


Appendix I

Preliminary hazard assessment

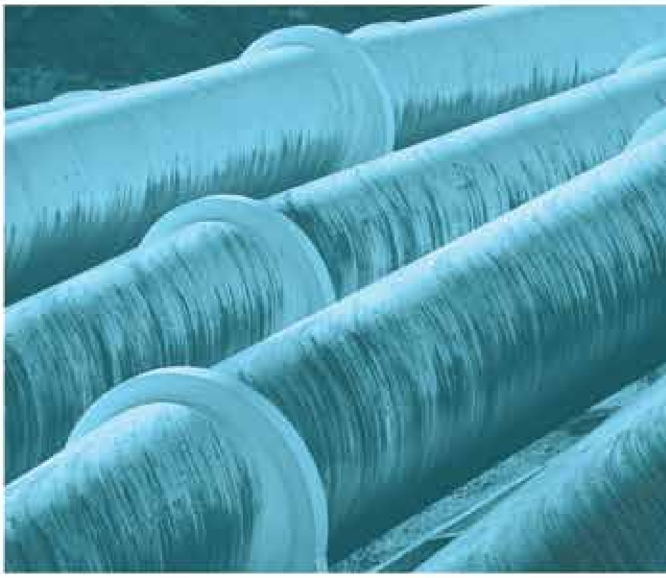




APA East Coast Grid Expansion, Moomba to Wilton Pipeline - Modification Report 1

Preliminary Hazard Assessment

Prepared by Sherpa Consulting for APA Group on behalf of EMM Consulting
July 2021

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EAST COAST GRID EXPANSION - MOOMBA-WILTON PIPELINE

MODIFICATION 1

PRELIMINARY HAZARD ANALYSIS

EMM CONSULTING PTY LTD

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ABBREVIATIONS

AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
APA	APA Group
AS	Australian Standard
BOM	Bureau of Meteorology
DP	Development Plan
DPIE	NSW Department of Planning, Industry and Environment
EI	Energy Institute
HAZID	Hazard Identification
HIPAP	Hazardous Industry Planning Advisory Paper
HP	High Pressure
IOGP	International Association of Oil and Gas Producers
km	kilometres
LFL	Lower Flammability Limit
LP	Low Pressure
MSP	Moomba Sydney Pipeline
MWP	Moomba Wilton Pipeline
PHA	Preliminary Hazard Analysis
PL16	Pipeline Licence No. 16
SSI	State Significant Infrastructure
SWQP	South West Queensland Pipeline
TJ/day	terajoules per day
VCE	Vapour Cloud Explosion

1. SUMMARY

1.1. Background

East Australian Pipeline Pty Ltd, part of the APA Group (APA) currently operates an underground high pressure natural gas transmission pipeline, extending from Moomba (South Australia) to Wilton (New South Wales), a distance of approximately 1,299 kilometres (km). The Moomba to Wilton Pipeline (MWP) is the mainline part of the Moomba Sydney Pipeline (MSP) and was constructed in 1976.

APA is proposing an expansion of gas transportation capacity on its East Coast Grid that links Queensland to southern markets ahead of projected potential 2023 supply risks. Expansion would be through the construction of additional compression stations and associated works on both the South West Queensland Pipeline (SWQP) and MWP in NSW.

The expansion will be delivered in a number of stages. The first stage of expansion works includes the construction of a single site of compression on each of the SWQP and MWP and will increase Wallumbilla to Wilton capacity by 12%. The first stage is targeted for commissioning in the first quarter of 2023 ahead of forecast southern state winter supply risks identified in the 2021 Australian Energy Market Operator (AEMO) Gas Statement of Opportunities (AEMO 2021).

The second stage of expansion works (an additional site on the SWQP and on the MWP) will add a further 13% capacity and will be staged to meet customer demand.

APA is undertaking engineering and design works on a potential third stage (three additional compressor locations on the MWP) of the East Coast Grid to add a further 25% transportation capacity. All up, these proposed capacity expansions would mean that the entirety of NSW peak demand could be met by gas flowing from northern sources.

The proposed East Coast Grid Expansion (the project) presents an optimal opportunity to maximise gas supply via existing infrastructure with minimal impact.

EMM Consulting Pty Ltd (EMM) has retained Sherpa Consulting Pty Ltd (Sherpa) to assess the hazards and risk aspects of the compressor stations in terms of their potential impact on the surrounding land use. This report has been prepared to address the hazard and risk impacts for Stage 1 and 2 and to support Modification Report 1. As such, only the hazard and risk impacts of the following compressor stations have been assessed in this report:

- Stage 1:
  - MW880 – Milne approximately 35 km south-west of Condobolin.
- Stage 2:
  - MW433 – Round Hill approximately 103 km north of Wilcannia.

The scope of work for the Modification Reports, Ref [1], requires consideration of hazards and risks related to proximity to other facilities and ongoing land use. To satisfy this requirement, a Preliminary Hazard Analysis (PHA) has been undertaken. The PHA has been undertaken with reference to the following Hazardous Industry Planning Advisory Papers (HIPAPs):

- HIPAP No. 6: Hazard Analysis, Ref [2].
- HIPAP No. 4: Risk Criteria for Land Use Safety Planning, Ref [3].

This PHA has been undertaken to support Modification Report 1 and should be read in conjunction with Modification Report 1 and all other supporting studies.

1.2. Findings

A PHA was undertaken of the compressor stations associated with APA's East Coast Grid Expansion (Modification 1) to assess the hazards and risk aspects of the compressor stations in terms of their potential impact on the surrounding land use. Quantitative results have been provided in terms of fatality, injury and property damage risk levels, which show that relevant HIPAP 4 quantitative risk criteria are met.

The NSW Department of Planning, Industry and Environment (DPIE) provides indicative societal risk criteria for when there is significant population around a potentially hazardous facility. As there is no significant population around either of the compressor stations; societal risk has not been calculated for this study.

In line with the requirement that '*the risk from a major hazard should be reduced wherever practicable, even where the likelihood of exposure is low*', additional risk reduction measures should be considered and implemented where practicable.

Potential risk reduction which may be considered include the following:

- Orientation of flanges and piping away from pipework associated with the existing ethane and natural gas scraper stations as well as the local equipment room.
- Fire, gas and smoke detection systems and fire suppression system for the compressor building and local equipment room.
- Protective painting on aboveground pipework to minimise corrosion.
- Protection from accidental vehicle impact through the use of bollards or other physical barriers.
- Security arrangements to prevent unauthorised site access.

2. INTRODUCTION

2.1. Background

East Australian Pipeline Pty Ltd, part of the APA Group (APA) currently operates an underground high pressure natural gas transmission pipeline, extending from Moomba (South Australia) to Wilton (New South Wales), a distance of approximately 1,299 kilometres (km). The Moomba to Wilton Pipeline (MWP) is the mainline part of the Moomba Sydney Pipeline (MSP) and was constructed in 1976.

Initially, the pipeline was owned and operated by the Pipeline Authority, a Commonwealth agency, and generally regulated under the Pipeline Authority Act 1973. The MWP is now owned and operated by APA; it was gazetted as State Significant Infrastructure (SSI) on 11 December 2020 and is authorised by Pipeline Licence No. 16 (PL16).

The MWP currently operates at a forward haul capacity of approximately 489 terajoules per day (TJ/day) (AEMC 2021)[1].

2.2. Project overview and context

NSW imports the majority of its natural gas from other states, and a gas shortfall on Australia's east coast is predicted by Winter 2023, with demand for gas forecast to outstrip supply.

APA is proposing an expansion of gas transportation capacity on its East Coast Grid that links Queensland to southern markets ahead of projected potential 2023 supply risks. Expansion would be through the construction of additional compression stations and associated works on both the South West Queensland Pipeline (SWQP) and MWP in NSW.

The expansion will be delivered in a number of stages. The first stage of expansion works includes the construction of a single site of compression on each of the SWQP and MWP and will increase Wallumbilla to Wilton capacity by 12%. The first stage is targeted for commissioning in the first quarter of 2023 ahead of forecast southern state winter supply risks identified in the 2021 Australian Energy Market Operator (AEMO) Gas Statement of Opportunities (AEMO 2021)[2].

The second stage of expansion works (an additional site on the SWQP and on the MWP) will add a further 13% capacity and will be staged to meet customer demand.

APA is undertaking engineering and design works on a potential third stage (three additional compressor locations on the MWP) of the East Coast Grid to add a further

[1] AEMC 2021, https://www.aemc.gov.au/energy-rules/national-gas-rules/gas-scheme-register/nsw-moomba-sydney-pipeline, viewed 15 June 2021.

[2] AEMO 2021, Gas Statement of Opportunities for eastern and south-eastern Australia, Australian Energy Market Operator, March 2021.

25% transportation capacity. All up, these proposed capacity expansions would mean that the entirety of NSW peak demand could be met by gas flowing from northern sources.

The proposed East Coast Grid Expansion (the project) presents an optimal opportunity to maximise gas supply via existing infrastructure with minimal impact.

The five compressor stations for the East Coast Grid Expansion will be constructed at the following locations on the MWP:

- Modification 1:
  - Stage 1:
    - MW880 – Milne approximately 35 km south-west of Condobolin.
  - Stage 2:
    - MW433 – Round Hill approximately 103 km north of Wilcannia.
- Modification 2:
  - Stage 3:
    - MW162 – Binerah Downs approximately 68 km north-west of Tibooburra.
    - MW300 – Mecoola Creek approximately 70 km south-east of Tibooburra.
    - MW733 – Gilgunnia approximately 63 km south-west of Nymagee.

EMM Consulting Pty Ltd (EMM) has retained Sherpa Consulting Pty Ltd (Sherpa) to assess the hazards and risk aspects of the compressor stations in terms of their potential impact on the surrounding land use. This report has been prepared to address the hazard and risk impacts for Stage 1 and 2 and to support Modification Report 1. As such, only the hazard and risk impacts at MW433 and MW880 have been assessed in this report. A separate report will be prepared to support Stage 3 in Modification Report 2.

The proposed locations of MW433 and MW880 are shown in Figure 4.1.

The scope of work for the Modification Reports, Ref [1], requires consideration of hazards and risks related to proximity to other facilities and ongoing land use. To satisfy this requirement, a Preliminary Hazard Analysis (PHA) has been undertaken. The PHA has been undertaken with reference to the following Hazardous Industry Planning Advisory Papers (HIPAPs):

- HIPAP No. 6: Hazard Analysis, Ref [2].
- HIPAP No. 4: Risk Criteria for Land Use Safety Planning, Ref [3].

This PHA has been undertaken to support Modification Report 1 and should be read in conjunction with Modification Report 1 and all other supporting studies.

2.3. Objectives

The objectives of this study are to:

- Conduct a PHA following the requirements of HIPAP No. 6, to provide information on the risk posed by the compressor stations on the surrounding land uses.
- Determine whether the risk posed by the compressor stations complies with the risk criteria specified in HIPAP No. 4.
- Provide risk treatment options if the risks do not comply with criteria.

2.4. Scope

The scope of work for Modification 1 comprises the following two compressor stations:

- MW433 – Round Hill (Lot 3 DP593787).
- MW880 – Milne (Lot 1 DP580284).

For each compressor station, the study boundary extends from the tie-in points to the existing pipeline and scraper stations.

2.5. Exclusions and limitations

The following exclusions and limitations apply to this study:

- Biosecurity and bushfire hazards (described in the 'hazards and risks' section of the scope of work, Ref [1]) are excluded as they are covered elsewhere in the Modification Report 1.
- Consideration of impacts on the biophysical environment (as required by HIPAP No. 6) has been excluded as it was not identified as a key issue in the 'hazards and risks' section of the scope of work, Ref [1], and is covered elsewhere in the Modification Report 1.
- The study is not an AS2885:2018 risk assessment. The results can be used by APA to inform any AS2885:2018 requirements.
- The study assesses the potential impact of the compressor stations on the surrounding offsite land use. As such, the potential impact of the stations on workers housed in the station accommodation buildings is excluded, as these are considered onsite.
- The existing natural gas and ethane pipelines, scraper stations and associated piping are excluded from the study, with the exception of potential impacts from the compressor stations to this equipment.
- Station vents have not been included in the assessment as these are only used for blowdown in event of emergency shutdown and for planned maintenance; they are designed not to pose any hazardous impacts on the surrounding land uses.

3. METHODOLOGY

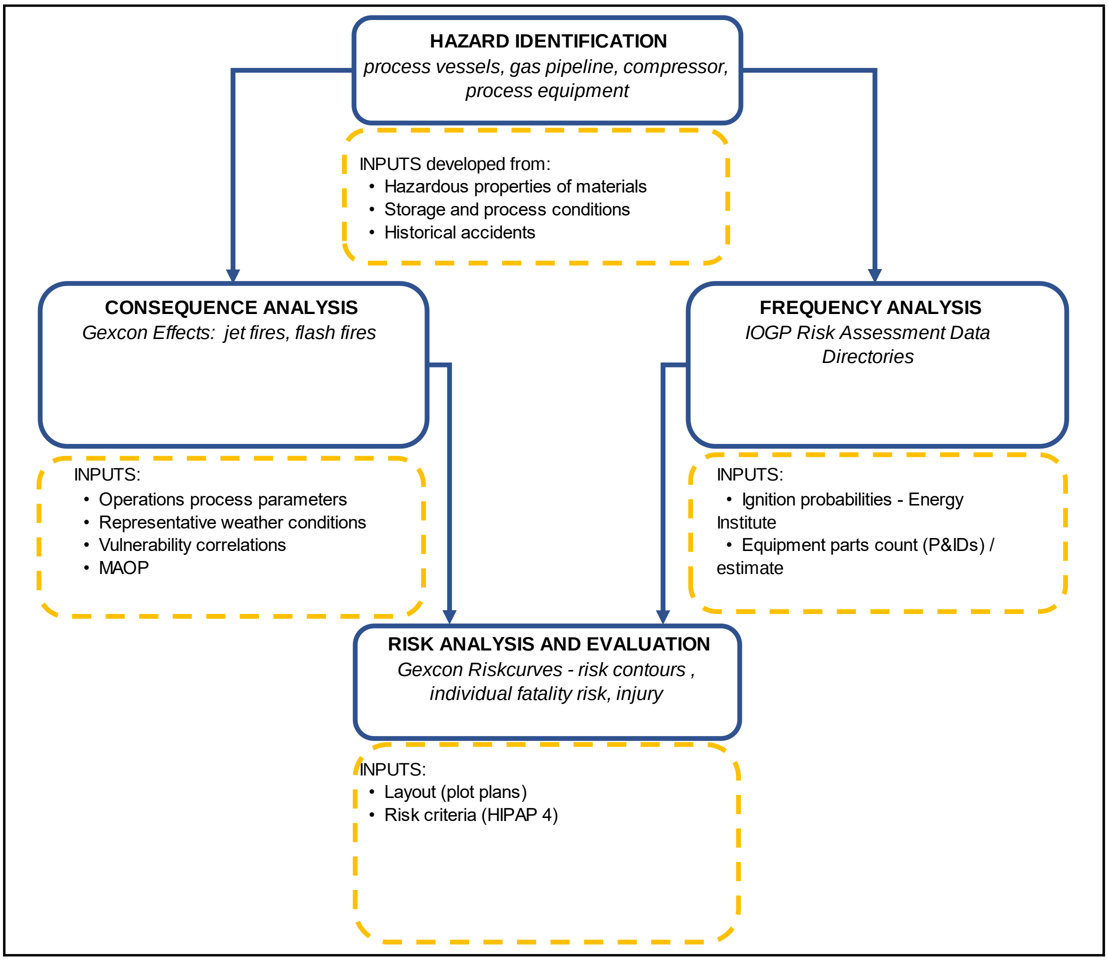
3.1. Overview

This study involves the following steps:

- Establish the overall study context, including:
  - a review of the process undertaken at the proposed sites, including the storage and process conditions.
  - identification of hazardous chemicals and their properties.
  - identification of risk tolerability criteria.
- Undertake hazard identification for the proposed sites and identify a list of scenarios for quantification of consequences and likelihood.
- Undertake a consequence analysis for the identified hazardous scenarios.
- Undertake analysis to estimate the frequency of hazardous scenarios.
- Undertake quantitative risk assessment by combining the consequences and their associated frequency to generate risk contours for the development.
- Assess the risk to neighbouring land uses against the requirements of the NSW Department of Planning, Industry and Environment (DPIE) Risk Criteria for Land-Use Safety Planning.

An overview of the PHA process is shown in Figure 3.1.

Figure 3.1: PHA process



4. CONTEXT

4.1. Site locations

The two sites for Modification 1 are listed in Table 4.1 and are located in regional NSW, as shown in Figure 4.1.

Table 4.1: Compression station information

ID	Name	Lot and DP
MW433	Round Hill	Lot 3 DP593787
MW880	Milne	Lot 1 DP580284

Both of the proposed sites for the compressor stations are on land owned by APA, with MW433 being approximately 380 m x 400 m with an area of 15.5 hectares (ha), and MW880 being approximately 400 m x 400 m with an area of 16 ha. The compressor station will have a final footprint of approximately 1.5 ha.

For the purposes of this study, the site boundaries for the compressor stations are taken to be the compressor study areas shown in Figure 4.1, which represent the boundaries of the Development Plan (DP) lots.

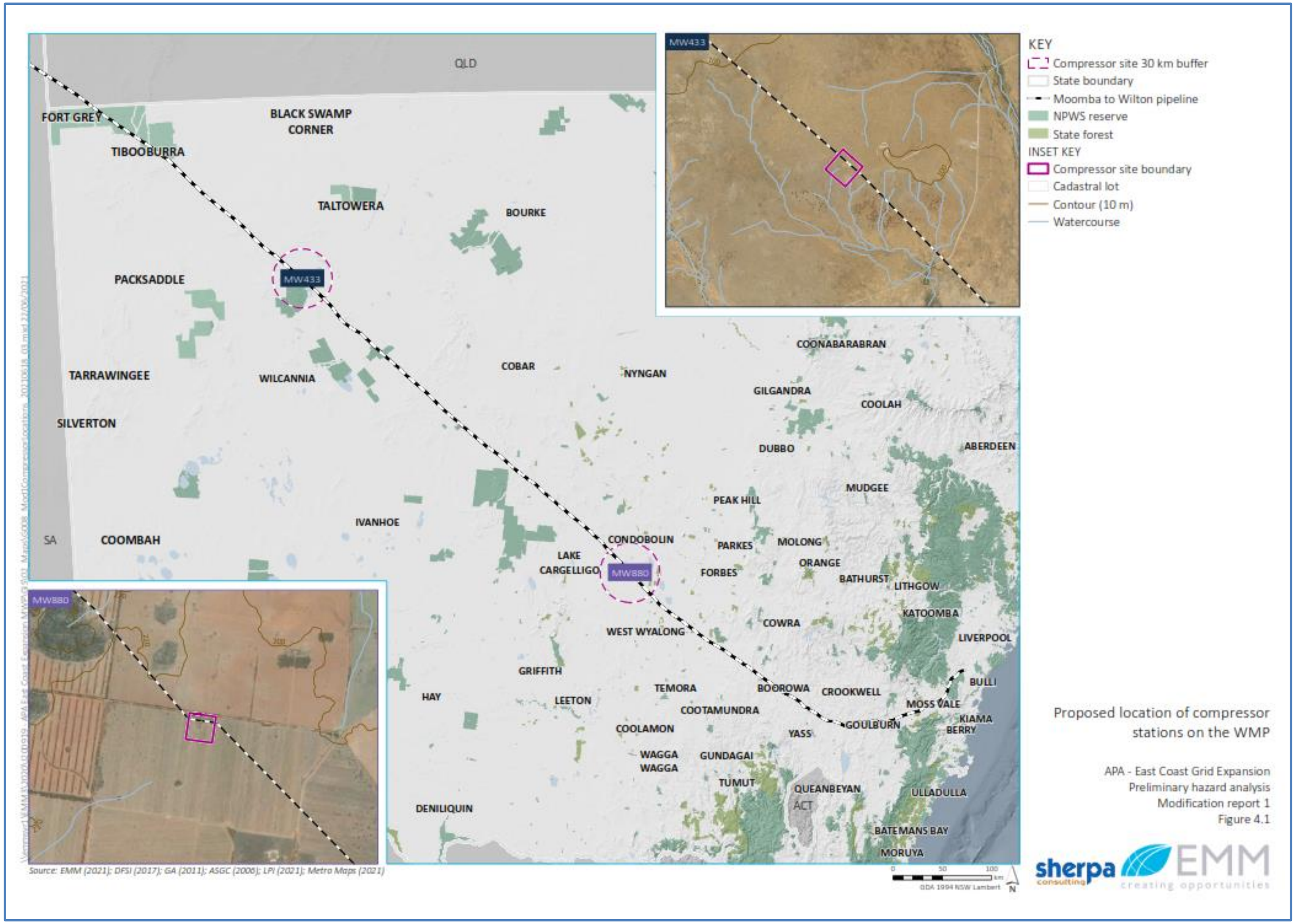
4.2. Meteorological conditions

Meteorological data for each compressor station was obtained using the Bureau of Meteorology (BOM) weather stations summarised in Table 4.2. The meteorological data used for the compressor stations are contained in APPENDIX A.

Table 4.2: Compression station weather data

ID	Name	BOM Weather station
MW433	Round Hill	White Cliffs AWS
MW880	Milne	Condobolin

Figure 4.1: Location of compressor stations



4.3. Process

4.3.1. Process description

The Process Flow Diagram (PFD) for the MW880 Milne compressor station is shown in Figure 4.2 and Figure 4.3. An example compressor station layout is shown in Figure 4.4. This is the ‘standard’ design for all compression stations and comprises:

- DN600 take-off line from the pipeline.
- Mars 100 gas turbine driven compressor.
- DN50 take-off line for High Pressure (HP) fuel gas supply to the compressor gas turbines, passing through pressure reduction and filtering equipment.
- Take-off line for Low Pressure (LP) fuel gas supply to the micro-turbine generator, passing through pressure reduction and filtering equipment. This take-off line is from the HP fuel gas skid.
- Aftercoolers.
- DN80 take-off lines to the maintenance vent from the fuel gas and the compressor discharge.
- DN600 return line to the pipeline.
- Micro-turbine power generator.

Ancillary equipment includes an instrument air compressor.

The study boundary extends from the tie-in points to the existing pipeline and pigging facilities, which is shown by the clouded area in Figure 4.2.

Figure 4.2: Process Flow Diagram for MW880 Milne (sheet 1)

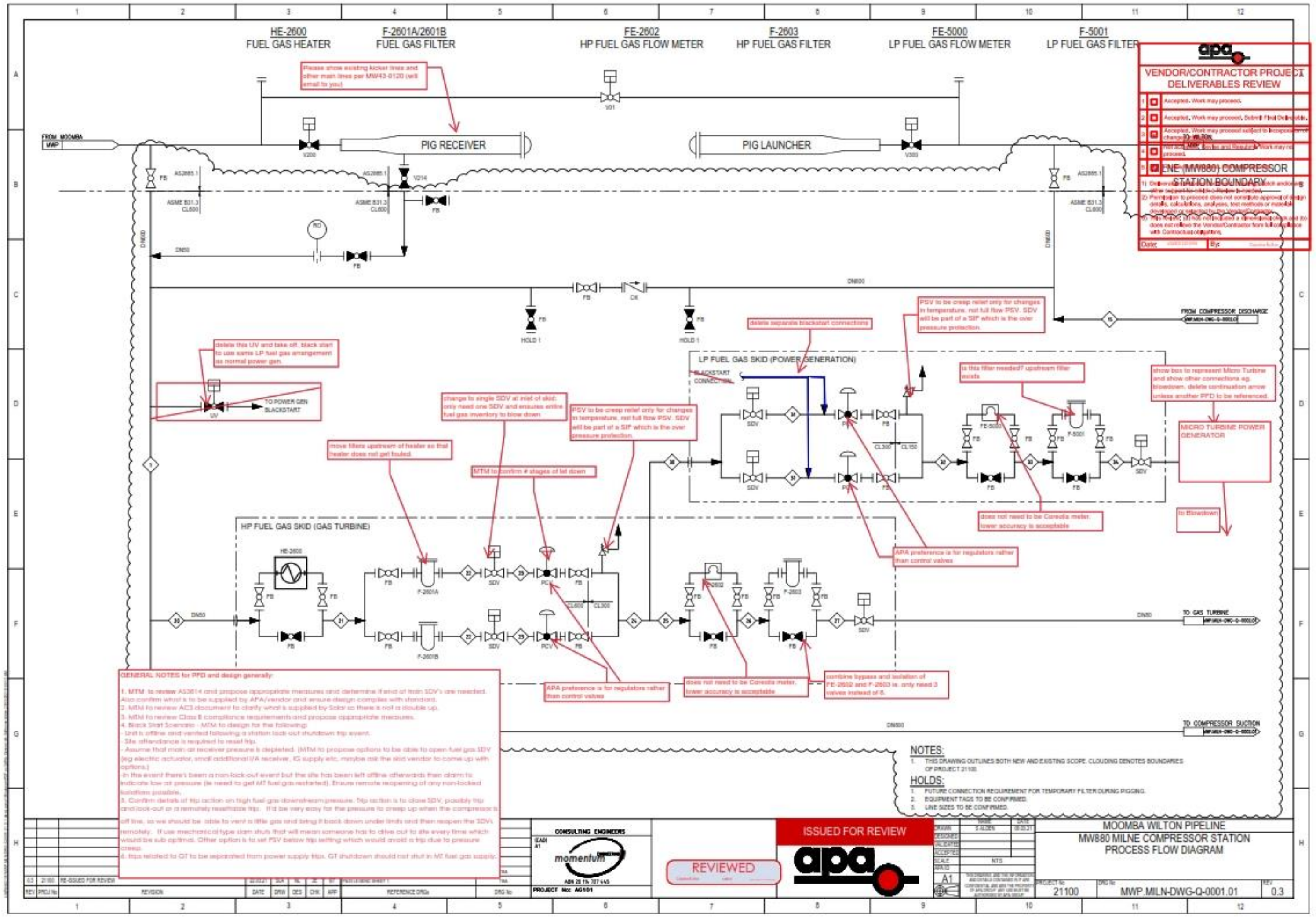


Figure 4.3: Process Flow Diagram for MW880 Milne (sheet 2)

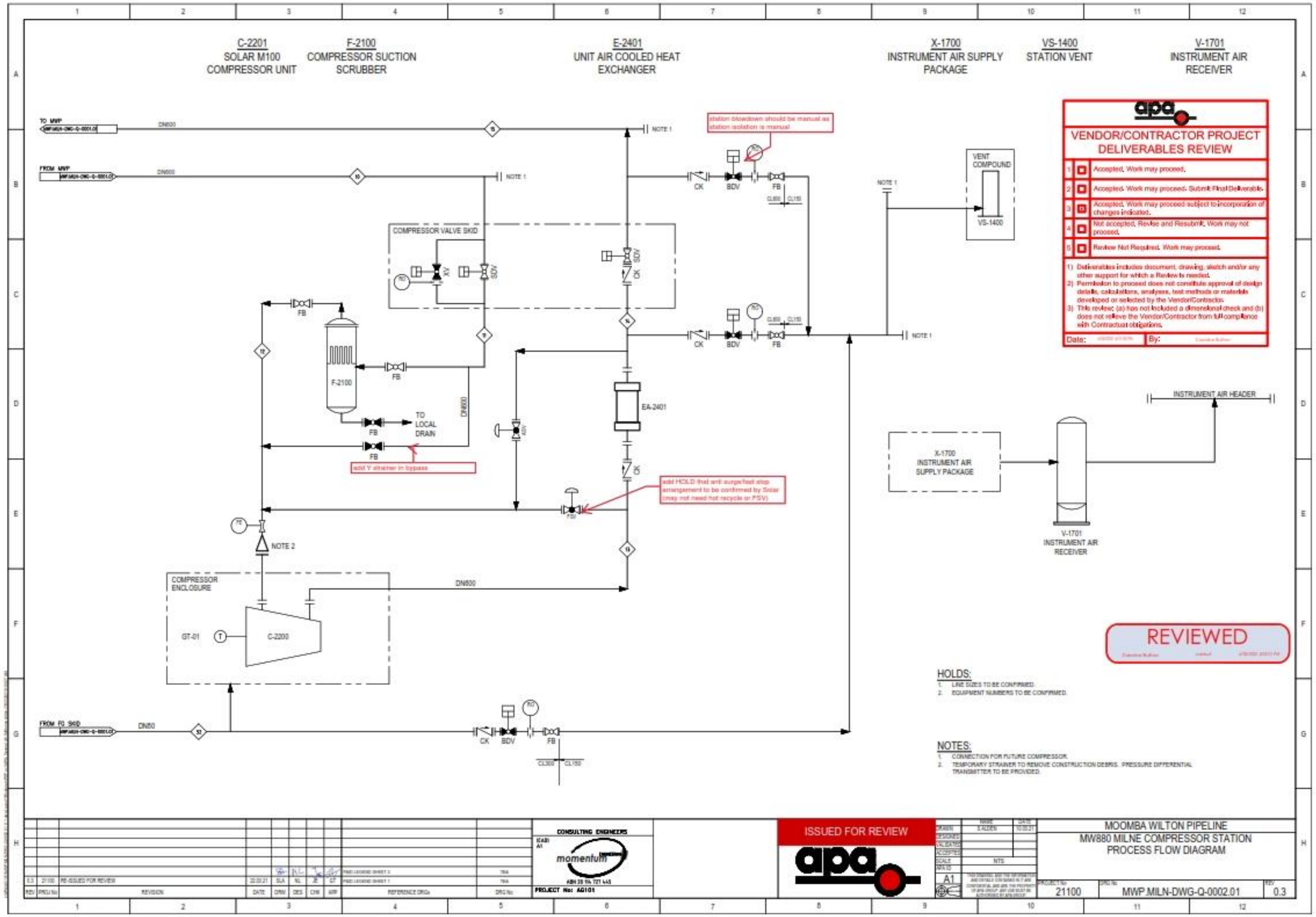


Figure 4.4: Example compression station layout

4.3.2. Identification of hazardous materials

For the compression stations, the hazardous substance of interest is natural gas; other substances used at the sites would not result in significant consequences if released. Table 4.3 provides a representative composition of natural gas from Moomba, Ref [4]; hazardous properties of natural gas are discussed in Section 5.2.

Table 4.3: Natural gas composition

Component	Composition (%)
Methane	95.7
Ethane	2.0
Propane	0.5
Nitrogen	1.2
Carbon dioxide	0.9
Total	**100.3**

4.4. Operation

Typical operations activities will involve minor maintenance and checks on equipment performance or for repair of any equipment breakdowns.

Regulatory compliance checks are carried out on different equipment as prescribed in applicable standards, but typically vary from one to eight year intervals subject to the equipment types.

Major services and engine overhauls will be carried out on five to ten year intervals subject to frequency of operations.

The sites are designed to operate as unmanned facilities. Typical site workforce for when attended is expected to be 1 to 2 people on site for most activities.

4.5. Criteria

4.5.1. Vulnerability

The only hazardous chemical identified in Section 4.3.2 was natural gas, which as a flammable gas has the potential for fires and explosions. To determine the impact of fires and explosion on people, it is necessary to relate their physical effects (e.g. heat radiation) to different levels of harm (e.g. injury and fatality) using vulnerability criteria.

From the hazard identification undertaken in this study (see Section 5), it is considered that vapour cloud explosions are unlikely given the low level of confinement and congestion at the compressor stations. For this study, vulnerability criteria for fatality, injury and escalation are required for thermal radiation (from jet and flash fires).

Thermal radiation

The vulnerability relationship for fatality for thermal radiation was taken from the TNO Green Book, Ref [5], and is defined by the following Probit:

$$Pr = -36.38 + 2.56(Q^{4/3}t)$$

where,	Pr	probit corresponding to probability of death	(-)
	Q	heat radiation level	(W/m^2)
	t	exposure time	(s)

The probability of fatality (P_{fat}) for heat radiation depends on the thermal radiation level and the exposure duration. For land-use planning studies, the duration typically ranges from 20 - 60 seconds. A 30 second exposure time was used in this study.

Injury and escalation criteria were set at a thermal radiation of 4.7 kW/m^2 and 23 kW/m^2 respectively, which is consistent with the description of this level in HIPAP 6.

Fires resulting from ignition of a gas cloud in an open area, i.e. without significant congestion or confinement is referred to as a 'flash fire'. It is assumed that if a person is within the extents of a fire, they are fatally injured and this assumption is used to determine the vulnerability of people to a flash fire, i.e. within the fire they are fatally injured and outside the flash fire they are uninjured.

A summary of the vulnerability criteria for thermal radiation used in this study is presented in Table 4.4.

Table 4.4: Vulnerability criteria – thermal radiation

Level (kW/m^2)	Impact (based on HIPAP 6)	Usage in study
4.7	Will cause pain in 15-20 seconds and injury after 30 seconds exposure	Threshold level for injury
7.3		1% probability of fatality (based on probit equation)
12.6	Significant chance of fatality for extended exposure. High chance of injury.	32% probability of fatality (based on probit equation)
23	Likely fatality for extended exposure and chance of fatality for instantaneous exposure. Unprotected steel will reach thermal stress temperatures which can cause failures.	95% probability of fatality (based on probit equation) Threshold level for escalation to neighbouring potentially hazardous installations or at land zoned to accommodate such installations
Within flash fire		100% probability of fatality assumed

4.5.2. Risk criteria for a potentially hazardous development

DPIE describe risk criteria in terms of both qualitative and quantitative aspects, Ref [3], with the following general qualitative principles:

- The avoidance of all avoidable risks.
- The risk from a major hazard should be reduced wherever practicable, even where the likelihood of exposure is low.
- The effects of significant events should, wherever possible be contained within the site boundary.
- Where the risk from an existing installation is already high, further development should not pose any incremental risk.

DPIE provides quantitative risk criteria for:

- Fatality.
- Injury.
- Property damage.

These criteria are described in Table 4.5, Table 4.6 and Table 4.7.

Table 4.5: Individual fatality risk criteria

Risk levels (individual fatality risk per year)[(a)]	Land-Use	Limit of exposure at the following locations
0.5×10^{-6}	Sensitive	Hospitals, child-care facilities, and old age housing.
1×10^{-6}	Residential	Residential developments and places of continuous occupancy such as hotels and tourist resorts.
5×10^{-6}	Commercial	Commercial developments, including offices, retail centres and entertainment centres.
10×10^{-6}	Recreational	Sporting complexes and active open space areas.
50×10^{-6}	Industrial	Target for site boundary
(a) Based on 24 hour-per-day exposure with no allowance for the protection buildings may offer or for the potential to move away and escape from a developing incident.		

Table 4.6: Individual injury risk criteria

Risk levels (individual injury risk per year)[(a)]	Type
50×10^{-6}	Incident heat flux radiation at residential and sensitive use areas should not exceed 4.7 kW/m^2
(a) Toxic and overpressure criteria excluded as it is not applicable to this study.	

Table 4.7: Property damage and accident propagation criteria

Risk levels (individual injury risk per year)[a]	Type
50×10^{-6}	Incident heat flux radiation at neighbouring potentially hazardous installations or at land zoned to accommodate such installations should not exceed 23 kW/m^2
(a) Toxic and overpressure criteria excluded as it is not applicable to this study.	

In addition, DPIE provides indicative societal risk criteria for when there is significant population around a potentially hazardous facility. There is no significant population around either of the compressor stations; societal risk criteria have therefore been excluded as it is not applicable to this study.

5. HAZARD IDENTIFICATION

5.1. Overview

Hazard Identification (HAZID) is the process of establishing the scenarios that could result in an adverse impact, together with their causes, consequences and existing safeguards. The focus of this study was loss of containment from process systems.

The HAZID comprised the following key steps:

- Identification of hazardous materials associated with the compressor stations with the potential for significant injury, fatality or property damage in the absence of controls.
- Review of external natural hazards or environmental conditions and their potential impact on the compressor stations.
- Identification of hazardous scenarios, recorded in a HAZID Word Diagram.
- Development of scenarios to carry forward for assessment.

5.2. Hazardous materials

The first step in the HAZID involved identifying the hazardous materials within the process systems associated with the compressor stations to be considered in the PHA. For the compression stations, the hazardous substance of interest is natural gas; other substances used at the sites would not result in significant consequences if released.

As shown in Table 4.3, natural gas at the compressor stations contains mainly methane, which is flammable between 5% and 15% by volume and is a simple asphyxiant. On release, the gas tends to rise as it has a lower density than air at ambient conditions. Loss of containment of natural gas from the compressor stations may result in fires, in the event of ignition.

5.3. External and natural hazards

As part of the hazard identification process, the potential for external and natural hazards to affect the compressor stations was reviewed and is summarised in Table 5.1. Based on this, it was considered that no adjustment to the PHA was required to account for external and natural hazards.

Table 5.1: External factors

External factors	Damage/outcome	Comments	Inclusion in PHA
Earthquake	Ground movement damaging/collapsing compressor station equipment, loss of containment and fire (if ignited)	Site not in a high-risk earthquake zone, and outside the hot-spots identified in the earthquake hazard maps. https://d28rz98at9flks.cloudfront.net/74811/Rec2012_071.pdf	No adjustment to PHA
Landslide/ subsidence	Ground movement damaging/collapsing compressor station equipment, loss of containment and fire (if ignited)	Compressor stations and surrounding areas located on relatively level ground. Potential for land slip/subsidence considered negligible.	No adjustment to PHA
Tsunami	Inundation and equipment movement/damage, loss of containment and fire (if ignited)	Compressor station sites not located close to the sea.	No adjustment to PHA
Cyclone / strong wind	Equipment damage from strong winds, loss of containment, loss of containment and fire (if ignited)	The equipment is designed to relevant standards to resist the combined effects on internal pressure due to contents, weight of platforms, ladders, live loads, wind loads, earthquake forces and hydrostatic test loads. Compressor station sites not identified as within a cyclone area.	No adjustment to PHA
Storm event/ flood (high rain)	High rainfall resulting in flooding impacting equipment	Inundation due to flooding may lead to asset damage. For MW433 Round Hill, the closest stream is located at least 2.5 km from the north-eastern site boundary while the closest lake (Poloko Lake) is at least 5 km from the site. There are no significant rivers, waterways or lakes within 5 km of MW880 Milne. Compressor equipment damage due to flooding is therefore not considered a significant risk of loss of containment.	No adjustment to PHA

External factors	Damage/outcome	Comments	Inclusion in PHA
Lightning	Ignition resulting in fire	BOM data on lightning events related to severe thunderstorms in NSW from 2000, Ref [6], indicates that the compressor station sites are not located in high lightning strike areas. Equipment complying with relevant Australian Standards will be installed to manage the risks associated with lightning.	No adjustment to PHA
Bushfire	External fire escalating to compressor equipment	Excluded from study scope (see Section 2.5).	No adjustment to PHA
Aircraft crash due to pilot error, bad weather or plane fault	Propagation to loss of containment and fires	No airports in immediate vicinity of the compressor sites.	No adjustment to PHA
Breach of security/ sabotage	Possible loss of containment and fires	The compressor stations are located in remote areas. Appropriate security measures (e.g. fencing) will be in place for the sites. Potential for security breach or sabotage leading to loss of containment considered negligible.	No adjustment to PHA
Vehicle crash	Propagation to loss of containment and fires	MW880 is located adjacent to local roads/tracks with minimal traffic. MW433 is approximately 2 km from the nearest local road. Appropriate measures (e.g. fencing, barriers) to prevent vehicle impact with compressor station equipment will be in place for the sites.	No adjustment to PHA
Fire/explosion on adjacent site	Escalation to compressor equipment	No sites adjacent to compressor stations.	No adjustment to PHA

5.4. Hazardous scenarios

Identification of hazardous scenarios for the compressor stations was undertaken based on a review of the hazards associated with materials processed at the compressor stations and Sherpa's experience in undertaking safety-related studies for various industries. The hazardous scenarios identified are recorded in the hazard identification word diagram in APPENDIX B.

The major hazardous scenarios are discussed in further detail in the next section. The hazard identification is used as a basis for identifying a list of credible scenarios for carrying forward to further quantitative risk assessment based on the potential for impact to land uses near the compressor stations.

5.5. Scenarios assessed

Table 5.2 gives a summary of the hazardous scenarios for the compressor stations which were identified for assessment in this PHA.

Table 5.2: Summary of hazardous scenarios for assessment

ID	Section description	Hazardous scenario
CSI	Compressor station inlet	Release of natural gas from compressor station inlet piping
CSC	Gas compressor	Release of natural gas from gas compressor or associated downstream equipment/piping to compressor station outlet
LPG	LP fuel gas skid (power generation)	Release of natural gas from LP fuel gas skid equipment/piping
HPG	HP fuel gas skid (gas turbine)	Release of natural gas from HP fuel gas skid equipment/piping

The potential consequences of the scenarios listed in Table 5.2 include the following:

- Jet fire, if a natural gas leak from a pressurised inventory is ignited immediately. A jet fire is an intense directional fire resulting from ignition of a vapour release with significant momentum (i.e. pressurised). The fire size is a function of the rate of flammable material released, which is in turn a function of pressure and release hole size.
- Flash fire, if ignition is delayed. If a natural gas release is not ignited immediately, a vapour cloud will form. Natural gas is buoyant and will disperse easily, the potential for a significant cloud build-up at ground level is low. If ignition subsequently occurs, the vapour cloud burns rapidly without a blast wave and will flash back to burn as a jet fire from the release point.
- Fireball on immediate ignition of a catastrophic rupture of a high pressure transmission gas pipeline is excluded as the transmission pipeline is outside the scope of the study.

- Vapour Cloud Explosion (VCE), if ignition of the vapour cloud occurs within a congested or confined plant area. The turbulence and flame front acceleration due to congestion gives the conditions to generate overpressure. The compressor stations do not have significant confinement or congestion; therefore, there is a very low likelihood of flash-fire flame-front acceleration and vapour cloud explosion overpressure. VCEs are therefore not considered further in this study.

Jet fires from the compressor station may impinge on aboveground pipework associated with the existing ethane and natural gas scraper stations, some of which may be pressurised. This may result in rupture of the pipework in the event of impingement for an extended duration. The frequency of occurrence of these escalation events is estimated in Section 7.5.

6. CONSEQUENCE ANALYSIS

6.1. Overview

Consequence analysis was undertaken for the hazardous scenarios summarised in Table 5.2. Consequence analysis comprises the following key steps:

- Definition of sections for the compressor station, based on phase, location and pressure.
- Definition of hole sizes and release rates.
- Consequence modelling. Gexcon Effects (a modelling software) was used to model the consequences of compressor station releases. Inputs for consequence analysis are summarised in Section 6.4. The consequence analysis results will be reported in terms of distances to specified levels of harm, as presented in Section 4.5.

6.2. Consequence modelling sections

For this project, the consequence modelling was carried out based on combinations of pressure and location, which were obtained from information provided by APA, the process flow diagrams and the standard station layout (see Section 4.3.1).

6.3. Hole sizes

Loss of containment from the compressor stations was modelled for the representative hole sizes given in Table 6.1. The hole sizes were derived from the International Association of Oil and Gas Producers (IOGP) process equipment hole size range, Ref [7]. The hole sizes selected were the geometric mean within the hole size range and were assigned as relevant to specific process equipment based on a parts count.

Table 6.1: Representative hole sizes for modelling loss of containment

Representative hole size used for PHA (mm)	Process equipment hole diameter range (mm), Ref [7]
2	1 to 3
6	3 to 10
22	10 to 50
85	50 to 150
Full bore	>150

6.4. Modelling parameters

Consequence modelling of identified hazardous scenarios was undertaken using Gexcon Effects. Table 6.2 summarises the process conditions used to model the scenarios identified in Section 5.5. These conditions are based on pressure ranges provided by APA and assumed representative temperatures.

Table 6.2: Process conditions for consequence analysis

ID	Section description	Material	Pressure (kPag)	Temp (°C)	Comment
CSI	Compressor station inlet	Natural Gas	4500	Ambient	Compressor suction pressure will range from 2.5 to 4.5 MPag
CSC	Gas compressor	Natural Gas	5700	60	Compressor discharge pressure will range from 3.5 to 5.7 MPag
LPG	LP fuel gas skid (power generation)	Natural Gas	700	Ambient	Fuel gas pressure of 0.7 MPag downstream of power generation skid
HPG	HP fuel gas skid (gas turbine)	Natural Gas	2500	Ambient	Fuel gas pressure of 2.5 MPag downstream of turbine fuel gas skid

Potential outcomes of the hazardous scenarios listed in Table 5.2 modelled in this study are:

- Jet fire, if a continuous natural gas release is ignited immediately.
- Flash fire, in the event of delayed ignition of a natural gas release.

The dispersion of natural gas releases was modelled using the weather conditions in APPENDIX A. The extent of flash fires was taken to be the flammable gas envelope, which was modelled using the Lower Flammability Limit (LFL) of methane.

For ruptures of the 600 mm compressor suction and discharge piping, it is considered that the flammable gas cloud would be ignited before it reaches its full extent, resulting in flashback to a jet fire. These rupture cases have therefore been modelled as resulting in jet fires if ignited.

6.5. Release rates

The release rate from a ruptured high pressure gas pipeline is characterised by an initial very high flow rate which rapidly decays to reach a steady state as the pipeline depressurises and the pressure wave moves away from the release location.

To avoid over-estimating the consequences of a release from a high pressure gas pipeline, the approach in AS 2885:2018, Ref [8], is to calculate a release rate for a quasi-steady state condition that exists 30 seconds after the initial release. This approach has been used to estimate the release rates from ruptures of the compressor suction and discharge lines. To avoid underestimating the release rate, a lower bound was set at the forward haul capacity of the MSP.

The release rates for ruptures of the compressor suction and discharge lines were modelled with Gexcon Effects using a 200 km pipeline section (equivalent to the largest distance between the compressor stations). The calculated release rates are summarised in Table 6.3. In line with the guidance in AS 2885, the release rates after 30 seconds (highlighted in green in Table 6.3) were used to model the fire consequence zones.

Table 6.3: Release rates for compressor suction and discharge line ruptures

Parameter	Section		Comment
	Compressor station inlet (CSI)	Gas compressor (CSC)	
Initial release rate (kg/s)	2330	2775	Release rate considered overly conservative for PHA.
Release rate after 30 seconds (kg/s)	1023	1100	Release rate used in PHA.
Quasi-steady state release rate (kg/s)	250	250	Release rate reached after approximately 200 seconds for both CSI and CSC.
MSP forward haul capacity (kg/s)	142	142	Based on future forward haul capacity of 611 TJ/day (current capacity of 489 TJ/day with additional 25% capacity following installation of MW433 and MW880).

For smaller hole sizes, the initial release rate was less than the MSP forward haul capacity. For these hole sizes, the initial release rates were used in the consequence assessment as it was assumed this would be sustained by the forward flow in the pipeline.

No account was taken for pressure decay that would occur following detection, isolation and blowdown. This is consistent with the approach adopted for determining radiation contour distances for full bore rupture of gas pipelines in AS 2885.

6.6. Results

Table 6.4 summarises the consequence distances for the hazardous scenarios assessed in this study; detailed results are contained in APPENDIX C. Based on the results of the consequence modelling, the following observations can be made:

- For jet fires, the distances to the 4.7 kW/m^2 heat radiation level (at which injury is anticipated) ranges from 2 m for a 2 mm hole size release from the LP fuel gas skid to approximately 620 m for a full bore rupture (600 mm) of the gas compressor discharge piping. The distances to the 23 kW/m^2 heat radiation level (at which property damage is anticipated) are lower and extend to approximately 510 m for a full bore rupture (600 mm) of the gas compressor discharge piping. Distances are modelled horizontally from the release location with the receptor 1.5 m above ground level.

- Flash fire impact areas are generally shorter in length and narrower, when compared to the jet fire impact areas. In the event of a flash back, the ensuing jet fire may therefore impact a larger area than the initial flash fire. This has been considered in the assessment by replacing the flash fire impact areas with the jet fire impact areas when the latter exceeds the former.

Table 6.4: Consequence results summary

ID	Hazard	Hole size (mm)	Maximum distance (m) to:			Minimum distance to site boundary (m)
			23 kW/m^2 (jet fire)	4.7 kW/m^2 (jet fire)	LFL (flash fire)	
CSI	Compressor station inlet	2	4	5	2	120 (MW880) 60 (MW433)
		6	11	13	5	
		22	37	44	18	
		85	125	150	212	
		600	501	610	N/A [(a)]	
CSC	Gas compressor	2	4	5	2	138 (MW880) 136 (MW433)
		6	11	14	5	
		22	38	46	19	
		85	131	158	73	
		600	510	621	N/A [(a)]	
LPG	LP fuel gas skid (power generation)	2	2	2	1	149 (MW880) 151 (MW433)
		6	5	6	2	
		22	17	20	7	
		80	55	66	26	
HPG	HP fuel gas skid (gas turbine)	2	3	3	1	161 (MW880) 149 (MW433)
		6	8	10	4	
		22	28	34	13	
		80	91	110	48	

Note:

(a) As detailed in Section 6.4, the flammable gas cloud from ruptures of the 600 mm compressor suction and discharge piping would be ignited before it reaches its full extent, resulting in flashback to a jet fire. These rupture cases have therefore been modelled as resulting in jet fires if ignited.

7. FREQUENCY ANALYSIS

7.1. Overview

The frequency of an event is the number of occurrences of the event over a specified period of time, generally taken as one year. The frequency of the hazardous scenarios for the compressor stations were estimated using event tree analysis and considering the following:

- Equipment leak frequencies.
- Ignition probability.
- Effect of safeguards.

7.2. Leak frequencies

Leak frequencies for the compressor stations were estimated by combining historical leak frequency data and a high level parts count of equipment within the stations using the PFDs shown in Section 4.3.1. Historical leak frequency data compiled by the IOGP (see APPENDIX D) was used for this study.

7.3. Ignition probability

Ignition probabilities for this study were derived based on the Energy Institute (EI) Research Report, Ref [9], as detailed in APPENDIX D. The EI information is based on plant size, plant type and release rate.

The EI Research Report provides some data and discussion on ignition timing. Although it suggests ignition timing may not always be a reliable indicator of the outcome, the usual approach in a risk assessment is to consider immediate ignition (resulting in a jet fire) versus delayed ignition (resulting in a flash fire). The EI Research Report indicates that the proportion of immediate ignition is 30% to 50%, with the remainder delayed – independent of release rate. For this study, a split of 50/50 immediate to delayed was adopted for releases, since in order to reach the large dispersion distances, a significant delay in ignition is required.

7.4. Effect of safeguards

Safeguards in place at the compressor stations may mitigate the consequences of loss of containment events. On loss of containment, gas will be released, which may be detected prior to ignition. If this were to occur and the pressure source isolated, then two consequences may be defined, i.e. a minor isolated consequence and a worse un-isolated consequence. Similarly, if the event is detected after ignition, then the consequent fire may be isolated, and its effects reduced. For the purpose of this study, all releases are taken to be un-isolated, which is a conservative approach.

7.5. Results

The frequencies estimated for the scenarios assessed in this study are shown in Table 7.1.

Table 7.1: Leak and outcome frequencies for compressor stations

ID	Hazard	Hole size (mm)	Leak frequency (per year)	Outcome frequency (per year)	
				Jet fire	Flash fire
CSI	Compressor station inlet	2	1.09×10^{-2}	5.04×10^{-6}	5.04×10^{-6}
		6	3.88×10^{-3}	2.79×10^{-6}	2.79×10^{-6}
		22	1.95×10^{-3}	6.98×10^{-6}	6.95×10^{-6}
		85	9.08×10^{-5}	5.40×10^{-6}	5.08×10^{-6}
		600	7.00×10^{-5}	3.81×10^{-5}	N/A (a)
CSC	Gas compressor	2	8.84×10^{-3}	4.16×10^{-6}	4.16×10^{-6}
		6	2.58×10^{-3}	1.97×10^{-6}	1.97×10^{-6}
		22	8.60×10^{-4}	3.65×10^{-6}	3.64×10^{-6}
		85	1.42×10^{-4}	9.83×10^{-6}	9.15×10^{-6}
		600	1.20×10^{-4}	6.51×10^{-5}	N/A (a)
LPG	LP fuel gas skid (power generation)	2	7.70×10^{-3}	3.35×10^{-6}	3.35×10^{-6}
		6	2.76×10^{-3}	1.33×10^{-6}	1.33×10^{-6}
		22	1.12×10^{-3}	1.12×10^{-6}	1.12×10^{-6}
		80	1.61×10^{-4}	1.38×10^{-6}	1.37×10^{-6}
HPG	HP fuel gas skid (gas turbine)	2	7.01×10^{-3}	3.15×10^{-6}	3.15×10^{-6}
		6	2.51×10^{-3}	1.50×10^{-6}	1.50×10^{-6}
		22	1.04×10^{-3}	1.17×10^{-6}	1.17×10^{-6}
		80	1.61×10^{-4}	4.72×10^{-6}	4.59×10^{-6}

Note:

(a) As detailed in Section 6.4, the flammable gas cloud from ruptures of the 600 mm compressor suction and discharge piping would be ignited before it reaches its full extent, resulting in flashback to a jet fire. These rupture cases have therefore been modelled as resulting in jet fires if ignited.

Jet fires from the compressor station may impinge on aboveground pipework associated with the existing ethane and natural gas scraper stations, some of which may be pressurised. This may result in rupture of the pipework in the event of impingement for an extended duration. The frequency of jet fires escalating to aboveground pipework at the existing ethane and natural gas scraper stations can be estimated as follows:

- Maximum jet fire frequency from Table 7.1 is 6.5×10^{-5} per year.
- Based on inspection of the layout of the compressor stations in relation to the existing scraper stations, it is considered that a jet fire may be oriented at the scraper station pipework within a 30° sector. The probability that a jet fire is pointed at the ethane and natural gas scraper stations pipework is taken to be 0.083 (30°/360°).

- Fire and gas detection will be provided in the compressor building, local equipment room and microturbines area, Ref [10]. In the event of fire and/or gas detection, shutdown and blowdown will be automatically initiated, Ref [11]. The probability that fire/gas detection, shutdown or blowdown systems fail to activate to prevent escalation is conservatively assumed to be 0.1.
- Probability of failure of impinged pipework is assumed to be 0.5.
- Frequency of jet fire escalation from compressor station is 0.3 x 10^{-6} per year.

The estimated frequency of jet fire escalation from the compressor station to aboveground pipework at the existing ethane and natural gas scraper stations is lower than the lowest risk criterion of 0.5 x 10^{-6} per year (fatality risk for sensitive land use). Jet fire escalation will therefore not contribute to fatality, escalation or property damage risk at the levels of concern (as specified by the risk criteria).

8. RISK ANALYSIS AND EVALUATION

8.1. Overview

Risk analysis was performed using Gexcon Riskcurves, which combines the consequences and frequencies of the identified hazardous scenarios. Assessment of the risk results against relevant risk criteria was then conducted.

Using the information from the quantitative analysis, assessment against qualitative criteria was then carried out.

8.2. Risk analysis

8.3. Fatality risk

Fatality risk results were reported as individual fatality risk contours, which are overlaid on the site maps. The contours represent the risk posed to geographical locations without factoring in a time at that location. The individual fatality risk contours for the compressor stations are shown in the following:

- Figure 8.1 for MW433 Round Hill.
- Figure 8.2 for MW880 Milne.

For both sites, the 50 x 10^{-6} per year fatality risk contour was not generated. Lower fatality risk levels corresponding to the criteria for recreational, commercial, residential and sensitive land uses were found to extend beyond the site boundary.

Figure 8.1: Individual fatality risk contours - MW433 Round Hill

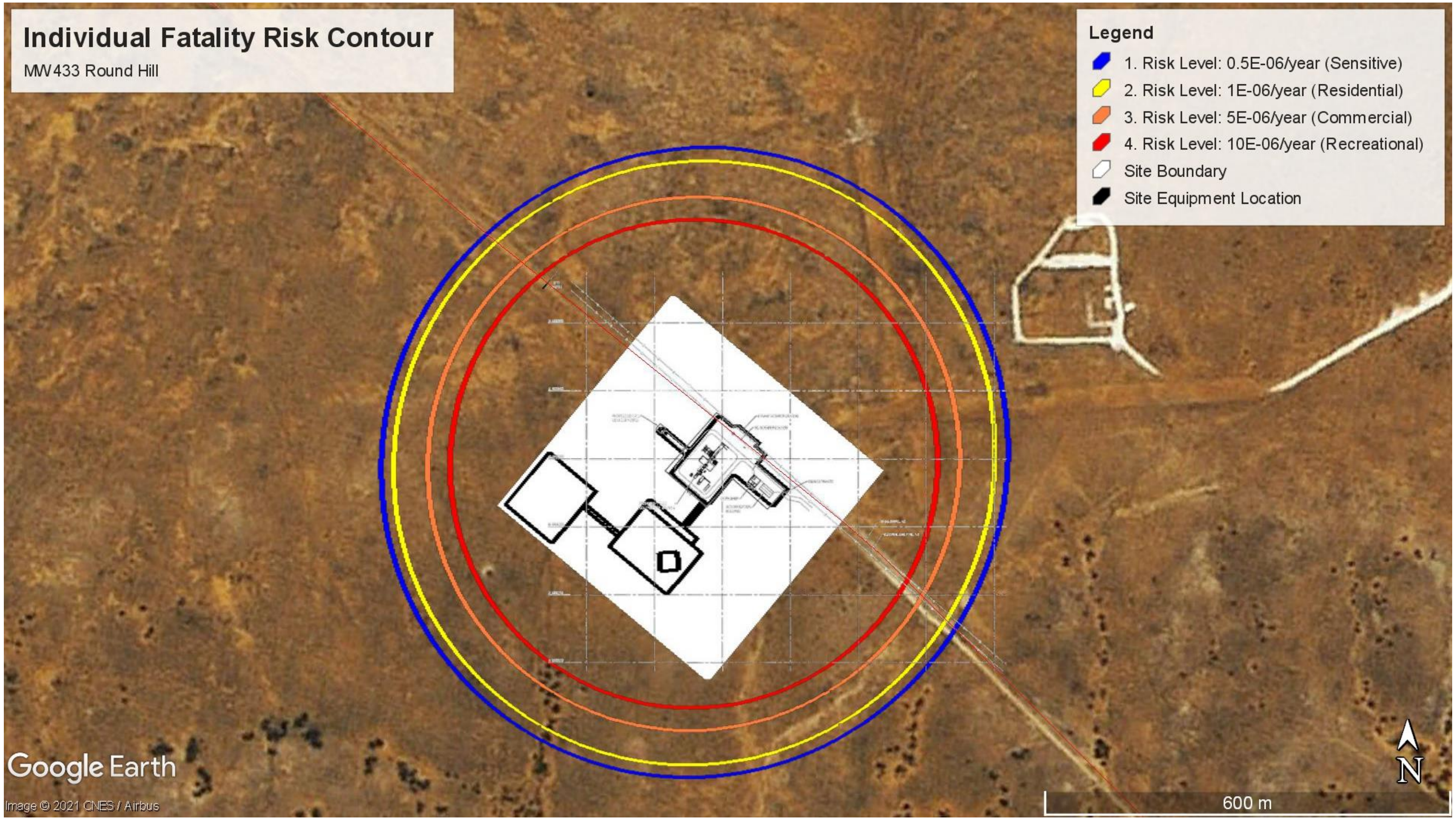
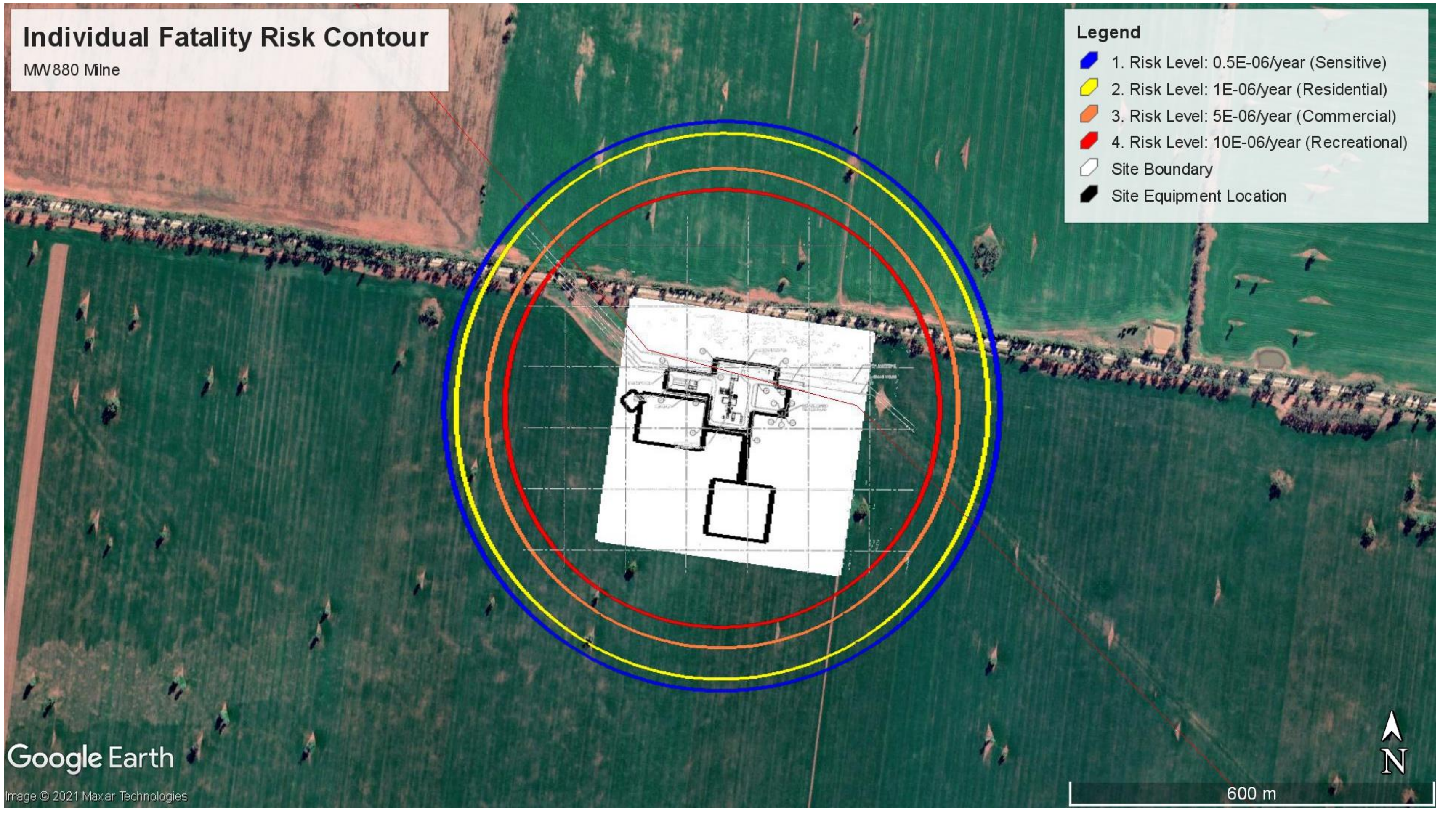


Figure 8.2: Individual fatality risk contours - MW880 Milne



8.4. Injury and property damage risk

Injury risk contours for the compressor stations are shown in the following:

- Figure 8.3 for MW433 Round Hill.
- Figure 8.4 for MW880 Milne.

The 50 x 10^{-6} per year injury risk contour was found to extend beyond the site boundary.

For both sites, the 50 x 10^{-6} per year property damage risk contour was not reached.

Figure 8.3: Injury risk contour - MW433 Round Hill

Figure 8.4: Injury risk contour - MW880 Milne

8.5. Risk evaluation

8.5.1. Fatality risk

Table 8.1 provides a comparison of the individual fatality risk assessed for the compressor stations against the individual fatality risk criteria specified by DPIE (see Section 4.5.2). All compressor stations were found to comply with the individual fatality risk criteria.

8.5.2. Injury and property damage risk

Table 8.2 provides a comparison of the injury and property damage risk assessed for the compressor stations against the injury and property damage risk criteria specified by DPIE (see Section 4.5.2). All compressor stations were found to comply with the injury and property damage risk criteria.

Table 8.1: Evaluation of individual fatality risk

Land use	Description	Risk criteria (per year)	Compliance with criteria?		Comments
			MW433	MW880	
Sensitive	Hospitals, child-care facilities and old age housing	0.5×10^{-6}	Yes	Yes	Although the risk contour extends beyond the site boundaries of the compressor stations, there are no sensitive land uses in this area.
Residential	Residential developments and places of continuous occupancy such as hotels and tourist resorts	1×10^{-6}	Yes	Yes	Although the risk contour extends beyond the site boundaries of the compressor stations, there are no residential land uses in this area.
Commercial	Commercial developments, including offices, retail centres and entertainment centres	5×10^{-6}	Yes	Yes	Although the risk contour extends beyond the site boundaries of the compressor stations, there are no commercial land uses in this area.
Recreational	Sporting complexes and active open space areas	10×10^{-6}	Yes	Yes	Although the risk contour extends beyond the site boundaries of the compressor stations, there are no recreational land uses in this area.
Industrial	Target for site boundary	50×10^{-6}	Yes	Yes	The 50×10^{-6} per year fatality risk level was not reached at the compressor stations.

Table 8.2: Evaluation of injury and property damage risk

Criteria type	Description	Risk criteria (per year)	Compliance with criteria?		Comments
			MW433	MW880	
Injury	Incident heat flux radiation at residential and sensitive use areas should not exceed 4.7 kW/m^2	50 x 10^{-6}	Yes	Yes	Although the injury contour extends beyond the site boundaries of the compressor stations, there are no sensitive land uses in this area.
Property damage	Incident heat flux radiation at neighbouring potentially hazardous installations or at land zoned to accommodate such installations should not exceed 23 kW/m^2	50 x 10^{-6}	Yes	Yes	The 50 x 10^{-6} per year risk level corresponding to an incident heat flux of 23 kW/m^2 was not reached at the compressor stations.

8.6. Sensitivity analysis

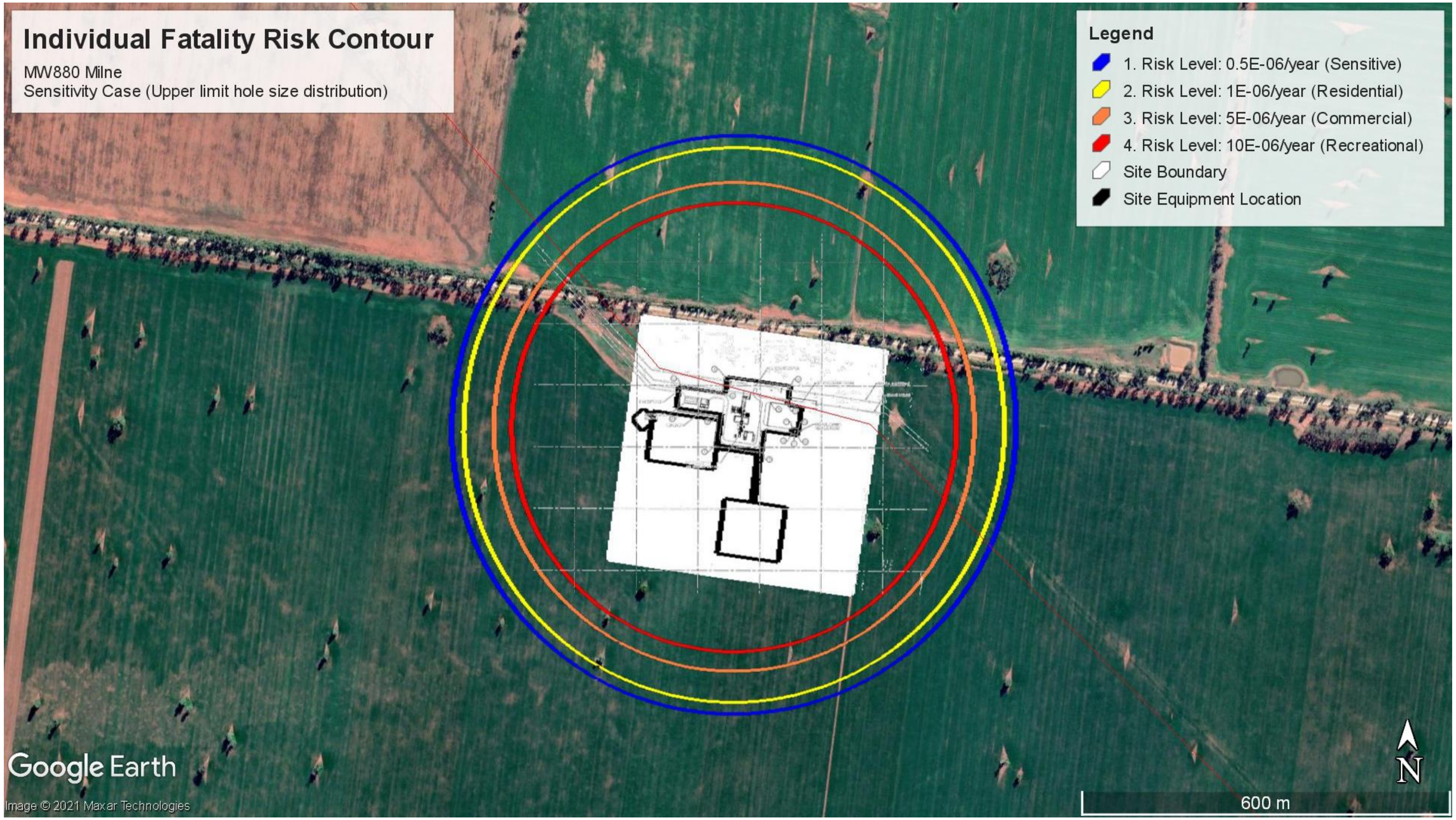
A sensitivity analysis was conducted to assess the impact of the hole sizes assumed in this study. As detailed in Section 6.3, information on leak sizes were derived from the IOGP process equipment hole size range, Ref [7]. For the base case for each of the compressor stations, the hole sizes selected were the geometric mean within the hole size range. For the sensitivity cases, the upper bounds of the hole size ranges were used as the representative hole sizes, as shown in Table 8.3.

Table 8.3: Comparison of hole sizes for base case and sensitivity analysis

Process equipment hole diameter range (mm), Ref [7]	Representative hole size used for PHA (mm)	
	Base case	Sensitivity case
1 to 3	2	3
3 to 10	6	10
10 to 50	22	50
50 to 150	85	150
>150	Full bore	Full bore

Figure 8.5 shows the individual fatality risk contours for MW880 Milne using the upper bound hole sizes. With reference to the base case individual fatality risk contours shown in Figure 8.2, it can be seen that the hole size distribution has little effect on the individual fatality risk contours. This is because the main contributors to the individual fatality risk are ignited events from full bore ruptures of the compressor station inlet (including compressor suction) and compressor discharge piping, which have the same hole size in the base and sensitivity cases.

Figure 8.5: Individual fatality risk contours for MW880 Milne – sensitivity analysis



8.7. Qualitative risk assessment

Assessment against the general qualitative risk principles is shown in Table 8.4.

Table 8.4: General qualitative risk principles

Qualitative criteria	Comment
Avoid avoidable risks	Capacity requirements and pipeline pressure profile dictates the need and location of the compression stations. Elimination is therefore not practicable.
The risk from a major hazard should be reduced wherever practicable, even where the likelihood of exposure is low.	Refer to Section 9.
The effects of significant events should, wherever possible be contained within the site boundary.	Consequence modelling has shown that the most likely leak sizes (i.e. smaller hole sizes) are contained within the DP lot boundary, refer to Section 6.5.
Where the risk from an existing installation is already high, further development should not pose any incremental risk.	The existing installation comprises ethane and natural gas scraper stations and the risks from these are not high.

9. RISK REDUCTION

9.1. Overview

The risk assessment results presented in Section 8 demonstrates that the risk of injury, fatality, and property damage associated with the compressor stations comply with the risk criteria defined by DPIE. In line with the requirement that '*the risk from a major hazard should be reduced wherever practicable, even where the likelihood of exposure is low*', additional risk reduction measures should be considered and implemented where practicable. The following section identifies potential risk reduction measures for consideration by APA.

9.2. Risk reduction measures

At this stage of the project, it is unclear what risk reduction measures will be included in the design of the compressor stations. Potential risk reduction measures may include the following:

- Orientation of flanges and piping away from pipework associated with the existing ethane and natural gas scraper stations as well as the local equipment room.
- Fire, gas and smoke detection systems and fire suppression system for the compressor building and local equipment room.
- Protective painting on aboveground pipework to minimise corrosion.
- Protection from accidental vehicle impact through the use of bollards or other physical barriers.
- Security arrangements to prevent unauthorised site access.

10. CONCLUSION

A PHA was undertaken of the compressor stations associated with APA's East Coast Grid Expansion (Modification 1) to assess the hazards and risk aspects of the compressor stations in terms of their potential impact on the surrounding land use. Quantitative results have been provided in terms of fatality, injury and property damage risk levels, which show that relevant HIPAP 4 quantitative risk criteria are met.

The DPIE provides indicative societal risk criteria for when there is significant population around a potentially hazardous facility. As there is no significant population around either of the compressor stations; societal risk has not been calculated for this study.

In line with the requirement that '*the risk from a major hazard should be reduced wherever practicable, even where the likelihood of exposure is low*', additional risk reduction measures should be considered and implemented where practicable. Potential risk reduction measures which may be considered are provided in Section 9.2.

APPENDIX A. METEOROLOGICAL DATA

A1. Data source

Meteorological data for each compressor station was obtained using the BOM weather stations summarised in Table A.1. The acquired data sets covered a period of 7 years, from 2012 to 2019.

Table A.1: Weather stations

ID	Name	BOM Weather station
MW433	Round Hill	White Cliffs AWS
MW880	Milne	Condobolin

A2. Data analysis

Analysis of the data was performed using the methodology outlined in the TNO Purple Book, Ref [12], to obtain the representative weather conditions (including wind speed and stability classes) appropriate for the PHA.

As cloud cover data was unavailable for the weather stations, representative weather conditions were determined based on the wind speed and whether occurrence was during the day or at night. An overview of the rule set used to determine the representative weather condition using the Purple Book approach is shown in Table A.2.

Table A.2: Rule set for representative weather conditions

Time of day	Wind speed range (m/s)	Pasquill stability class	Average wind speed (m/s)
Day	< 2	B	1.2
	2 – 4	D	3.0
	> 4	D	6.0
Night	< 1.5	F	0.9
	1.5 – 3	E	2.2
	3 – 5	D	3.8
	> 5	D	6.6

For the PHA model, the data were consolidated into different representative weather conditions. The meteorological data sets used for the assessment and the associated wind roses are presented in the following sections.

A3. Data used

A3.1. MW433 Round Hill

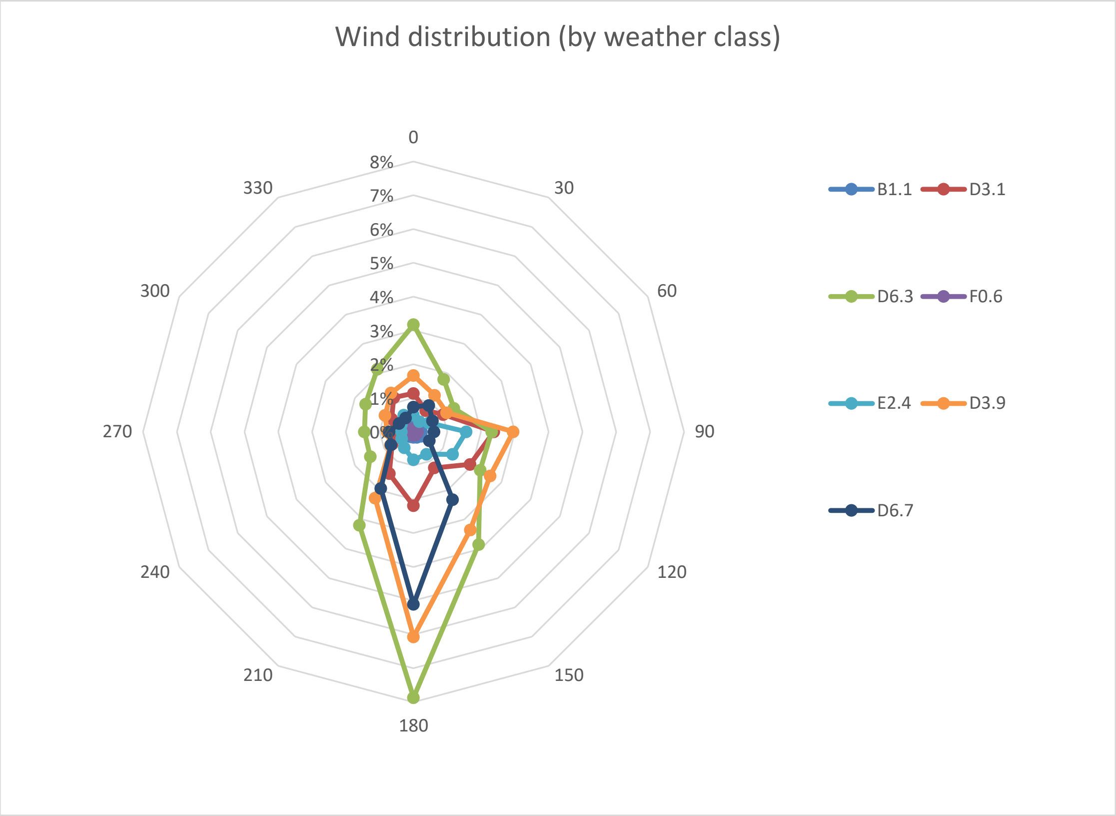
Direction wind from (degrees true)	B1.1 Day	B1.1 Night	D3.9 Day	D3.9 Night	D3.1 Day	D3.1 Night	D6.7 Day	D6.7 Night	D6.3 Day	D6.3 Night	E2.4 Day	E2.4 Night	F0.6 Day	F0.6 Night	Total Day	Total Night
0	0.40	0.00	0.00	3.31	2.25	0.00	0.00	1.45	6.30	0.00	0.00	0.98	0.00	0.26	8.95	6.00
30	0.40	0.00	0.00	2.48	1.43	0.00	0.00	1.79	3.56	0.00	0.00	0.68	0.00	0.27	5.39	5.23
60	0.33	0.00	0.00	2.25	2.02	0.00	0.00	1.29	2.75	0.00	0.00	1.05	0.00	0.29	5.09	4.88
90	0.54	0.00	0.00	5.86	4.72	0.00	0.00	1.20	4.60	0.00	0.00	3.10	0.00	0.33	9.86	10.49
120	0.59	0.00	0.00	5.20	3.84	0.00	0.00	1.07	4.52	0.00	0.00	2.65	0.00	0.32	8.95	9.24
150	0.45	0.00	0.00	6.67	2.46	0.00	0.00	4.60	7.66	0.00	0.00	1.53	0.00	0.31	10.56	13.10
180	0.39	0.00	0.00	12.06	4.35	0.00	0.00	10.15	15.63	0.00	0.00	1.65	0.00	0.30	20.37	24.16
210	0.42	0.00	0.00	4.51	2.84	0.00	0.00	3.84	6.35	0.00	0.00	1.09	0.00	0.27	9.61	9.70
240	0.35	0.00	0.00	1.56	1.45	0.00	0.00	1.53	2.93	0.00	0.00	0.81	0.00	0.30	4.74	4.20
270	0.37	0.00	0.00	1.55	1.10	0.00	0.00	1.43	2.88	0.00	0.00	0.70	0.00	0.31	4.34	4.00
300	0.38	0.00	0.00	1.93	1.48	0.00	0.00	0.97	3.25	0.00	0.00	0.82	0.00	0.29	5.11	4.02
330	0.44	0.00	0.00	2.63	2.32	0.00	0.00	0.93	4.25	0.00	0.00	1.13	0.00	0.29	7.01	4.99
Total	**5.06**	**0.00**	**0.00**	**50.00**	**30.26**	**0.00**	**0.00**	**30.26**	**64.68**	**0.00**	**0.00**	**16.19**	**0.00**	**3.54**	**100.00**	**100.00**

A3.2. MW880 Milne

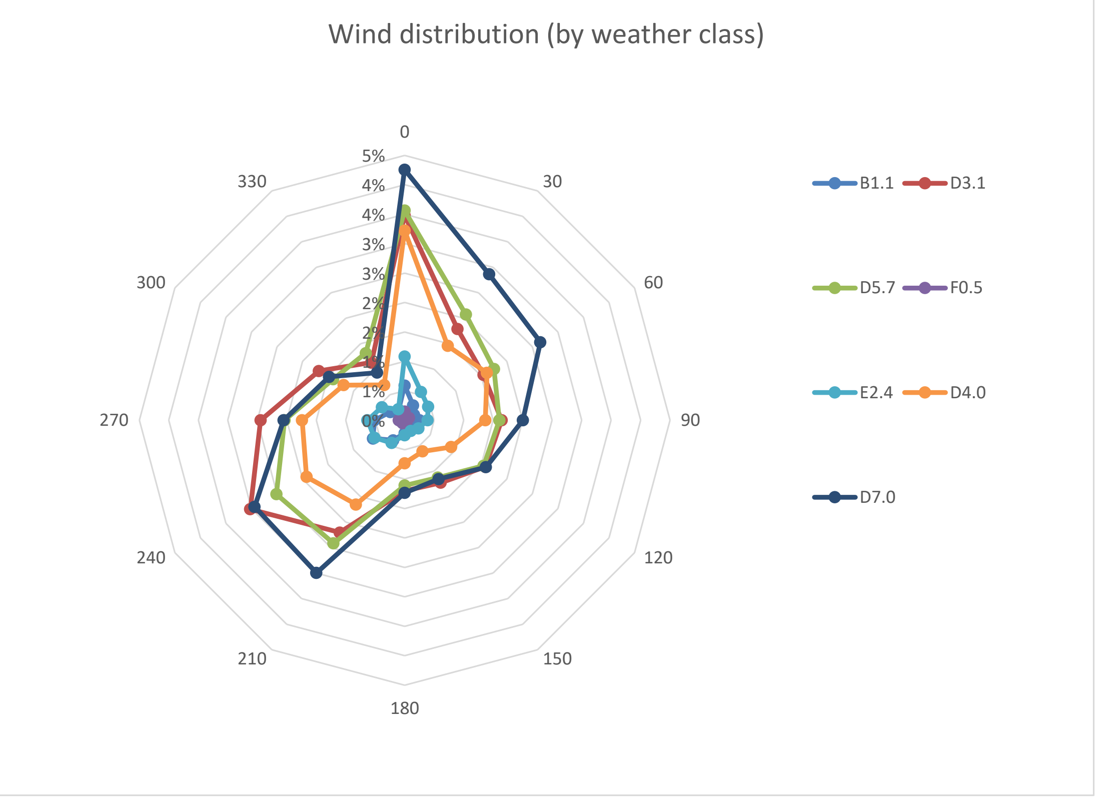
Direction wind from (degrees true)	B1.1 Day	B1.1 Night	D4.0 Day	D4.0 Night	D3.1 Day	D3.1 Night	D7.0 Day	D7.0 Night	D5.7 Day	D5.7 Night	E2.4 Day	E2.4 Night	F0.5 Day	F0.5 Night	Total Day	Total Night
0	1.33	0.00	0.00	6.42	6.94	0.00	0.00	8.48	7.10	0.00	0.00	2.16	0.00	0.40	15.36	17.47
30	0.72	0.00	0.00	2.91	3.57	0.00	0.00	5.71	4.13	0.00	0.00	1.11	0.00	0.22	8.43	9.95
60	0.52	0.00	0.00	3.21	3.07	0.00	0.00	5.29	3.48	0.00	0.00	0.91	0.00	0.27	7.07	9.68
90	0.64	0.00	0.00	2.72	3.28	0.00	0.00	3.99	3.20	0.00	0.00	0.78	0.00	0.18	7.12	7.67
120	0.55	0.00	0.00	1.81	3.15	0.00	0.00	3.17	3.08	0.00	0.00	0.54	0.00	0.18	6.78	5.70
150	0.47	0.00	0.00	1.22	2.44	0.00	0.00	2.30	2.24	0.00	0.00	0.41	0.00	0.15	5.15	4.07
180	0.59	0.00	0.00	1.45	2.39	0.00	0.00	2.46	2.21	0.00	0.00	0.51	0.00	0.15	5.19	4.56
210	0.93	0.00	0.00	3.29	4.39	0.00	0.00	5.97	4.81	0.00	0.00	0.88	0.00	0.22	10.12	10.36
240	1.38	0.00	0.00	3.83	6.02	0.00	0.00	5.85	5.00	0.00	0.00	1.18	0.00	0.22	12.41	11.08
270	1.17	0.00	0.00	3.47	4.87	0.00	0.00	4.09	4.06	0.00	0.00	1.26	0.00	0.30	10.09	9.11
300	0.71	0.00	0.00	2.38	3.34	0.00	0.00	2.95	2.79	0.00	0.00	0.89	0.00	0.24	6.84	6.46
330	0.56	0.00	0.00	1.38	2.26	0.00	0.00	1.86	2.63	0.00	0.00	0.43	0.00	0.21	5.44	3.88
Total	**9.56**	**0.00**	**0.00**	**34.10**	**45.72**	**0.00**	**0.00**	**52.12**	**44.72**	**0.00**	**0.00**	**11.05**	**0.00**	**2.74**	**100.00**	**100.00**

A4. Wind roses

A4.1. MW433 Round Hill



A4.2. MW880 Milne



APPENDIX B. HAZARD IDENTIFICATION WORD DIAGRAM

Area	Hazard Scenario	Causes/Threats	Consequences	Typical Control Measures	Assess in PHA?	Comments
Compressor station inlet	Release of natural gas from compressor station inlet piping	• Corrosion • Mechanical failure (e.g. flange/gasket leak) • Overpressure • Maintenance error	If ignited, a jet/flash fire would occur, resulting in equipment damage and potentially: • injury/fatality of personnel (if present) • injury to third parties (if present in the vicinity) An explosion is considered unlikely due to the low level of confinement / congestion at the compressor station.	• Technical integrity of compression equipment, including corrosion allowance, pipe stress analysis, separation distance from existing pipeline equipment, orientation of equipment, external painting, QC checks including flange bolt tightness, hydrotesting and pressurisation leak checks and low level of confinement/congestion. • Inspection and preventative maintenance program, including in-service inspections of equipment, in-service testing of Emergency Shutdown systems and instrument calibration. • Operating procedures and trained operators • Secured area around gas compression station. • Remote monitoring of pressure and flow (low pressure detection and isolation). • Emergency shutdown system (independent safety PLC for critical process safety items, i.e. overpressure events). • Fire and gas detection in the compressor building, local equipment room and microturbines area. • Emergency response procedures.	Yes	Clean natural gas with low corrosive potential. Includes fuel gas heater, fuel gas filter and compressor suction scrubber

Area	Hazard Scenario	Causes/Threats	Consequences	Typical Control Measures	Assess in PHA?	Comments
Gas compressor	Release of natural gas from gas compressor or associated downstream equipment/piping to compressor station outlet	• Corrosion • Mechanical failure (e.g. flange/gasket leak) • Overpressure • Maintenance error	If ignited, a jet/flash fire would occur, resulting in equipment damage and potentially: • injury/fatality of personnel (if present) • injury to third parties (if present in the vicinity) An explosion is considered unlikely due to the low level of confinement / congestion at the compressor station.	• Technical integrity of compression equipment, including corrosion allowance, pipe stress analysis, separation distance from existing pipeline equipment, orientation of equipment, external painting, QC checks including flange bolt tightness, hydrotesting and pressurisation leak checks and low level of confinement/congestion. • Inspection and preventative maintenance program, including in-service inspections of equipment, in-service testing of Emergency Shutdown systems and instrument calibration. • Operating procedures and trained operators • Secured area around gas compression station. • Remote monitoring of pressure and flow (low pressure detection and isolation). • Emergency shutdown system (independent safety PLC for critical process safety items, i.e. overpressure events). • Fire and gas detection in the compressor building, local equipment room and microturbines area. • Emergency response procedures.	Yes	Clean natural gas with low corrosive potential. Includes air cooled heat exchanger

Area	Hazard Scenario	Causes/Threats	Consequences	Typical Control Measures	Assess in PHA?	Comments
LP fuel gas skid (power generation)	Release of natural gas from LP fuel gas skid equipment/piping	• Corrosion • Mechanical failure (e.g. flange/gasket leak) • Overpressure • Maintenance error	If ignited, a jet/flash fire would occur, resulting in equipment damage and potentially: • injury/fatality of personnel (if present) • injury to third parties (if present in the vicinity) An explosion is considered unlikely due to the low level of confinement / congestion at the compressor station.	• Technical integrity of compression equipment, including corrosion allowance, pipe stress analysis, separation distance from existing pipeline equipment, orientation of equipment, external painting, QC checks including flange bolt tightness, hydrotesting and pressurisation leak checks and low level of confinement/congestion. • Inspection and preventative maintenance program, including in-service inspections of equipment, in-service testing of Emergency Shutdown systems and instrument calibration. • Operating procedures and trained operators • Secured area around gas compression station. • Remote monitoring of pressure and flow (low pressure detection and isolation). • Emergency shutdown system (independent safety PLC for critical process safety items, i.e. overpressure events). • Fire and gas detection in the compressor building, local equipment room and microturbines area. • Emergency response procedures.	Yes	Clean natural gas with low corrosive potential. Includes LP fuel gas flow meter, LP fuel gas filter and micro-turbine generator

Area	Hazard Scenario	Causes/Threats	Consequences	Typical Control Measures	Assess in PHA?	Comments
HP fuel gas skid (gas turbine)	Release of natural gas from HP fuel gas skid equipment/piping	• Corrosion • Mechanical failure (e.g. flange/gasket leak) • Overpressure • Maintenance error	If ignited, a jet/flash fire would occur, resulting in equipment damage and potentially: • injury/fatality of personnel (if present) • injury to third parties (if present in the vicinity) An explosion is considered unlikely due to the low level of confinement / congestion at the compressor station.	• Technical integrity of compression equipment, including corrosion allowance, pipe stress analysis, separation distance from existing pipeline equipment, orientation of equipment, external painting, QC checks including flange bolt tightness, hydrotesting and pressurisation leak checks and low level of confinement/congestion. • Inspection and preventative maintenance program, including in-service inspections of equipment, in-service testing of Emergency Shutdown systems and instrument calibration. • Operating procedures and trained operators • Secured area around gas compression station. • Remote monitoring of pressure and flow (low pressure detection and isolation). • Emergency shutdown system (independent safety PLC for critical process safety items, i.e. overpressure events). • Fire and gas detection in the compressor building, local equipment room and microturbines area. • Emergency response procedures.	Yes	Clean natural gas with low corrosive potential. Includes HP fuel gas flow meter, HP fuel gas filter and gas turbine

APPENDIX C. CONSEQUENCE MODELLING

This appendix contains the consequence modelling results:

- Jet fires.
- Flash fires.

			Jet fire - distance to heat radiation (m)															Flash fire - Distance to LFL (m)				
			B 1.1 m/s			D 3.5 m/s			D 6.4 m/s			E 2.4 m/s			F 0.5 m/s			B 1.1 m/s	D 3.5 m/s	D 6.4 m/s	E 2.4 m/s	F 0.5 m/s
Description	**Pressure (barg)**	**Hole size (mm)**	**23 kW/m^2**	**12.6 kW/m^2**	**4.7 kW/m^2**	**23 kW/m^2**	**12.6 kW/m^2**	**4.7 kW/m^2**	**23 kW/m^2**	**12.6 kW/m^2**	**4.7 kW/m^2**	**23 kW/m^2**	**12.6 kW/m^2**	**4.7 kW/m^2**	**23 kW/m^2**	**12.6 kW/m^2**	**4.7 kW/m^2**					
Compressor station inlet	45	2	4	4	4	3	3	4	3	3	3	4	4	4	4	4	5	2	2	2	2	2
Compressor station inlet	45	6	10	11	12	9	9	11	8	8	10	10	10	12	11	12	13	5	5	5	5	5
Compressor station inlet	45	22	34	36	41	29	31	36	25	28	33	32	34	39	37	39	44	18	18	18	18	18
Compressor station inlet	45	85	115	123	140	99	107	125	88	96	114	109	117	135	125	133	150	139	134	98	212	212
Compressor station inlet	45	600	462	494	569	402	436	514	357	391	470	440	473	550	501	534	610	N/A	N/A	N/A	N/A	N/A
Gas compressor	57	2	4	4	4	3	3	4	3	3	3	4	4	4	4	4	5	2	2	2	2	2
Gas compressor	57	6	11	11	13	9	10	11	8	9	10	10	11	12	11	12	14	5	5	5	5	5
Gas compressor	57	22	35	38	43	30	33	38	27	29	34	34	36	41	38	41	46	19	19	19	19	19
Gas compressor	57	85	121	129	148	105	113	132	92	101	120	115	123	142	131	140	158	73	73	73	73	73
Gas compressor	57	600	470	503	580	409	443	523	363	397	478	448	481	559	510	544	621	N/A	N/A	N/A	N/A	N/A
LP fuel gas skid	7	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	1	1	1	1	1
LP fuel gas skid	7	6	5	5	6	4	4	5	4	4	4	4	5	5	5	5	6	2	2	2	2	2
LP fuel gas skid	7	22	16	17	19	13	14	17	12	13	15	15	16	18	17	18	20	7	7	7	7	7
LP fuel gas skid	7	80	51	54	62	44	47	55	39	42	50	48	52	59	55	58	66	26	26	26	26	26
HP fuel gas skid	25	2	3	3	3	2	3	3	2	2	2	3	3	3	3	3	3	1	1	1	1	1
HP fuel gas skid	25	6	8	8	9	7	7	8	6	6	7	7	8	9	8	9	10	4	4	4	4	4
HP fuel gas skid	25	22	26	28	31	22	24	28	20	21	25	25	26	30	28	30	34	13	13	13	13	13
HP fuel gas skid	25	80	84	90	103	73	78	91	64	70	83	80	86	99	91	97	110	48	48	48	48	48

APPENDIX D. FREQUENCY ANALYSIS

D1. Historical leak frequency data

Table D.1 summarises historical leak frequency data compiled by the IOGP, Ref [7], which were used for this study.

Table D.1: Historical leak frequency data from IOGP

Equipment Type	Leak Frequency per hole size in mm					Units
Hole size range→	1-3	3-10	10-50	50-150	>150	
Representative hole size→	2	6	22	85	Rupture	
Compressor (reciprocating)	2.4×10^{-2}	8.0×10^{-3}	2.6×10^{-3}	4.0×10^{-4}	4.8×10^{-4}	per compressor-year
Compressor (centrifugal)	3.4×10^{-3}	6.8×10^{-4}	1.3×10^{-4}	1.0×10^{-5}	2.5×10^{-6}	per compressor-year
Heat exchanger (shell side)	1.20×10^{-3}	4.10×10^{-4}	1.40×10^{-4}	2.40×10^{-5}	1.20×10^{-5}	per exchanger-year
Heat exchanger (tube side)	8.20×10^{-4}	3.80×10^{-4}	1.80×10^{-4}	4.30×10^{-5}	3.30×10^{-5}	per exchanger-year
Heat exchanger (plate)	3.90×10^{-3}	2.00×10^{-3}	1.10×10^{-3}	3.20×10^{-4}	3.10×10^{-4}	per exchanger-year
Heat exchanger (Fin Fan)	1.00×10^{-3}	4.90×10^{-4}	2.40×10^{-4}	6.00×10^{-5}	4.90×10^{-5}	per exchanger-year
Instrument fitting	1.80×10^{-4}	6.80×10^{-5}	2.50×10^{-5}			per instrument-year
Pig receiver/launcher	2.3×10^{-3}	7.2×10^{-4}	2.2×10^{-4}	3.3×10^{-5}	1.4×10^{-5}	per pig trap year
Pressure vessel (process)	3.9×10^{-4}	2.0×10^{-4}	1.0×10^{-4}	2.7×10^{-5}	2.4×10^{-5}	per vessel-year
Pressure vessel (storage)	2.3×10^{-5}	1.2×10^{-5}	7.1×10^{-6}	4.3×10^{-6}	4.7×10^{-7}	per vessel-year
Pump (centrifugal)	5.1×10^{-3}	1.8×10^{-3}	5.9×10^{-4}	9.7×10^{-5}	4.8×10^{-5}	per pump year
Pump (reciprocating)	3.3×10^{-3}	1.9×10^{-3}	1.2×10^{-3}	3.7×10^{-4}	4.3×10^{-4}	per pump year
Filter	1.3×10^{-3}	5.1×10^{-4}	1.9×10^{-4}	3.5×10^{-5}	2.0×10^{-5}	per filter-year
Flanges ANSI Raised Face - 50mm	2.6×10^{-6}	7.6×10^{-7}	1.2×10^{-6}			per flange-year
Flanges ANSI Raised Face - 150mm	3.7×10^{-6}	1.1×10^{-6}	9.0×10^{-7}	6.0×10^{-7}		per flange-year
Flanges ANSI Raised Face - 300mm	5.9×10^{-6}	1.7×10^{-6}	1.4×10^{-6}	1.8×10^{-7}	3.4×10^{-7}	per flange-year
Flanges ANSI Raised Face - 450mm	8.3×10^{-6}	2.4×10^{-6}	2.0×10^{-6}	2.6×10^{-7}	3.6×10^{-7}	per flange-year
Flanges ANSI Raised Face - 600mm	1.1×10^{-5}	3.2×10^{-6}	2.6×10^{-6}	3.3×10^{-7}	3.8×10^{-7}	per flange-year
Flanges ANSI Raised Face - 900mm	1.7×10^{-5}	4.9×10^{-6}	4.2×10^{-6}	5.4×10^{-7}	4.4×10^{-7}	per flange-year
Valve (automated) - 50mm	2.4×10^{-4}	7.3×10^{-5}	3.0×10^{-5}			per valve-year
Valve (automated) - 150mm	2.2×10^{-4}	6.6×10^{-5}	1.9×10^{-5}	8.6×10^{-6}		per valve-year
Valve (automated) - 300mm	2.1×10^{-4}	6.3×10^{-5}	1.8×10^{-5}	2.4×10^{-6}	6.0×10^{-6}	per valve-year
Valve (automated) - 450mm	2.0×10^{-4}	6.0×10^{-5}	1.7×10^{-5}	2.3×10^{-6}	5.9×10^{-6}	per valve-year
Valve (automated) - 600mm	2.0×10^{-4}	5.9×10^{-5}	1.7×10^{-5}	2.2×10^{-6}	5.9×10^{-6}	per valve-year

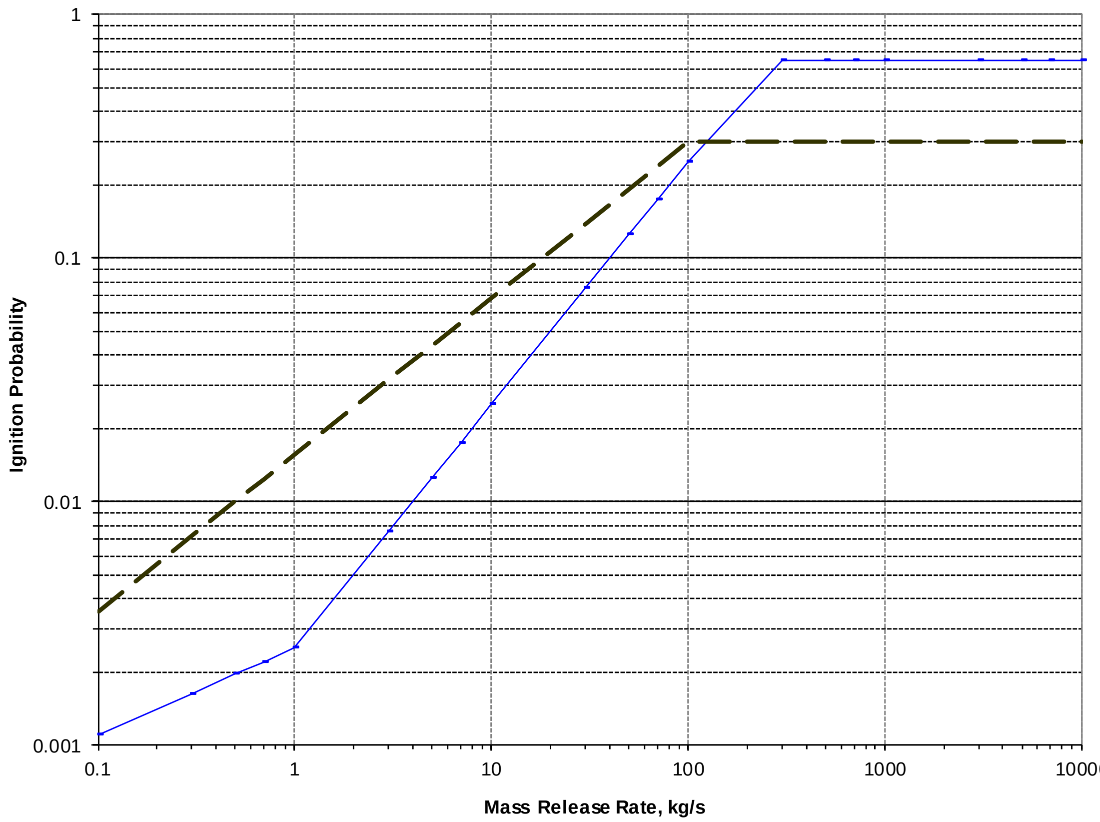
Equipment Type	Leak Frequency per hole size in mm					Units
Hole size range→	1-3	3-10	10-50	50-150	>150	
Representative hole size→	2	6	22	85	Rupture	
Valve (automated) - 900mm	1.9×10^{-4}	5.6×10^{-5}	1.6×10^{-5}	2.2×10^{-6}	5.9×10^{-6}	per valve-year
Valve (manual) - 50mm	2.0×10^{-5}	7.7×10^{-6}	4.9×10^{-6}			per valve-year
Valve (manual) - 150mm	3.1×10^{-5}	1.2×10^{-5}	4.7×10^{-6}	2.4×10^{-6}		per valve-year
Valve (manual) - 300mm	4.3×10^{-5}	1.7×10^{-5}	6.5×10^{-6}	1.2×10^{-6}	1.7×10^{-6}	per valve-year
Valve (manual) - 450mm	5.3×10^{-5}	2.1×10^{-5}	8.0×10^{-6}	1.5×10^{-6}	1.9×10^{-6}	per valve-year
Valve (manual) - 600mm	6.2×10^{-5}	2.4×10^{-5}	9.4×10^{-6}	1.8×10^{-6}	2.1×10^{-6}	per valve-year
Valve (manual) - 900mm	7.8×10^{-5}	3.0×10^{-5}	1.2×10^{-5}	2.2×10^{-5}	2.3×10^{-6}	per valve-year
Process Piping - 50mm	5.5×10^{-5}	1.8×10^{-5}	7.0×10^{-6}			per m-year
Process Piping - 150mm	2.6×10^{-5}	8.5×10^{-6}	2.7×10^{-6}	6.0×10^{-7}		per m-year
Process Piping - 300mm	2.3×10^{-5}	7.6×10^{-6}	2.4×10^{-6}	3.7×10^{-7}	1.7×10^{-7}	per m-year
Process Piping - 450mm	2.3×10^{-5}	7.5×10^{-6}	2.4×10^{-6}	3.6×10^{-7}	1.7×10^{-7}	per m-year
Process Piping - 600mm	2.3×10^{-5}	7.4×10^{-6}	2.4×10^{-6}	3.6×10^{-7}	1.6×10^{-7}	per m-year
Process Piping - 900mm	2.3×10^{-5}	7.4×10^{-6}	2.3×10^{-6}	3.6×10^{-7}	1.6×10^{-7}	per m-year

D2. Ignition probability

The EI Research Report, Ref [9], was used for ignition probabilities of releases from the compressor stations. These EI information is based on plant size, plant type and release rate. For the purposes of this study, 'ignition model no. 8 - large plant gas LPG (gas or LPG release from large onshore plant)' was used. This ignition model is intended for application to releases of flammable gases, vapour or liquids significantly above their normal boiling point from large onshore outdoor plants (plant area above 1,200 m^2, site area above 35,000 m^2).

Figure D.1 shows the ignition probability vs mass release rate (blue). The ignition probability for gas suggested by Cox et al, Ref [13], is shown for reference as the black dashed line. Form this graph, it can be seen that the Cox et al ignition probability is higher for low release rates (up to 100 kg/s), but the EI ignition probability is higher above 100kg/s, with a maximum ignition probability of approximately 0.65, which is double that for the Cox et al relationship.

Figure D.1: Ignition probabilities



The EI Research Report provides some data and discussion on ignition timing. Although it suggests ignition timing may not always be a reliable indicator of the outcome, the usual approach in a PHA is to consider immediate ignition (resulting in a jet fire or fireball) versus delayed ignition (resulting in a flash fire or VCE). The EI Research Report indicates that the proportion of immediate ignition is 30% to 50%, with the remainder delayed – independent of release rate. For this study, a split of 50/50 immediate to delayed was adopted for releases, since in order to reach the large dispersion distances, a significant delay in ignition is required.

APPENDIX E. REFERENCES

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