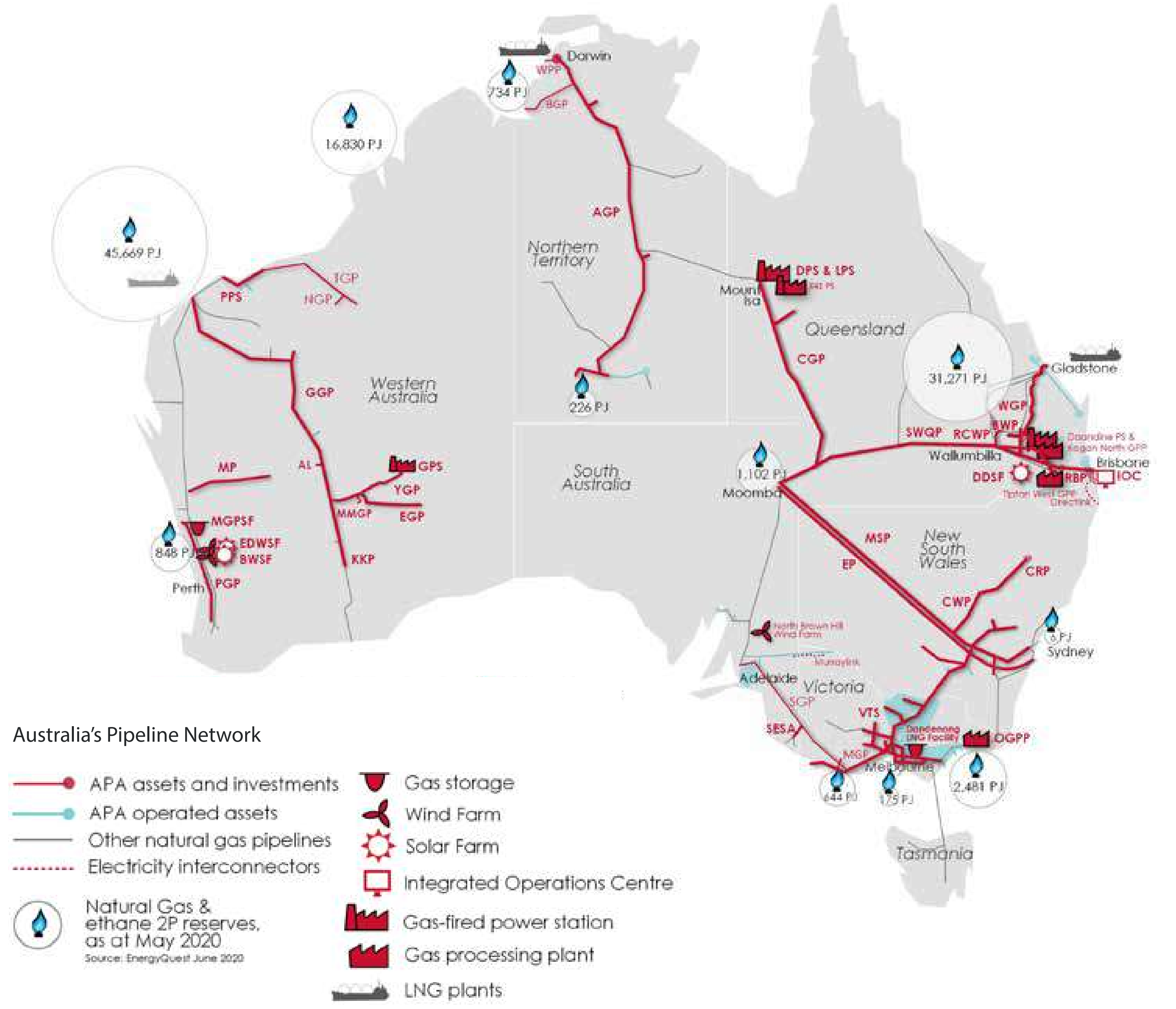
1
introduction.

apa and its role

APA Group (APA) is Australia's largest natural gas infrastructure business with gas transmission pipelines spanning across Australia to deliver approximately half of the nation's gas.

Gas transmission pipelines are regulated under federal, state and local legislation and statutory requirements. These requirements help protect the pipeline from external interference and ensure the integrity of the pipeline and the safety of the surrounding community.

APA's pipelines are designed, constructed, operated and maintained in accordance with Australian Standards (AS 2885 Pipelines – gas and liquid petroleum). While APA has direct management and operational control over its assets and investments, it is a critical role for APA to manage any emerging risks in keeping with AS 2885.



purpose of this document

Australian high pressure gas pipelines have an excellent safety record, but as land use changes around them, due to increasing urban growth across Australia, the risk to pipeline safety also becomes greater.

APA transmission pipelines are increasingly coming into contact with land development projects. Therefore, these guidelines have been created to steer planners and developers towards the best ways to incorporate the pipelines and their associated safety requirements in the design phase of any planning scheme or development.

This document clarifies APA's minimum requirements for landscape and urban design in areas where transmission pipelines exist.

Adherence to these Guidelines does not exempt the developer from meeting the requirements of the relevant environment, access and safety legislation as well as AS2885 and local Council requirements.

These guidelines contain specific information on how to plan and design around APA transmission pipelines and achieve the best outcomes and safety for urban developments.

how to use these guidelines

These guidelines set out APA's expectations for site planning, urban design and landscape outcomes and should be consulted in the early stages of the planning and design process to guide the preparation of masterplans for subdivisions.

This document will inform landscape architects of the required conditions and general rules for the installation of landscape hard elements (like paths, pavements, furniture, signage, etc) and soft elements like planting within an easement.

These guidelines are applicable to all development types including residential, commercial and industrial.

Landscape Design Professionals:

All planning applications involving the development of an area adjacent to an APA easement should include a professionally prepared landscape plan. Lists of qualified landscape architects are available from:

The Australian Institute of Landscape Architects
Ph (02) 6248 9970 http://www.aila.org.au

2

apa easements & urban growth areas.

apa
easements

APA assets are generally located within easements ranging from 7 to 35 metres in width. Easements provide protection of APA's assets (pipelines) and ensure:

- APA has preserved the opportunity to looping pipelines in the future.
- APA is able to access the pipeline for working and maintenance purposes.
- Access for patrols.

For the purpose of these guidelines a typical 20m wide easement with a single pipeline 6m in from one boundary has been assumed. Whilst typical, there are numerous variations to these dimensions across APA assets.

A 20m easement with one pipeline has the potential for another pipeline in the future. For the purpose of these guidelines the future pipeline is assumed to be 6m from the opposite side of the easement.

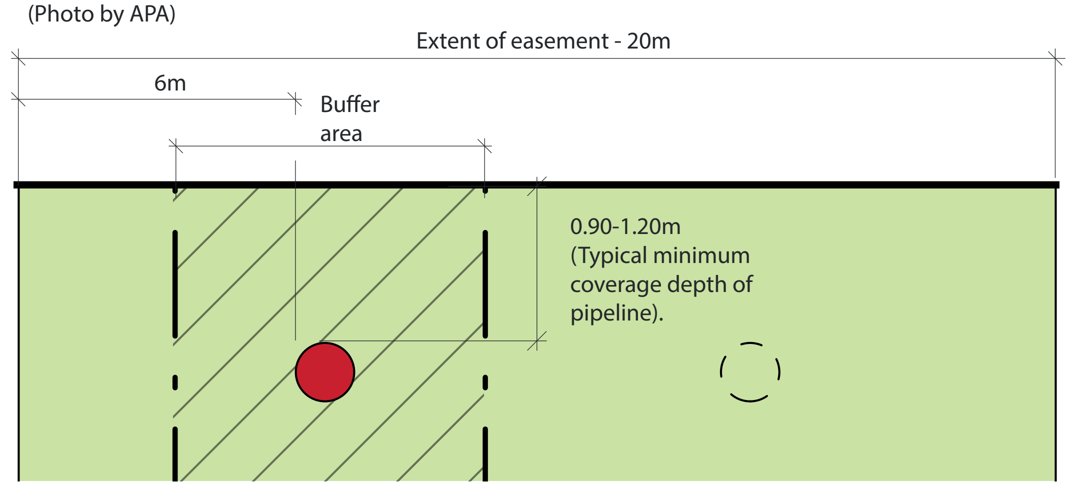
The larger vacant side of the easement which is likely to be used for future looping of the pipeline is called the "live side" of the easement.

Easements are typically linear following the pipeline alignment, so if there is a change of direction in the pipeline (corner) then the easement will follow.

All easements will have pipeline marker posts installed within line of sight of each other and as close as possible to the pipeline. Their primary purpose is identifying and warning of the existence of underground gas assets.

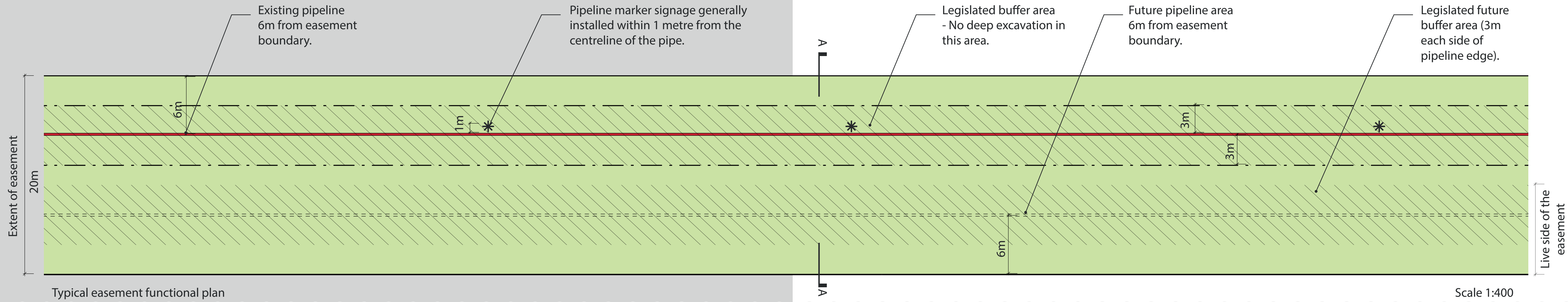
Refer to chapter 4 landscape guidelines for further information.

Signage post along pipeline
(Photo by APA)



Typical easement cross section (AA)

Scale 1:200



Typical easement functional plan

Scale 1:400

preferred outcomes

APA pipeline easements can provide a great opportunity to increase open spaces and green amenities within new urban areas. With the ongoing pressure to urbanise peri-urban and rural areas, there is no doubt that green corridors can add value for growing communities and also be a marketing differential for new developments.

It is APA's preferred position that the easements are designed to be linear green spaces and that these spaces will ultimately become council public reserves and opens spaces.

Precedent image

Landscaped areas with sculptures

Precedent image

Potential for long view lines and long green corridors

Precedent image

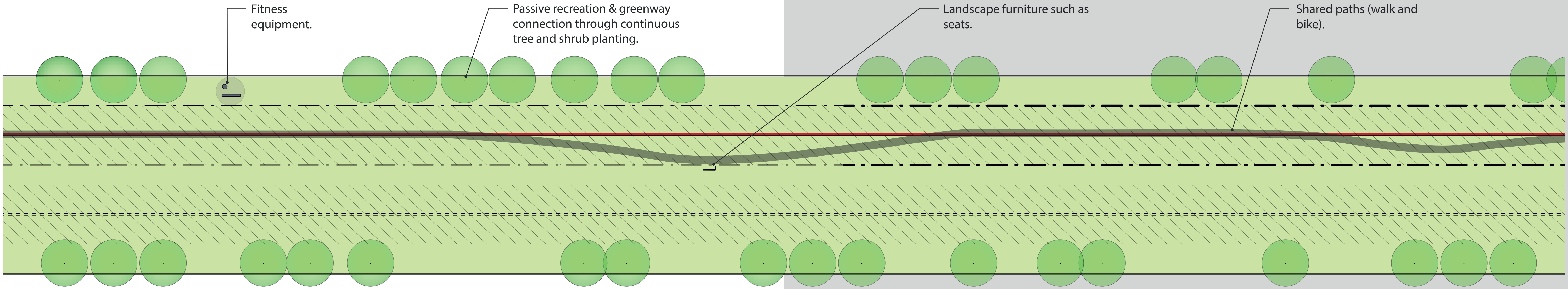
Easement corridors with landscape treatment combined with reserves

Precedent image

Potential to expand and connect shared path network

Precedent image

Expansive grass and low planting areas



Indicative easement plan - with landscape treatment

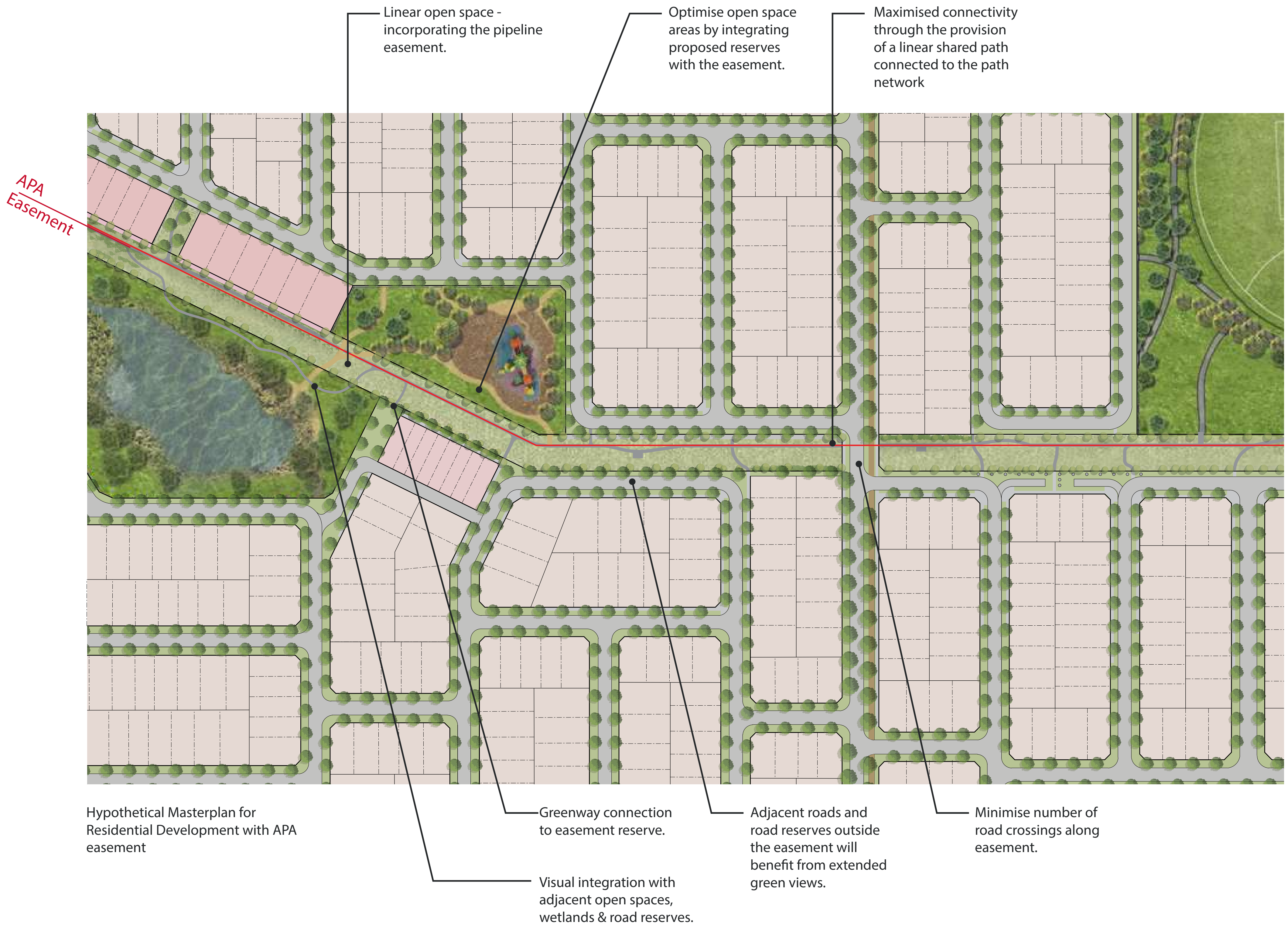
Scale 1:400

3
urban design guidelines.

urban design criteria

APA easements can be integrated into urban development projects in many different ways. The identification of an existing APA easement and pipeline corridor in the early stages of planning and urban design will result in better outcomes. The following key criteria should be considered when planning and designing around and within APA easements:

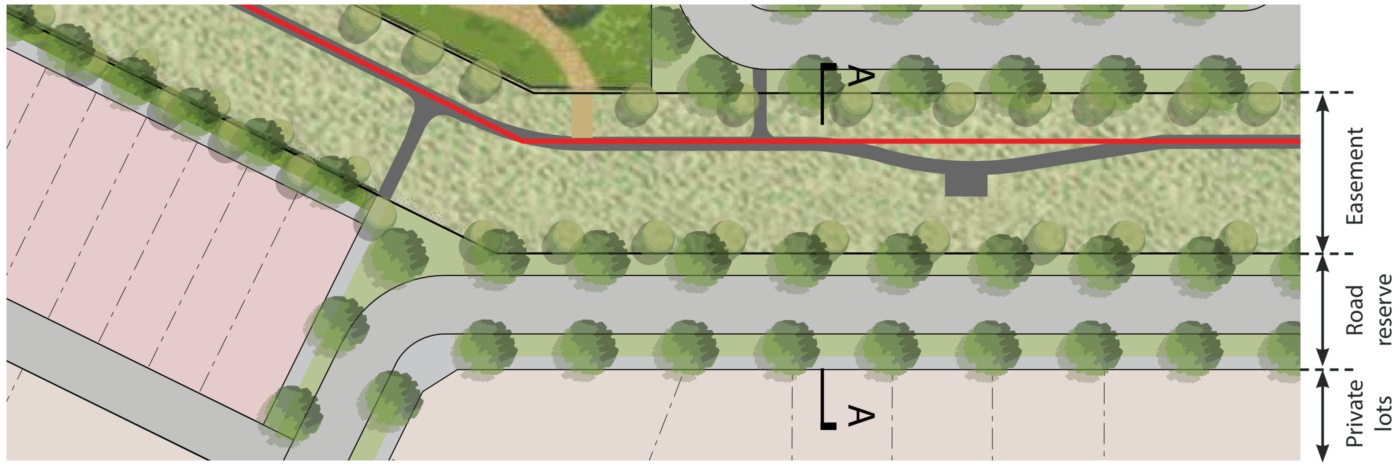
- The primary purpose of the easement is for the transmission of gas through existing and future gas transmission infrastructure.
- The easement and warning signage are statutory safety features pursuant to Australian Standard 2885. They are a fundamental tool in ensuring the safe operation of the transmission network, compliance with the relevant safety standards and provide for the safety of the public and assets from implications of a pipeline failure.
- Create a liner landscape reserve that runs the full length of the gas pipeline easement.
- Optimise passive recreation uses of the gas pipeline easement through the provision of a connective shared pathway network.
- Possibility for visual integration of gas pipeline easement into adjacent passive open spaces, drainage reserves, wetlands, retarding basin areas and road reservations.
- Minimised number of crossing and extent of road pavement over the pipeline easement.
- Roads and road reserves are to be located outside of the easement, except where there is a 90 degree road crossing.
- Service infrastructure (e.g. drains, other utilities etc) are not permitted to be located within the easement except at crossings.
- 'Easements on easements' is an unacceptable outcome except for infrastructure crossings.
- APA may require that a Construction Management Plan (CMP) be prepared to address any road crossings and works over the pipeline (including landscaping works), however this can be incorporated within any CMP required by Council.
- After works in the vicinity of APA's pipeline are completed, APA will issue a statement of compliance (where applicable) on request from the developer.



Hypothetical Masterplan for Residential Development with APA easement

design examples

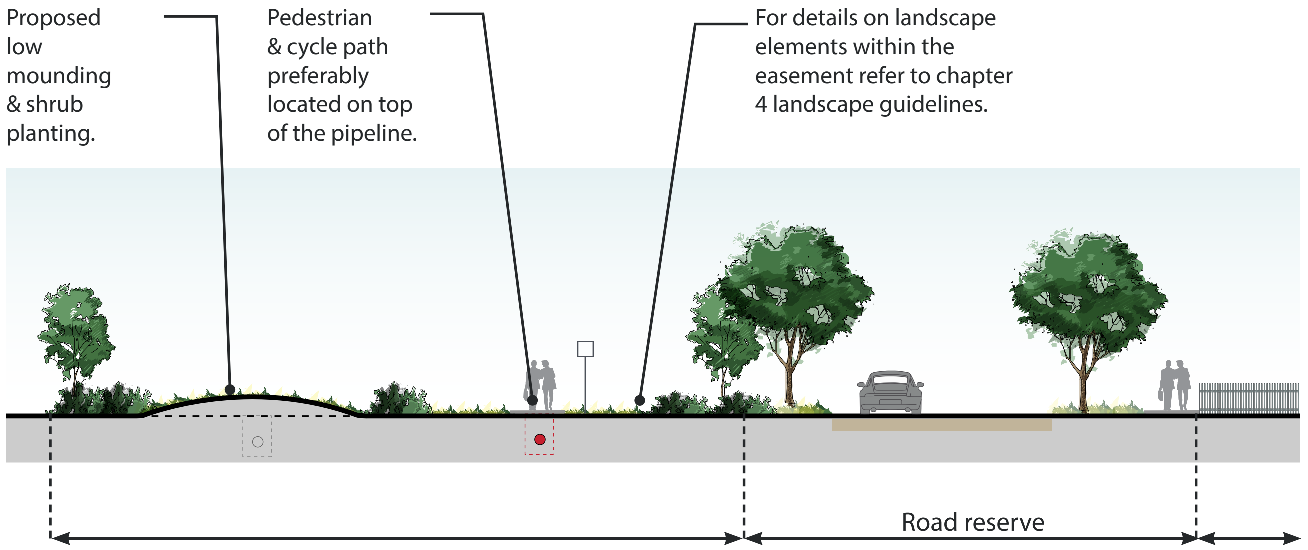
Road frontage interface



Typical plan

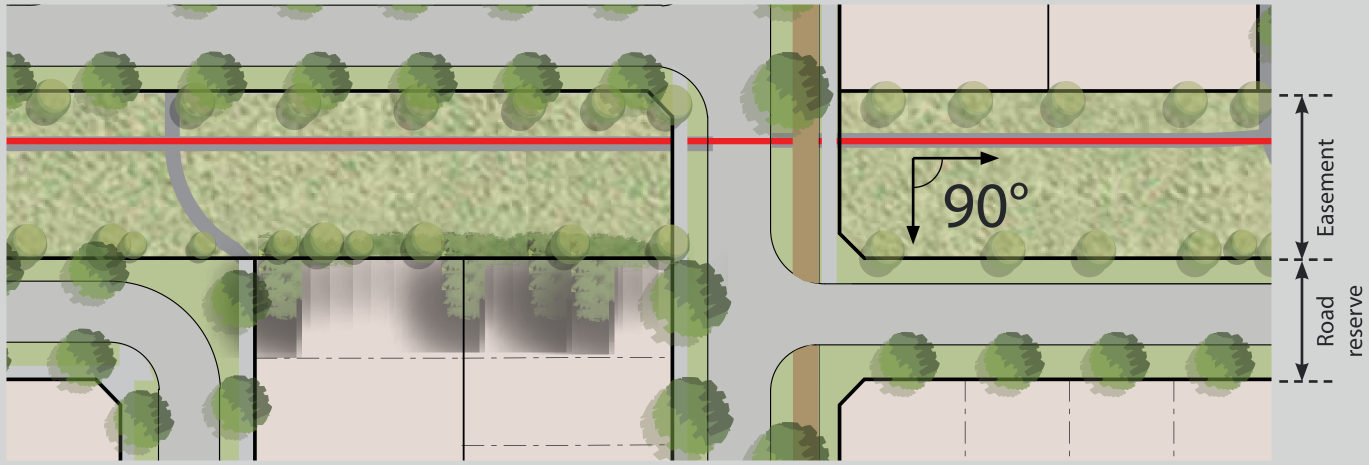
APA does not allow streets to be located over its easements other than road crossings.

Roads and road reserves can be located alongside APA easements but not encroaching into it. The easement can provide a visual " connection" of the road reserve nature strip.



Typical cross section

Road crossing



Typical plan

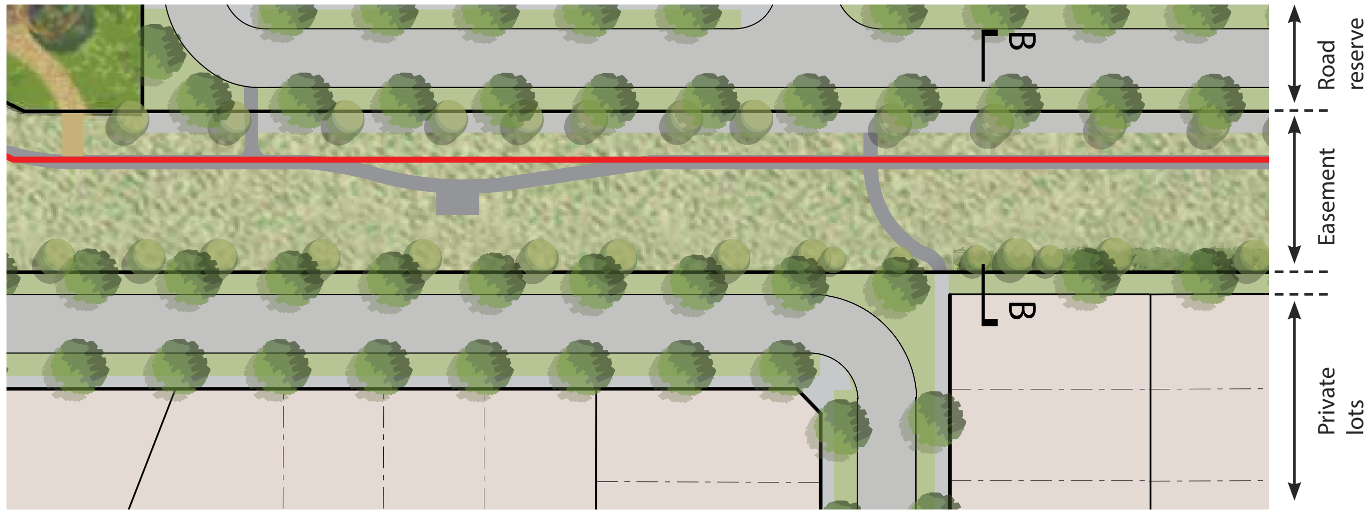
APA allows for roads and streets to cross the easement. Crossings should be at 90 degrees to the easement alignment. It is APA's preference to reduce the number of crossing points and refer to local design criteria guiding typical urban block lengths.

The cost associated with crossing the pipeline should be taken into consideration. The potential protective measures such as slabbing, proving and possible recoating costs, can be significant which the proponent needs to be aware of and account for.

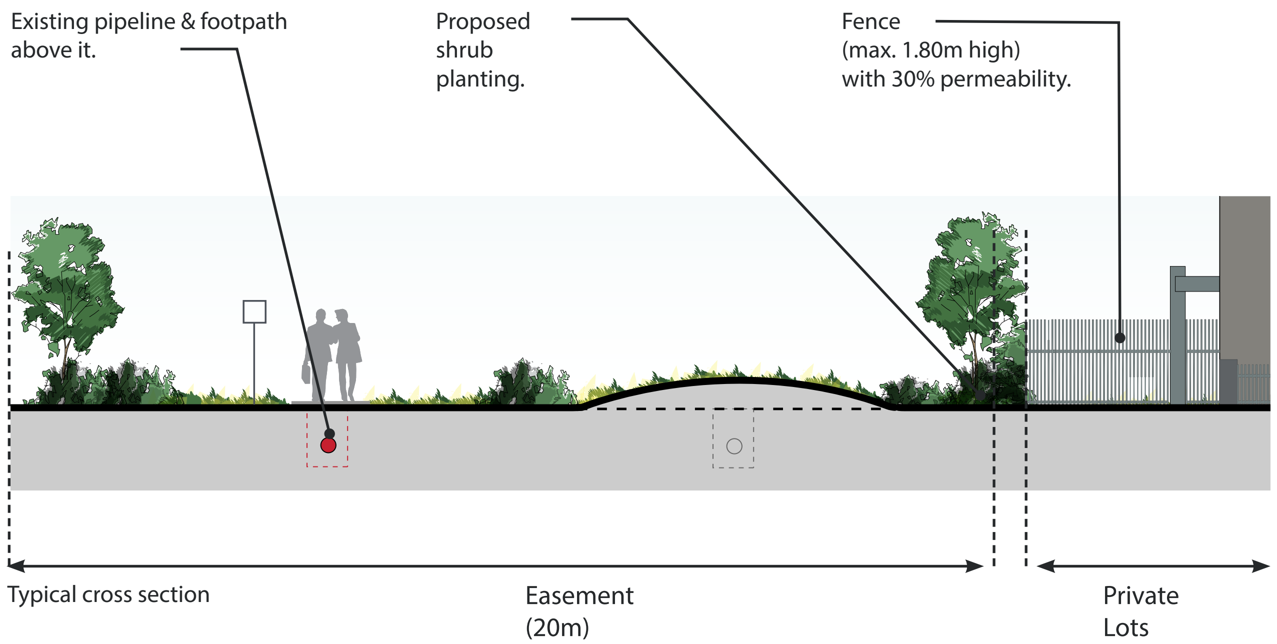
Typically infrastructure including utility crossing points should be grouped. APA strongly discourages the parallel co-location of other services within its easements and will only consider a proposal to do so in exceptional circumstances. Road and services crossings are subject to APA's third party works approval process.

Minimum depth of cover to the top of pipeline is typically between 0.90-1.20m. Refer to chapter 4 - landscape guidelines on page 26 for details. Any works over the pipeline will require the pipeline to be positively proved to confirm its exact depth and location.

Side fence interface

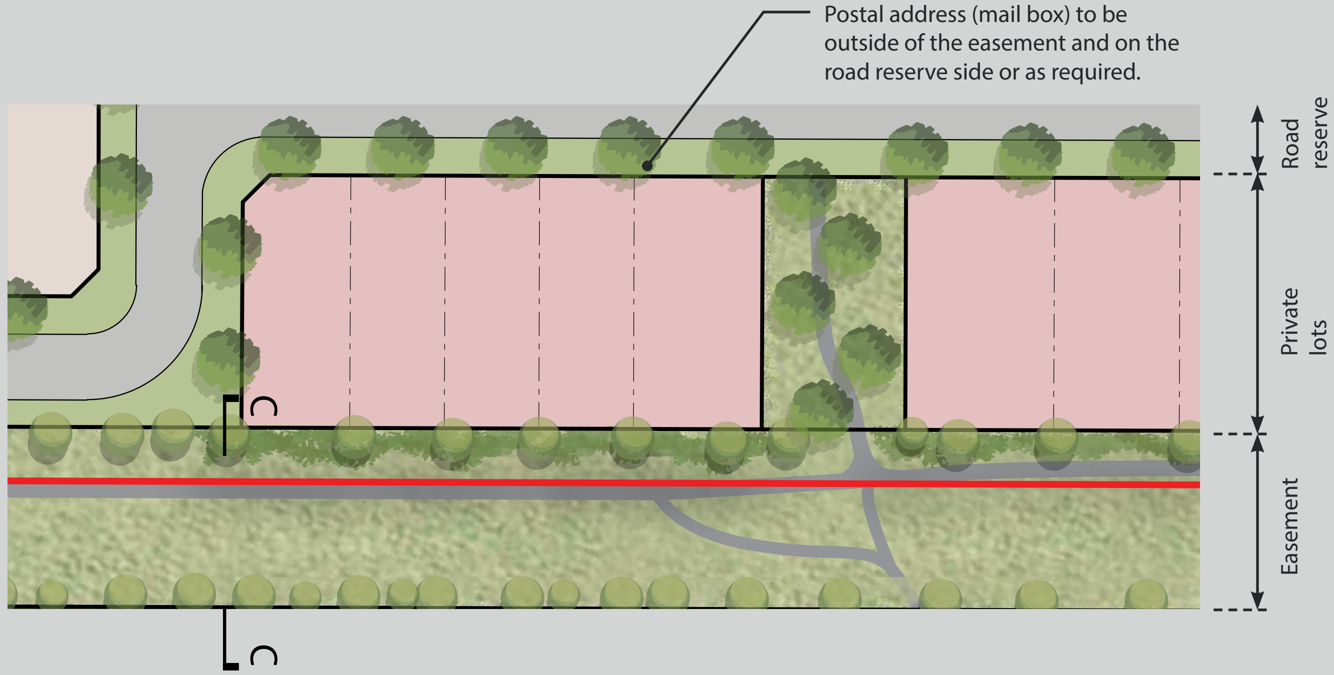


Typical plan

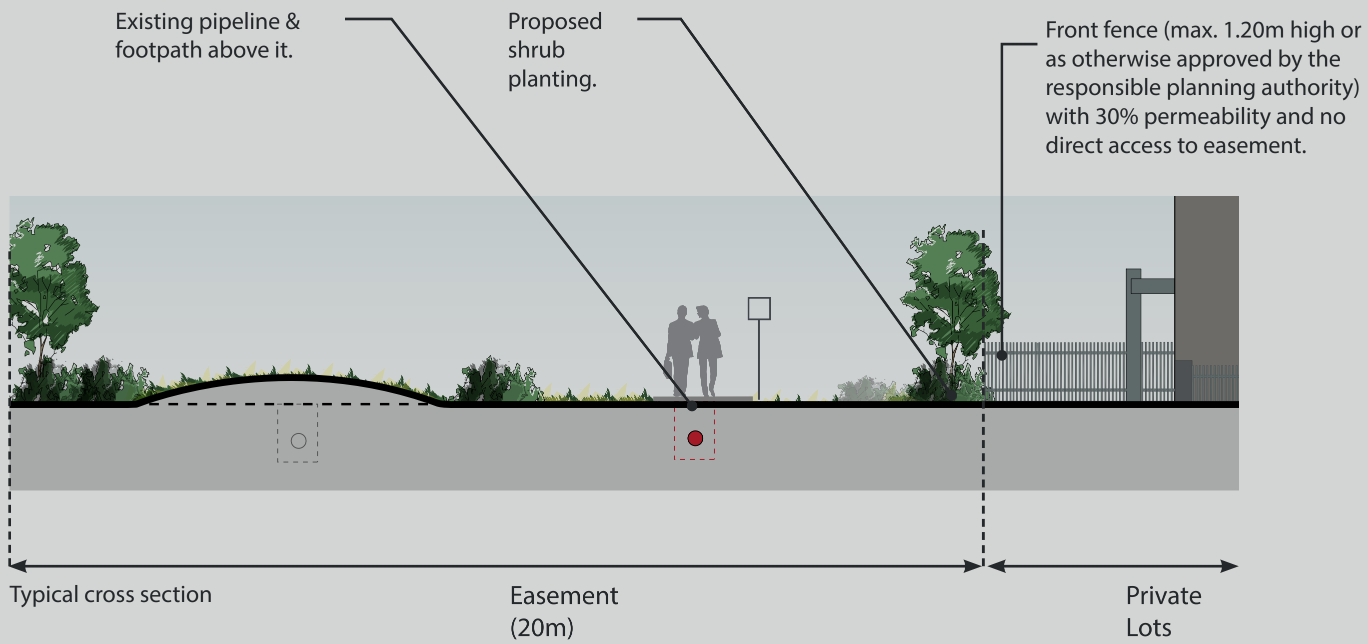


Typical cross section

Double fronted lots interface

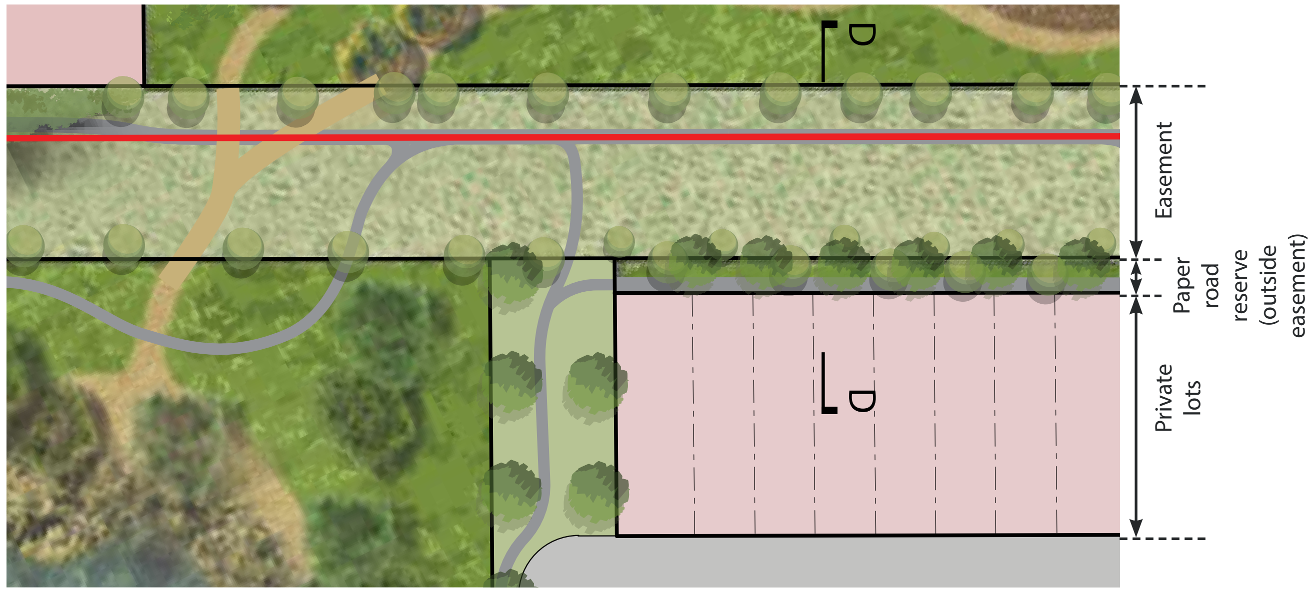


Typical plan

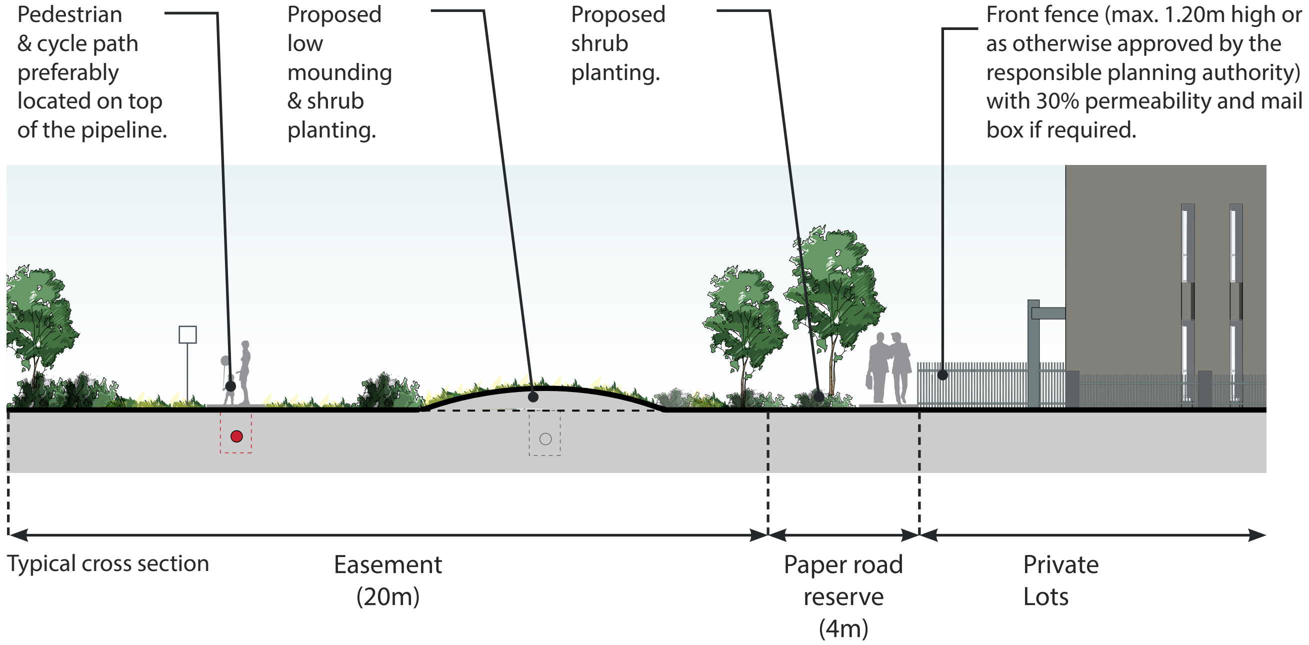


Typical cross section

Terrace interface

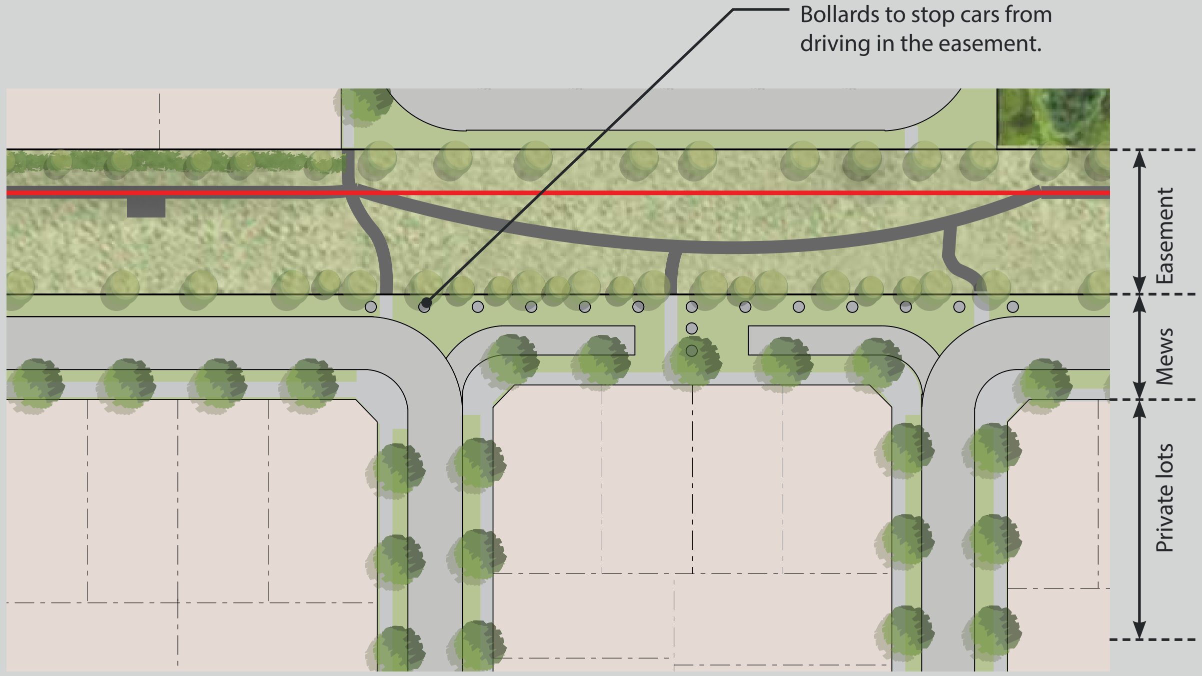


Typical plan



Typical cross section

Mews interface



Typical plan

4

landscape design guidelines.

landscape design criteria

The following general criteria apply to all landscape design and works within easements, regardless of location and context:

- Shared paths are acceptable within the easement to optimise connectivity within the development.
- Paths to be mostly located on top of the pipeline, acknowledging that in order to achieve good design outcomes some meandering of the path may be accepted.
- Potential opportunity for artworks and other hard infrastructure (eg. benches) to be installed in selected locations and integrated within the landscape.
- Select landscaping species which ensure unobstructed views between pipeline indicator markers and avoid any impact on existing subterranean pipe infrastructure and likely future pipeline routes.
- Selected plant species list to be agreed with APA.
- Landscaping and hardscaping outcomes must be mindful of future council and APA maintenance requirements and cost.

Refer to the next sections in this chapter on pages 18-28 for detailed guidelines on landscape design.

Hypothetical easement reserve with landscape treatment illustration

landscape design within apa easements

Pipeline markers & sight line preservation

All APA easements have Pipeline Markers installed along their entirety. Pipeline Markers have the primary purpose of identifying and warning of the existence of underground gas assets. Pipeline Markers will provide an emergency contact number. It is imperative that line of sight between markers exists so that the pipelines alignment is visible and can be evaluated from the ground.

Pipeline Markers will be placed at intervals in accordance with the Location Classes of the pipeline as determined by AS2885:

Residential
Land that is developed for community living. Markers to be spaced at a maximum of 100m intervals.

High Density
Land that is developed for high density community use. Markers to be spaced at a maximum of 50m intervals.

Industrial and Heavy Industrial
Land that is developed for Industrial and heavy industrial use. Markers are to be spaced at a maximum of 100m intervals.

In addition to the spacing outlined above, Pipeline Markers will also be located at:

- Both sides of road, track or rail crossings.
- Utility crossings both above and below ground (where physically practical).
- Change in topography (where a cumulative change may impact on line of sight).
- Change of pipe direction (where physically practical).
- Property boundaries.

Markers are typically located directly above the pipeline or within 1m from the pipeline's edge. If not possible e.g. due to a road, footpath etc they are offset to the nature strip closest to the pipeline, but located so as to be visible from one another.

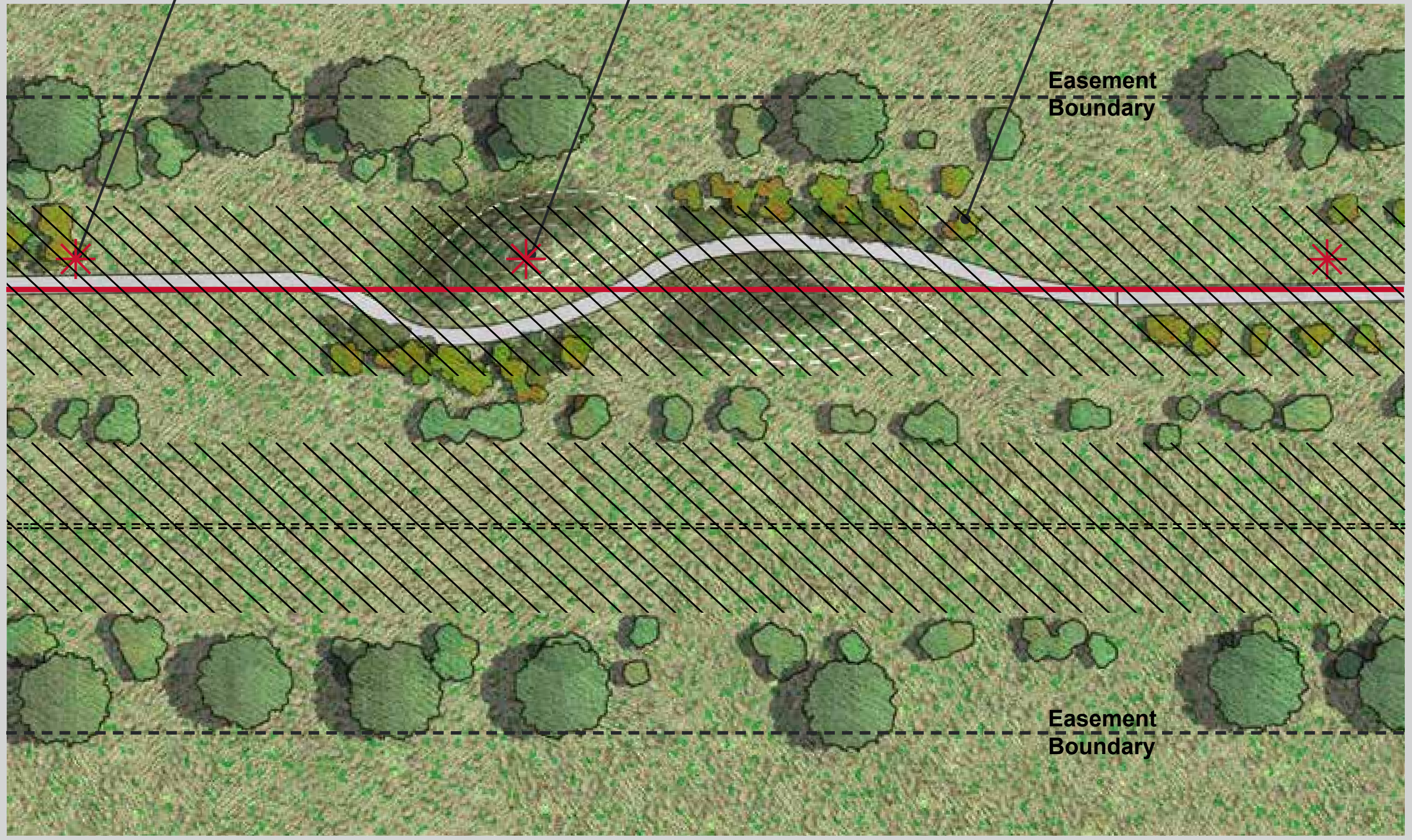
Vegetation and landscape furniture must be carefully considered and selected so it will not obstruct sightlines between markers. Refer to the section "Furniture and Planting" on page 20 for further information.

Consecutive pipeline markers must remain clearly visible. (Photo by APA)

Each pipeline marker to be visible from previous marker.

Markers to be placed when change of topography occurs.

Low planting only on marker alignment to not obstruct sight line.



20m Wide easement linear reserve - Typical plan

Clear zones and offset requirements

Excavation works
Excavations will be considered within the 3 metre buffer area, like pedestrian and cycle paths and roads crossing perpendicular to the pipeline alignment. Refer to chapter 3 Urban Design guidelines on page 13 for further information on road crossing.

The minimum cover of depth required from top of pipe to surface level is typically between 0.90 - 1.2 metres, as per Australian Standard AS 2885, and this cover needs to be maintained at all times unless an alternative protective measure is put in place to the satisfaction of APA. Prior to works this depth needs to be physically confirmed and proved on site, as in many instances surface levels change over time.

Excavation works within the easement or 3m of the pipeline edges,where no easement exists, will require APA third party approval and site supervision by an APA officer.

Landscape furniture & lighting:
Landscape furniture like seats and picnic tables can potentially be installed on the easement and will be subject to third party approval by APA.

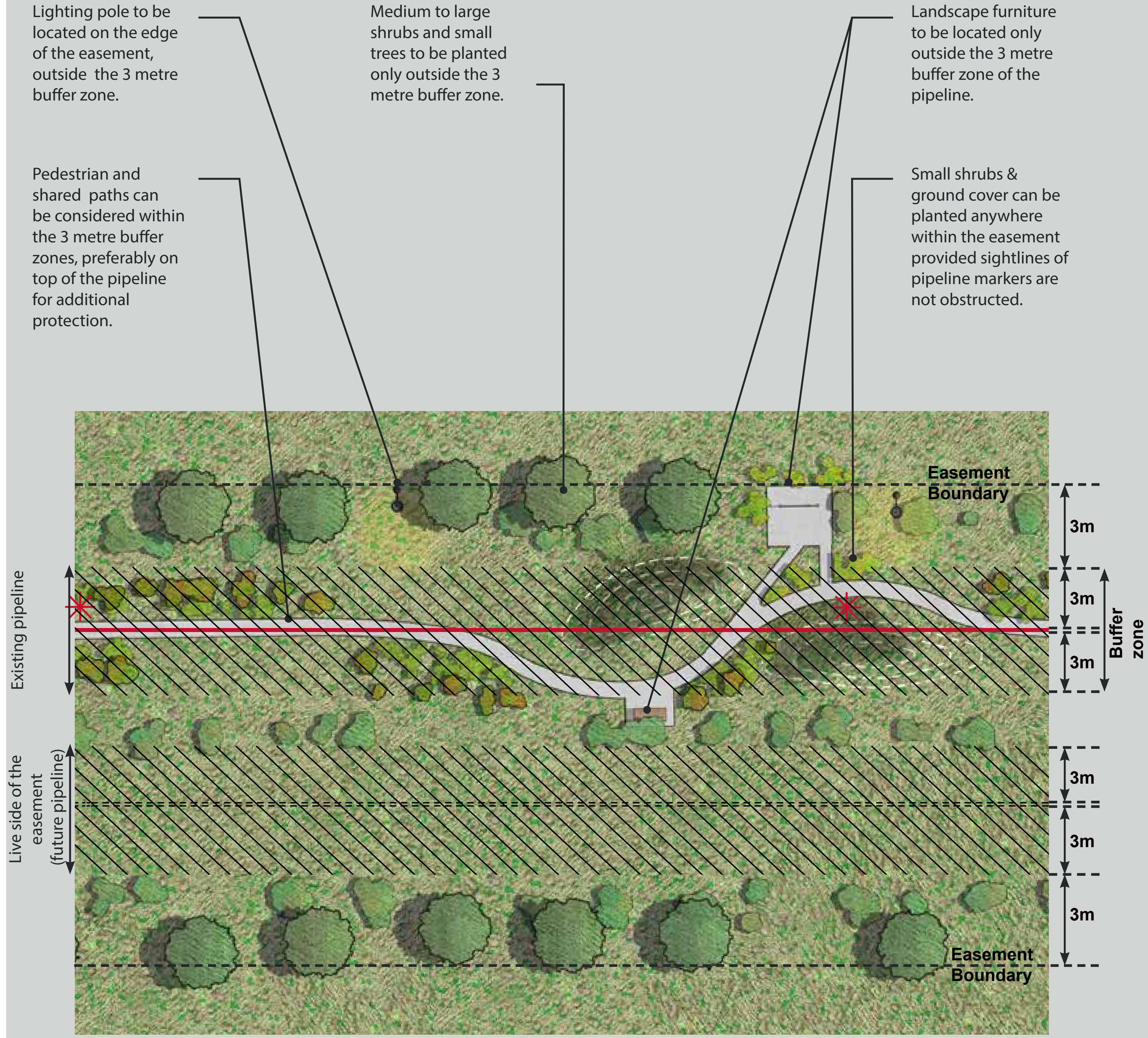
Significant larger landscape structures such as small shelters or pergolas and fitness equipment can be proposed on the easements, outside of the 3m buffer area, however it will be assessed by APA on a case by case basis.

Likewise lighting poles can be proposed and would have the same requirements as described above.

Planting:
Small trees and medium/large shrub planting will be considered on the easement, however they should be located outside of the 3m buffer area on either side of the pipeline and preferably not on the live side of the easement.

Small shrubs, groundcovers with limited size root balls and lawn can be installed in any location on the easement.

Refer to the section 'Planting' on page 21 for further information.



20m Wide easement linear reserve - Typical plan

Paths and hard surfaces

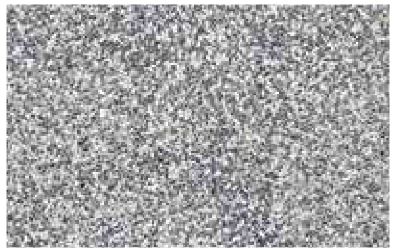
Material selections

Hard paved areas

Hard paved areas can be either paths and seating areas, and will be constructed in:

- Broom finish concrete
- Exposed aggregate and coloured concrete
- Any other finishes agreed with APA

Broom finish concrete



Exposed aggregate concrete

Gravel areas & edge

A cement stabilised, compacted gravel path can be used as an alternative to a hard paved treatment. Gravel paths can have timber or steel edges.

Gravel

Timber edge

	Recomended size	Material	Maximum depth of excavation
Paths	2.5m wide pedestrian & bike path	Concrete/ gravel	200mm
Other paved areas	Size of furniture + additional 300mm on each side	Concrete (so furniture can be bolted to it)	200mm

Steel edge

Furniture

Furniture selection

Simple furniture and feature elements can be proposed within the landscape design for APA easements (subject to approval), such as:

- Seats and benches
- Rubbish bins
- Sculptures
- Bike racks
- Directional signage
- Fitness equipment

Fitness equipment

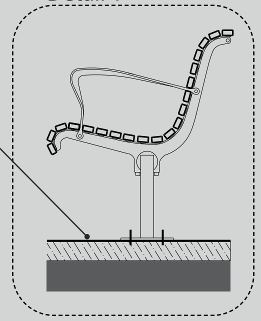
Seat & benches

Rubbish bin

Bike racks

Furniture location

Detail 1

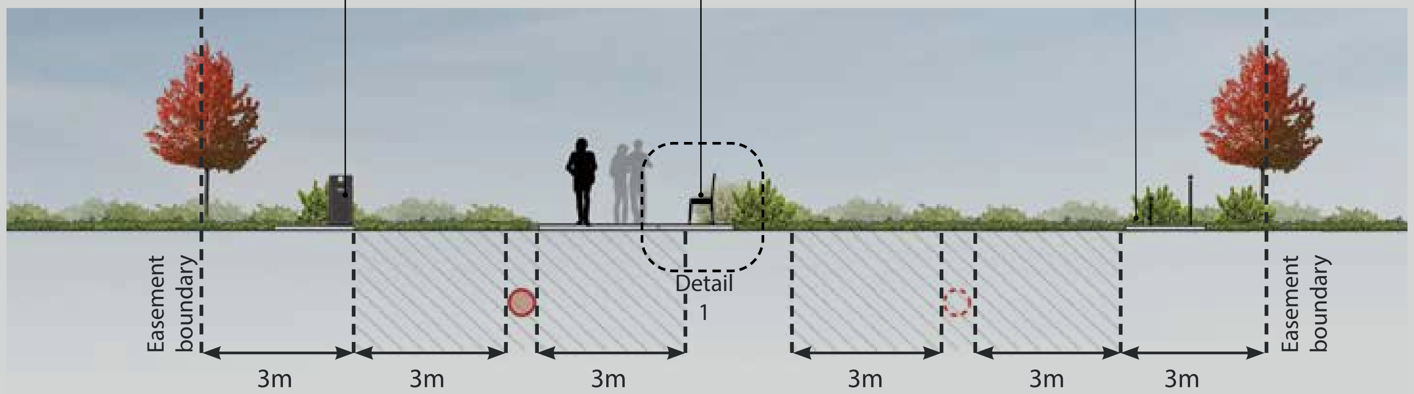


All furniture to be installed on the concrete pad by bolt fixing.

Rubbish bin on concrete pad outside the 3m buffer area.

Park furniture on concrete pad outside of the buffer area.

Fitness equipment on concrete pad outside of the buffer area.



20m Easement reserve & furniture location - Typical section

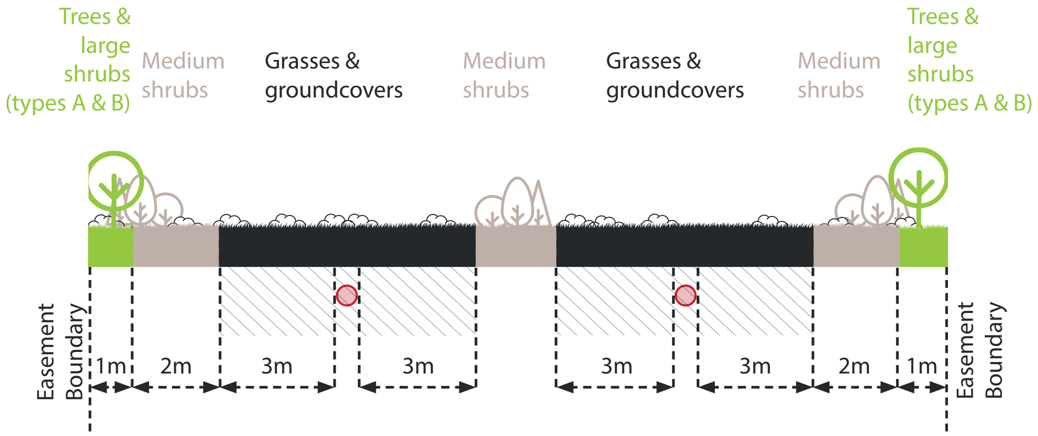
Planting

Planting is an important component of landscape design and good visual outcomes can be achieved within the easements with a well planned planting design.

Planting selection

Grass, small shrubs and groundcovers are permitted within APA easements. Small trees and large shrubs might be permitted however the key issues for consideration are:

- Be careful not to spread weeds.
- Choose appropriate plants for your area.
- For the purpose of pipeline accessibility, medium/small trees and large shrubs must be installed outside of the 3m buffer area.
- Small trees can be considered on the live side of the easement if located close to its edge.
- Proximity of tree roots can disband pipeline protective coating, which creates a risk to the pipeline. Also, roots wrapping around the pipeline can damage the pipeline in the event of tree removal.
- Ensure that trees and large shrubs do not obscure the visibility of marker posts from one another.
- Explore the possible use of root barriers as an option if appropriate.
- Applicants to clearly show information about maximum size of root balls, maximum tree growth on landscape plans for APA to review.
- It is APA's preference that higher vegetation is not installed on the 'live side' of the easement.



Planting selection & locations - Typical diagram

Tree & large shrub selection
Type A

Small trees and large shrubs should adhere to the specification below:

	Mature Height	Mature Canopy Diameter	Mature root ball diameter
Maximum size	8m	5m	5m

Species example

Acer platanoides 'Crimson Sentry'
Agonis flexuosa burgundy
Acmena smithii sublime
Banksia marginate
Corymbia citriodora dwarf
Callistemon viminalis
Tristaniopsis laurina 'luscious'
Lagerstroemia sp
Liquidambar styraciflua 'Golden sun'
Koelreuteria paniculata
Fraxinus griffithii

Corymbia citriodora dwarf

Callistemon viminalis

Fraxinus griffithii

Tree & large shrub selection
Type B

Tall trees and shrubs can be selected if they have a rootball with a small diameter, as specified below;

	Mature Height	Mature Canopy Diameter	Mature root ball diameter
Maximum size	12m	3m	3m

Species examples

Betula pendula fastigiata
Cedrella sinensis
Grevillea baileyana
Pyrus calleriana capital / edgewood
Syzygium australe pinnacle

Cedrella sinensis

Betula pendula 'fastigiata'

Pyrus calleriana 'Capital'

Planting

Medium & small shrubs selection:

	Mature Height	Mature Diameter	Mature root ball
Maximum size	2.5m	3m	2m

Species examples

Correa alba
Acacia cognata 'Limelight'
Callistemon viminalis 'Captain Cook'
Goodenia ovata
Rhagodia spinescens
Westringia naringa

Westringia naringa

Rhagodia spinescens

Ground cover & Grasses selection selection:

	Mature Height	Mature Diameter	Mature root ball
Maximum size	0.7m	1.5m	-

Species examples

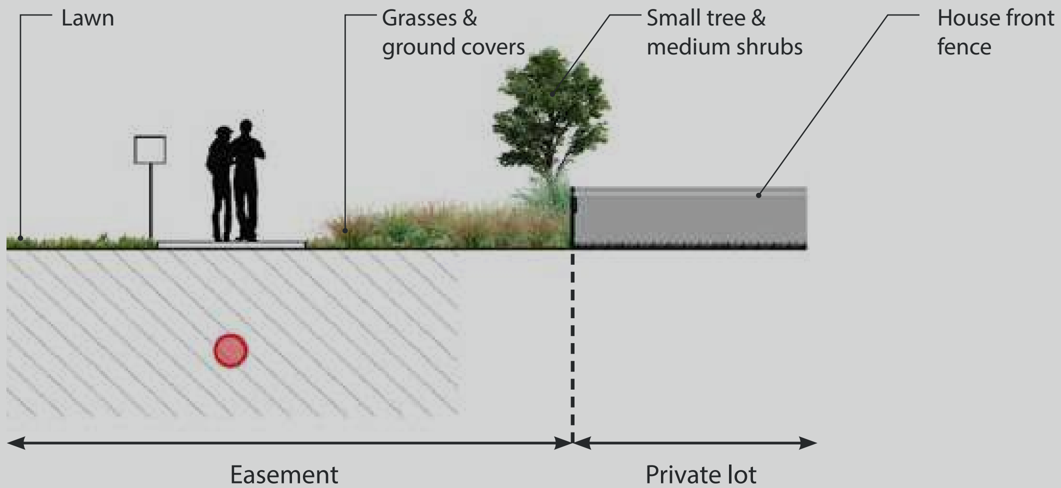
Myoporum parviflora
Dianella sp
Liriope sp
Carex testacea
Isolepis nodosa
Carpobrotus rossii
Rosemary officinalis prostrate
Hibbertia scandens
Grevillea 'Poorinda royale mantle'

Myoporum parviflora

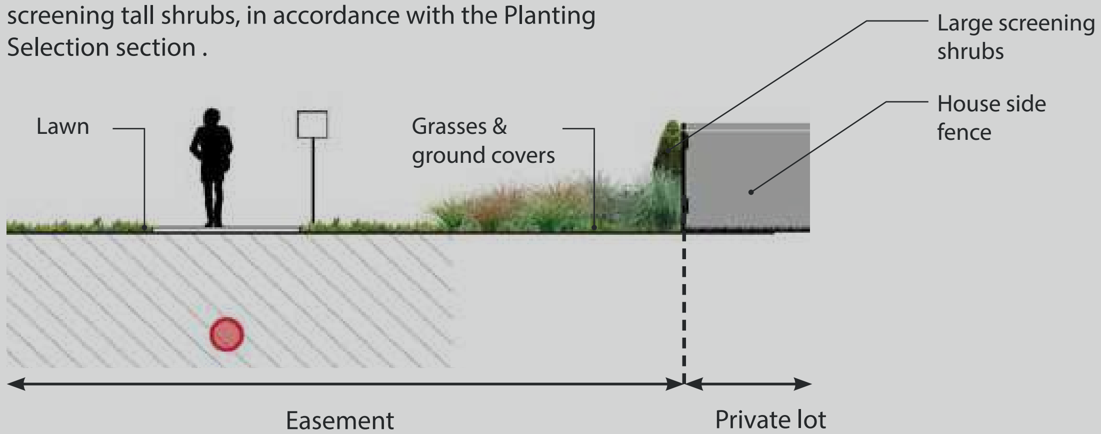
Carpobrotus rossii

Planting design

- Planting palettes are to be in accordance with the specifications provided on the Planting Selection section and will be subject to APA's approval.
- Planting design at the easement should respond to the proposed landscape design of adjacent areas (e.g. extending the visuals from adjacent parklands and streetscapes using the same trees if possible, and not blocking the views with large and medium shrubs at the easement boundary with those areas).
- Planting design at the easement should be cognisant of adjacent uses and building context (when applicable, e.g. by maintaining lower planting when adjacent to house frontage fences and not blocking solar light with trees and large shrub planting when adjacent to housing).



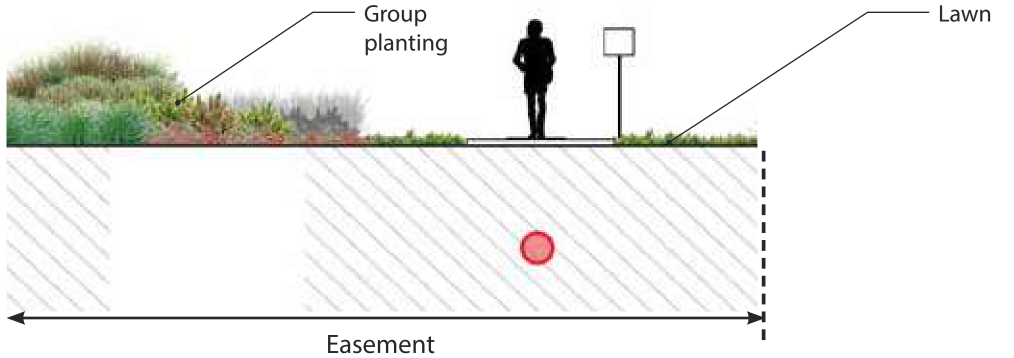
- Undesirable views from the easement linear reserve should be screened when possible, through the use of screening tall shrubs, in accordance with the Planting Selection section .



Planting

Planting design

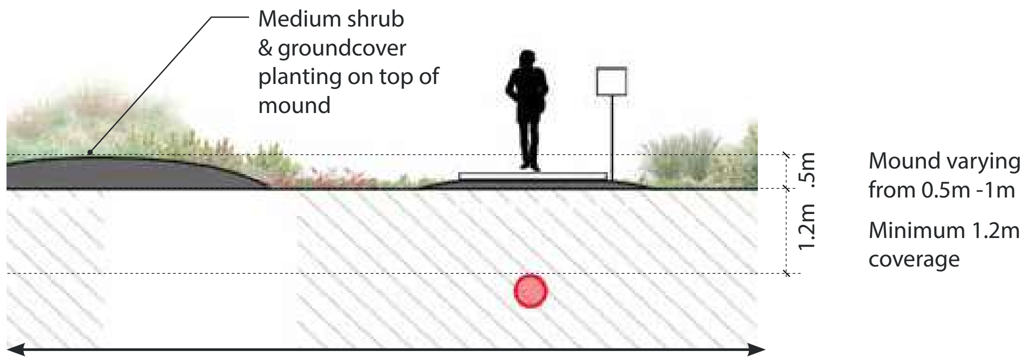
- Planting should be proposed in large isolated groups and layered when possible to provide a contrasting composition of scales, colours and textures. Layering should be oriented to enhance the visual at interfaces such as back and side fences.



- Lawn is to be the predominant easement landscape treatment, in conjunction with groundcover and grass group planting in locations as specified on the Planting Selection section above. This will provide extensive green views along the linear reserve of easements. Ensure that consideration is given to ease of mowing, avoiding acute angles and tight spaces with a minimum lawn width of 2m to be provided.

Soil and Mounding

- Additional soil layers or mounding can be considered on the landscape design for the easement reserve. A minimum of 1.2m soil coverage is to be maintained at all times on the easement unless otherwise specified by APA. Soil can be added on top of this cover to add protection and provide some visual interest to the corridor.
- Mounding can have shrub planting, paths and small furniture on it. Ensure that the pipeline marker is located over the pipeline and remains visible at all times.



Precedent images - Mounding with lawn

landscape design examples

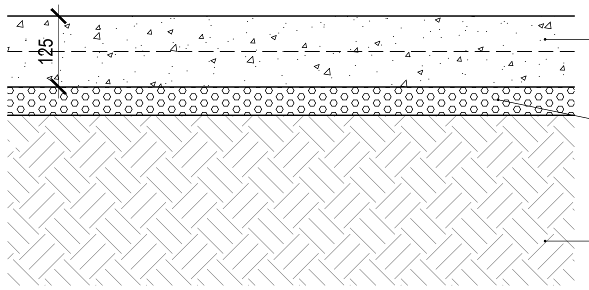
Scenario 1 – Easement adjacent to Road or Street

Scenario 2 – Easement adjacent to Reserve or Parkland

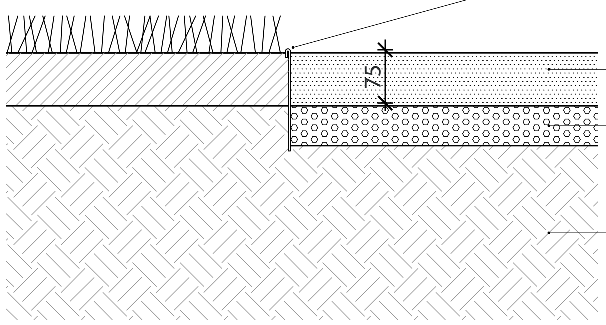
Technical details & notes

NOTE: DETAILS BELOW ARE INDICATIVE AND WILL BE SUPERSEDED BY COUNCIL STANDARD DETAILS.

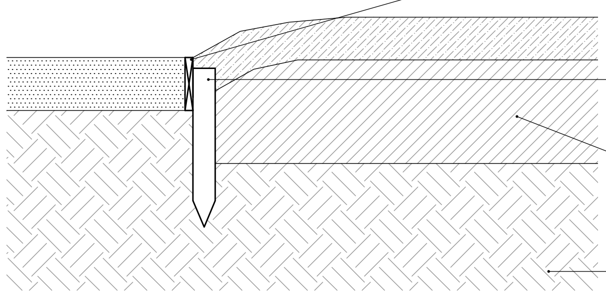
Detail 1: Typical concrete pavement



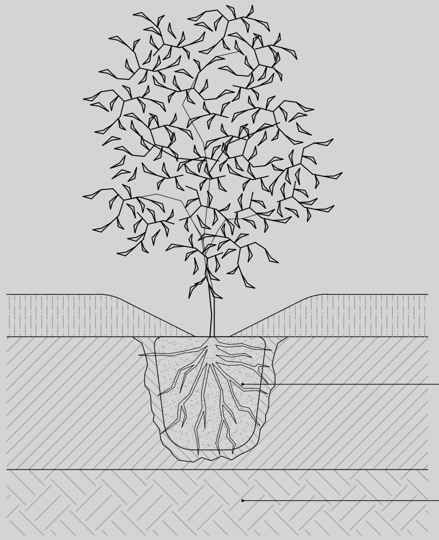
Detail 2: Typical steel edge and gravel paving



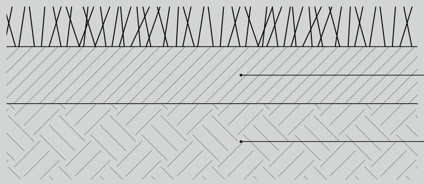
Detail 3: Typical timber edge



Detail 4: Typical small shrub / groundcover



Detail 5: Typical lawn



5
approvals.

approval process & requirements

APA is a referral authority in all states and territories in Australia for planning application to subdivide land that includes an APA gas pipeline easement.

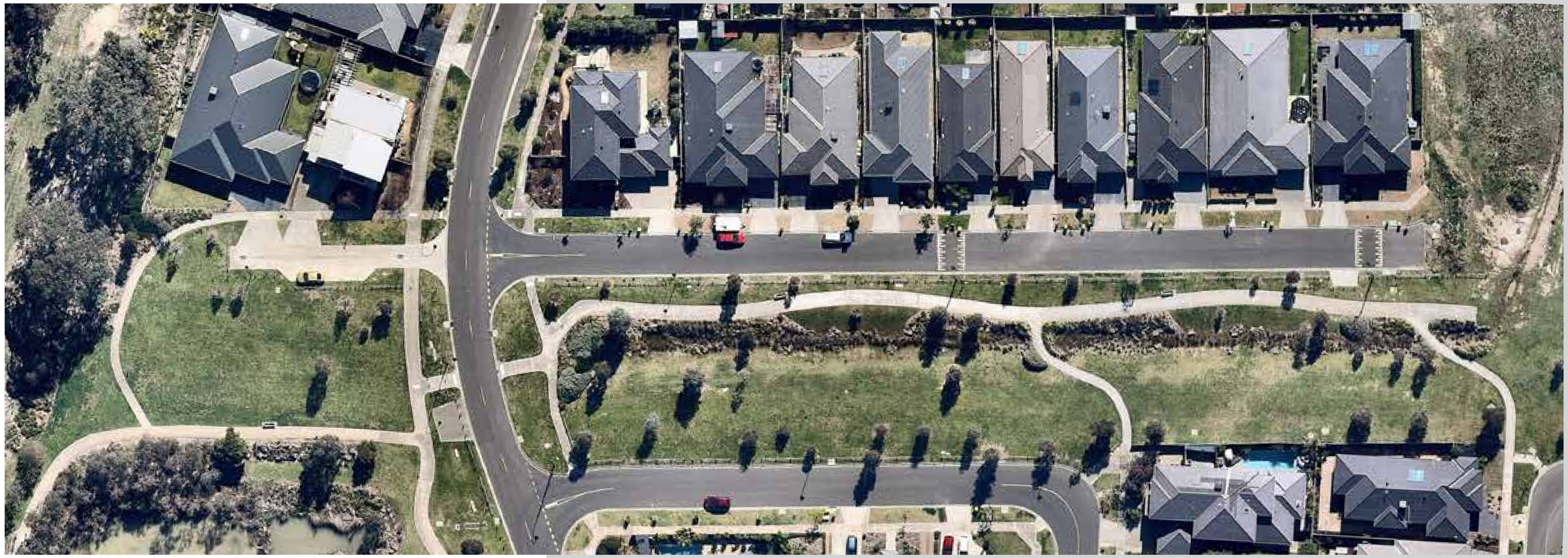
APA will continue to collaborate with local authorities to ensure safe land use around the gas pipelines, and can also provide local authorities with mapping via the Australian Pipeline Database to assist in identifying our pipelines and assets.

Third party works approval is required for any works within an APA easement or within three (3) metres of the pipeline, where no easement exists.

Applications for APA approval should include:

- A professionally prepared landscape plan by a qualified landscape architect.
- Details and specification of any earthworks proposed on the easement/pipeline area.
- Planting plan and schedule showing species, quantities, size when installed, mature size, height, canopy and root ball sizes.
- Likely timing of works.

Call APA on 1800 427 532 for further information or go to www.apa.com.au



Aerial view of apa easement in Victoria (apa photo)

6
questions.

frequently asked questions

Approval Process

What are the notification requirements for subdivisions containing APA easements?

APA is a referral authority for planning applications to subdivide land that include APA pipeline easement in all states and territories in Australia. As such, the Responsible Authority will notify APA directly, or require applicants to notify APA of their proposed subdivision for APA consideration.

What are the approval requirements for works within APA easements?

3rd party works approval is required for any works within APA's easements or within 3m of the pipeline (where no easement exists).

Pipeline Cover

What is the depth of the pipeline in relation to the finished surface level on an easement?

Typically the minimum depth of cover is between 0.90-1.2m from top of pipe to surface level, however the exact depth needs to be physically confirmed (proved) as in many instances surface levels change over time. APA will not permit the depth of cover to be reduced over the pipeline.

Services

Can services/infrastructure be located within easements or cross it?

APA does not generally allow other services to co-locate in its easements, however APA does permit service crossings. Crossings should be at 90 degrees and if possible the number of crossings should be limited. Service crossings require APA 3rd party works approval.

Roads and Streets

Can streets be located within easements or cross it?

APA does not allow roads to be located over its easements other than road crossings that are perpendicular to the easement (e.g at 90 degrees). Crossings will require protective slabbing of the pipeline and APA 3rd party works approval.

Is there a minimum distance between each crossing of streets, roads and services along an easement?

There is no minimum distance, however it is APA's preference to reduce the number of crossing points. APA would refer to relevant urban design block lengths in any given jurisdiction. Typically infrastructure crossing points should be grouped – all services together. There is also a cost associated with crossing the pipeline e.g. potential protective measures such as slabbing, possible recoating costs, proving and supervision costs, which are passed onto the developer as the agent of change.

Furniture & Playgrounds

Can furniture be installed within easements, like seats and picnic sets?

Yes, subject to 3rd party works approval, refer to these guidelines' Landscape Guidelines chapter. Please note that playground equipment should be located outside the easement.

Irrigation

Can irrigation be installed within easements?

Yes, as long as it is specific to managing the landscape on the linear reserve, subject to 3rd party works approval.

Lighting

Can light poles be installed within easements?

Yes, subject to 3rd party works approval.

Offset Distances

What is the minimum setback from the pipeline that needs to be maintained?

The minimum setback to be maintained from the pipeline within the easement is 3m for any excavation works. Preferably an additional 2m either side (total 5m) for future access/working room should not be significantly embellished.

Any excavation greater than 300mm within the easement will require supervision by an APA officer. Significant trees should not be located on the live side of the easement (to allow for future pipelines if required).

Member of the Surbana Jurong Group

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