



**REVISED PRELIMINARY HAZARD ANALYSIS,
GAS PIPELINE PROJECT,
SHOALHAVEN STARCHES,
BOMADERRY, NSW,
MODIFICATION APPLICATION NO.1 (MOD 1) -
MP10_0144 & MP 10_0108**

Prepared by: Dean Shewring

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Pinnacle Risk Management Pty Limited
ABN 83 098 666 703

PO Box 5024 Elanora Heights
NSW Australia 2101
Telephone: (02) 9913 7284
Facsimile: (02) 9913 7930

Preliminary Hazard Analysis, Shoalhaven Starches, Gas Pipeline Project

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EXECUTIVE SUMMARY

The Shoalhaven Starches factory located on Bolong Road, Bomaderry, produces a range of products for the food, beverage, confectionary, paper and motor transport industries including starch, gluten, glucose and ethanol.

Shoalhaven Starches have approval to install a new natural gas pipeline to their site. The following two major changes are required:

- The Gas Pressure Reduction Facility will be approximately 150 m south-west of the approved location on the north Packing Plant site; and
- The pipeline diameter will be increased from 150 mm to 300 mm.

As part of the project requirements, a revised Preliminary Hazard Analysis (PHA) is required for the modified natural gas pipeline.

The risks associated with the proposed modified natural gas pipeline have been assessed and compared against the Department of Planning risk criteria.

The results presented in this report show compliance with all risk criteria.

Societal risk, area cumulative and propagation risk, and environmental risk are also concluded to be acceptable.

The primary reason for the low risk levels from the natural gas pipeline is the low likelihood of significant pipe failures leading to off-site impact from jet or flash fires, or explosions. This is due, in part, to the design, operation and maintenance requirements of the Australian Standards (e.g. AS2885).

Based on the analysis in this PHA, there are no further recommendations to be made.

GLOSSARY

AS	Australian Standard
DG	Dangerous Good
DN	Diameter Nominal
DoP	NSW Department of Planning
EGP	Eastern Gas Pipeline
GPRF	Gas Pressure Reduction Facility
HIPAP	Hazardous Industry Planning Advisory Paper
HSE UK	Health and Safety Executive United Kingdom
LEL	Lower Explosive Limit
PHA	Preliminary Hazard Analysis
QRA	Quantitative Risk Assessment
SFARP	So Far As Reasonably Practicable
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value

REPORT

1 INTRODUCTION

1.1 BACKGROUND

Shoalhaven Starches is a member of the Manildra Group of companies. The Manildra Group is a wholly Australian owned business and the largest processor of wheat in Australia. It manufactures a wide range of wheat-based products for food and industrial markets both locally and internationally.

The Shoalhaven Starches factory located on Bolong Road, Bomaderry, produces a range of products for the food, beverage, confectionary, paper and motor transport industries including starch, gluten, glucose and ethanol.

On the 30th October 2012 the then Independent Planning Commission approved Concept Plan (MP10_0144) and Project Application (MP_10_0108) for the Shoalhaven Starches Gas Pipeline Project. This project provided for the installation of a 5.5 km gas pipeline connecting the Shoalhaven Starches factory site located at Bolong Road, Bomaderry directly to the Eastern Gas Pipeline (EGP) at Pestells Lane, Meroo Meadow.

Shoalhaven Starches have been reviewing the design requirements for this project and seek to undertake the following modifications to the project / concept approval:

- To relocate the approved location of the Gas Pressure Reduction Facility (GPRF) at the approved Manildra Packing Plant site to the north of Bolong Road; and
- To alter the internal diameter of the pipeline which will result in an increase in the internal diameter of the pipeline from DN (diameter nominal) 150 mm to DN 300 mm. This is required to meet the expected demands for natural gas for the site's processing facilities.

For the Concept and Project Approvals MP 10_0144 and MP 10_0108, the location of the Gas Pressure Reduction Facility was approved at the north-eastern boundary of Lot 16 DP 1121337 which is situated on the northern side of Bolong Road opposite the Shoalhaven Starches factory site. Project Approval MP 06_0228 for the Shoalhaven Starches Expansion project, approved the construction of a Packing Plant on this same parcel of land. At the time of the Concept and Project Approvals MP 10_0144 and MP 10_0108, the location of the Gas Pressure Reduction Facility did not conflict with the siting of the approved Packing Plant.

The siting and footprint of the Packing Plant have been modified. Furthermore, Shoalhaven Starches have been seeking to undertake further modifications to the approved Packing Plant under Project Approval MP 06_0228 (Mod 22). The

modifications that have been approved and which are now proposed for the siting and footprint of the Packing Plant and its associated works now conflict with the approved location of the GPRF.

To overcome this conflict it is proposed to relocate the approved GPRF towards the southern boundary of the site and setback from the Bolong Road frontage. This site has been selected as it is the only location that is now free of approved development and upon which the required footprint and configuration of the GPRF can now be sited on this land while also enabling suitable proximity and access to the approved Gas Fired Co-generation Plant that the pipeline is to feed.

Effectively, the change in location means the GPRF will be approximately 150 m south-west of the approved location on the Packing Plant site.

The last, approved Hazard Analysis for the Gas Pipeline Project was performed by URS (Ref 1). This report included the following:

- An AS2885 Safety Management Study risk assessment. As the pipeline route to Manildra does not change then the results of this study are still relevant. No further Safety Management Study is therefore required in this updated Preliminary Hazard Analysis (PHA). Note, however, the change in the location of the GPRF is included in this revised PHA; and
- A quantitative hazard analysis. As the pipeline diameter is proposed to be increased from 150 mm to 300 mm then this hazard analysis is updated in this revised PHA.

Shoalhaven Starches requested that Pinnacle Risk Management prepare the PHA for the proposed modifications. This PHA has been prepared in accordance with the guidelines published by the Department of Planning (DoP) Hazardous Industry Planning Advisory Paper (HIPAP) No 6 (Ref 2).

1.2 OBJECTIVES

The main aims of this PHA study are to:

- Identify the credible, potential hazardous events associated with the proposed modifications, i.e. the relocation of the GPRF and the pipeline diameter increase;
- Evaluate the level of risk associated with the identified potential hazardous events to surrounding land users and compare the calculated risk levels with the risk criteria published by the DoP in HIPAP No 4 (Ref 3);
- Evaluate the potential for propagation events;
- Review the adequacy of the proposed safeguards to prevent and mitigate the potential hazardous events; and
- Where necessary, submit recommendations to Shoalhaven Starches to ensure that the proposed modified pipeline is operated and maintained at

acceptable levels of safety and effective safety management systems are used.

1.3 SCOPE

This PHA assesses the credible, potential hazardous events and corresponding risks associated with the Shoalhaven Starches proposed modified gas supply pipeline from Meroo Meadow.

There are no Dangerous Goods road or rail transport requirements to or from the site as part of this project. Therefore, transport is not assessed.

1.4 METHODOLOGY

In accordance with the approach recommended by the DoP in HIPAP 6 (Ref 2) the underlying methodology of the PHA is risk-based, that is, the risk of a particular potentially hazardous event is assessed as the outcome of its consequences and likelihood.

The PHA has been conducted as follows:

- Initially, the proposed modifications and their locations were reviewed to identify credible, potential hazardous events, their causes and consequences. Proposed safeguards were also included in this review;
- As the potential hazardous events are located at a significant distance from other sensitive land users, the consequences of each potential hazardous event were estimated to determine if there are any possible unacceptable off-site impacts;
- Included in the analysis is the risk of propagation between the proposed pipeline and the adjacent land users; and
- If adverse off-site impacts could occur, assess the risk levels to check if they are within the criteria in HIPAP 4 (Ref 3).

2 SITE DESCRIPTION

The Shoalhaven Starches factory site is situated on various allotments of land on Bolong Road, Bomaderry, within the City of Shoalhaven (see Figure 1). The factory site, which is located on the south side of Bolong Road on the northern bank of the Shoalhaven River, has an area of approximately 12.5 hectares.

The town of Bomaderry is located approximately 0.5 km to the west of the factory site and the Nowra urban area is situated 2.0 km to the south west of the site. The “Riverview Road” area of the Nowra Township is situated approximately 600 metres immediately opposite the factory site across the Shoalhaven River.

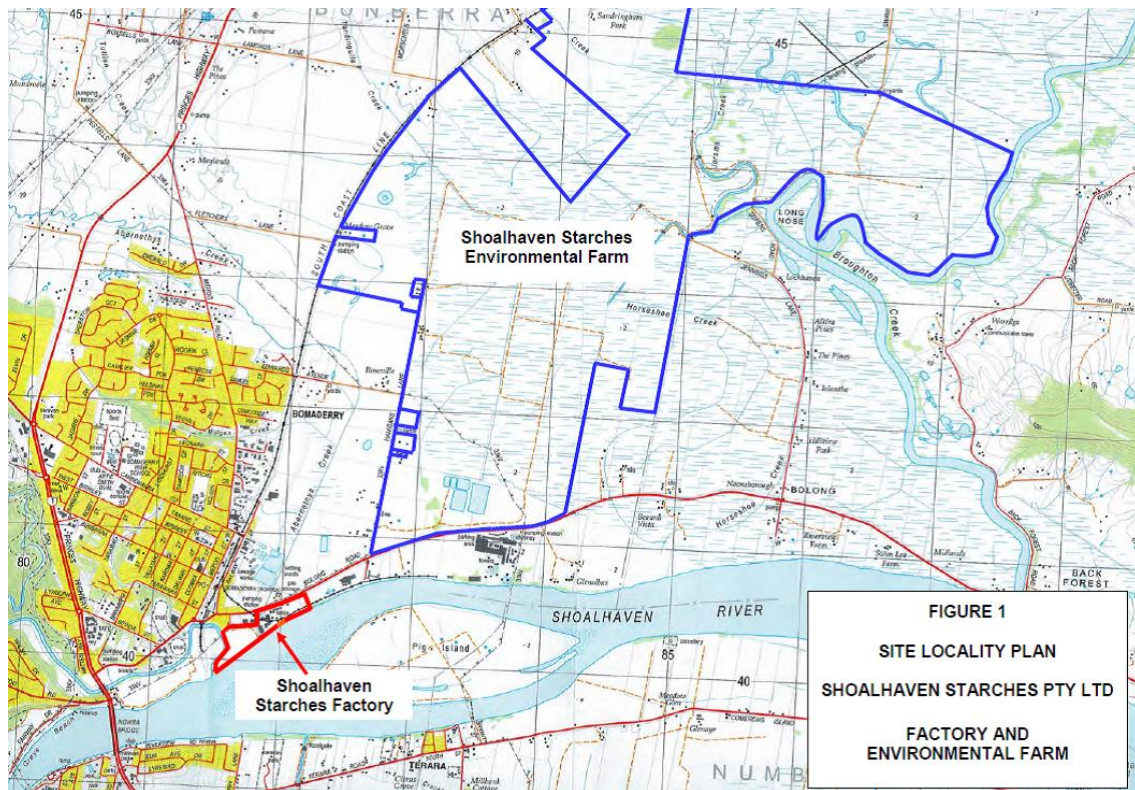
The village of Terara is situated approximately 1.5 kilometres to the south east of the site, across the Shoalhaven River. Pig Island is situated between the factory site and the village of Terara and is currently used for cattle grazing.

There are a number of industrial land uses, which have developed on the strip of land between Bolong Road and the Shoalhaven River. Industrial activities include a metal fabrication factory, the Shoalhaven Starches site, Shoalhaven Dairy Co-op (formerly Australian Co-operative Foods Ltd – now owned by the Manildra Group) and the Shoalhaven Paper Mill (also now owned by the Manildra Group). The industrial area is serviced by a privately-owned railway spur line that runs from just north of the Nowra-Bomaderry station via the starch plant and the former Dairy Co-op site to the Paper Mill.

The Company also has an Environmental Farm of approximately 1,000 hectares located on the northern side of Bolong Road. This area is cleared grazing land and contains spray irrigation lines and wet weather storage ponds (total capacity 925 Mega litres). There are at present six wet weather storage ponds on the farm that form part of the waste water management system for the factory. A seventh pond approved in 2002 was converted into the biological section of the new wastewater treatment plant has now been commissioned.

The Environmental Farm covers a broad area of the northern floodplain of the Shoalhaven River, stretching from Bolong Road in the south towards Jaspers Brush in the north. Apart from its use as the Environmental Farm, this broad floodplain area is mainly used for grazing (cattle). The area comprises mainly large rural properties with isolated dwellings although there is a clustering of rural residential development along Jennings Lane (approximately 1 kilometre from the site), Back Forest Road (approximately 500 metres to 1.2 kilometres to the west) and Jaspers Brush Road (approximately 1.2 kilometres to the north).

Figure 1 - Site Locality Plan



Security of the site is achieved by a number of means. This includes site personnel and security patrols by an external security company (this includes weekends and night patrols). The site operates 7 days per week (24 hours per day). Also, the site is fully fenced and non-operating gates are locked. Security cameras are installed for staff to view visitors and site activities.

There are approximately 180 people on site during Monday to Fridays 8 am to 5 pm and 100 people on site at other times.

The main natural hazard for the site is flooding. No other significant external events are considered high risk for this site.

A layout drawing showing the approved pipeline route from Meroo Meadow to the Shoalhaven Starches site is shown in Figure 2.

A layout drawing showing the relocated GPRF is shown in Figure 3.

Figure 2 - Pipeline Route

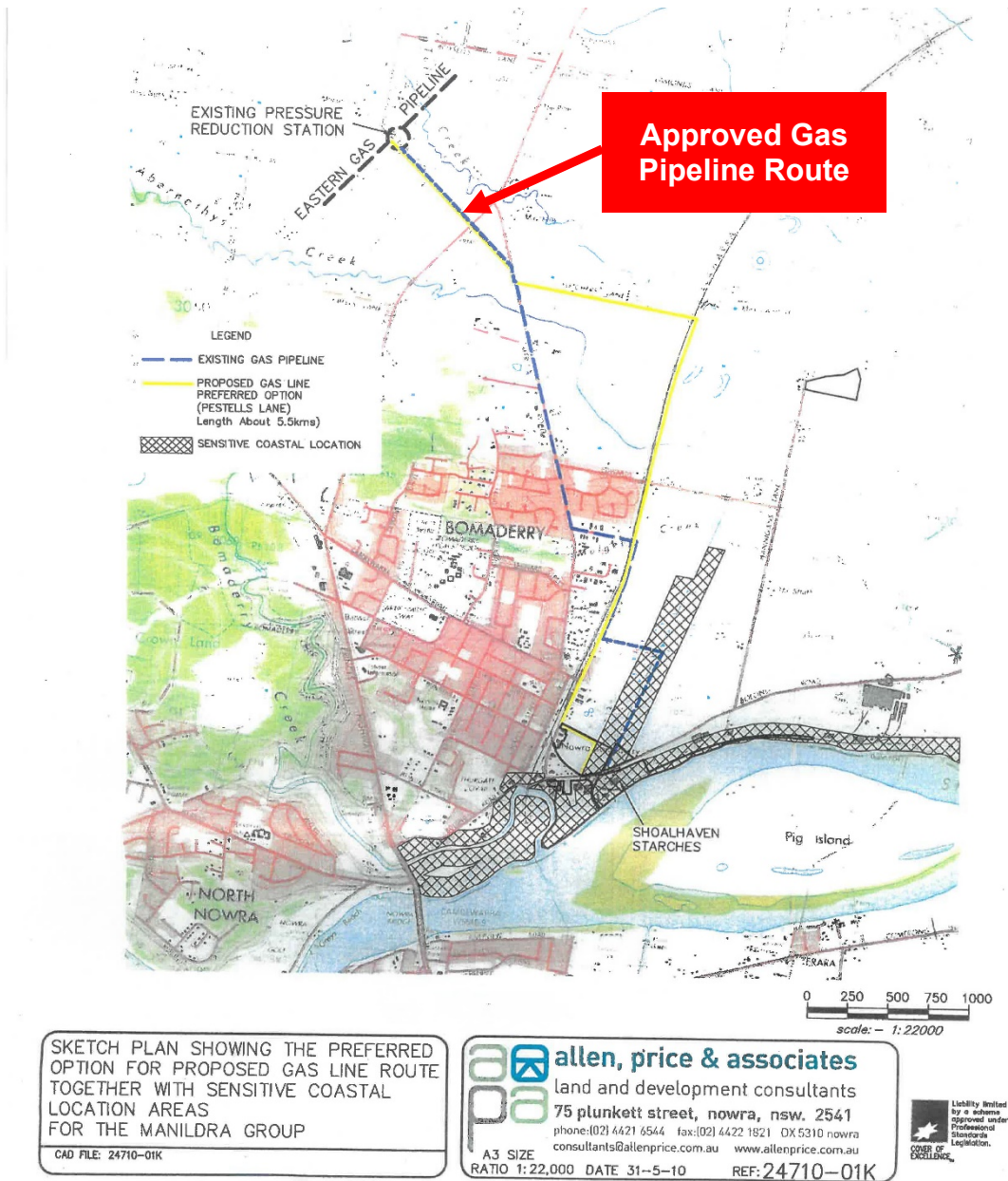
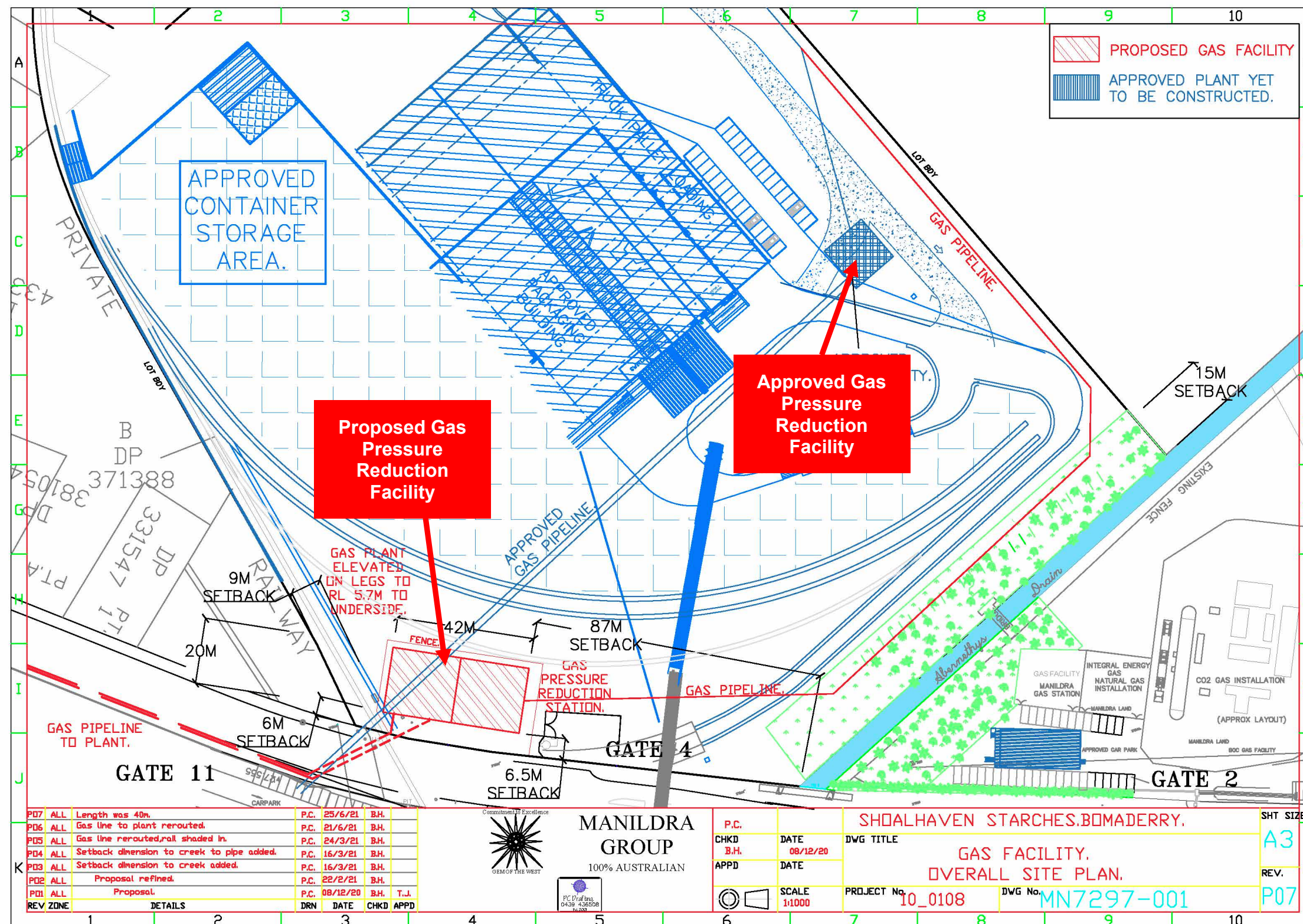


Figure 3 – Relocated Gas Pressure Reduction Facility



3 PROCESS DESCRIPTION

3.1 GAS PRESSURE REDUCTION FACILITY

The GPRF reduces gas pressure from up to 15,000 kPa to two operating pressures, i.e.:

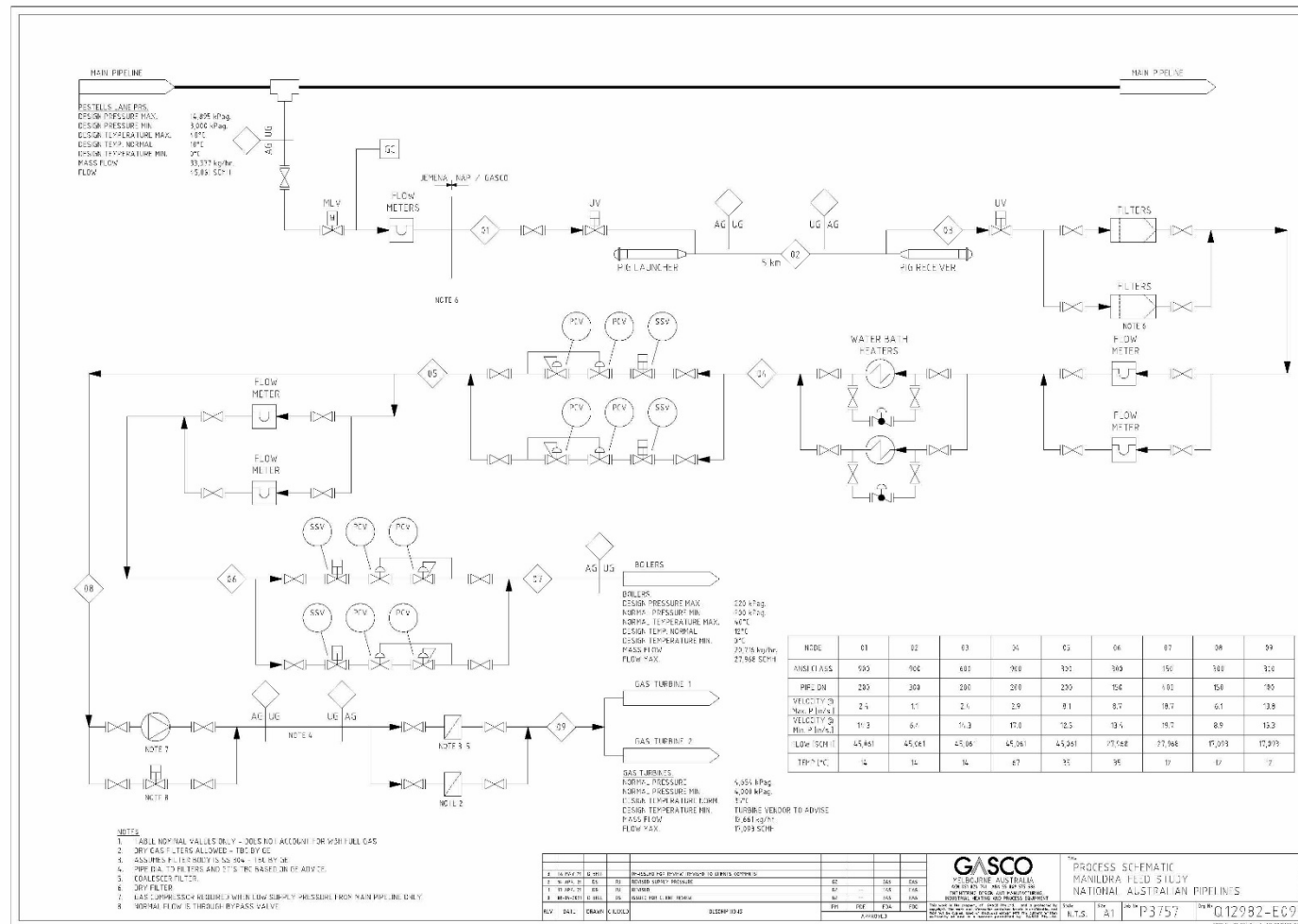
- 4,000 kPa for supply to the proposed co-generation plant; and
- 210 kPa as required by other Shoalhaven Starches operations. This is the standard natural gas supply pressure to the existing users throughout the site.

A process flow diagram is provided in Figure 4. The pipeline will contain the following main features:

- Flow measurement at the tie-in point to the Eastern Gas Pipeline;
- The pipeline will be primarily underground, i.e. approximately 5 km. This section of the pipe will include pig traps for routine maintenance;
- At the Manildra site, the gas will be filtered, monitored for flow and then heated in a water-bath heater. This is to avoid generating low temperatures when the gas pressure is reduced;
- The gas pressure will then be reduced to approximately 4,000 kPa, i.e. this is the main Gas Pressure Reduction Facility. This will include redundant pressure regulators and an actuated emergency isolation valve. There will be a pressure safety valve downstream in case the valves pass when closed;
- The gas will then be split into two streams:
 - One stream will flow at 4,000 kPa to the Co-Generation Plant; and
 - The other stream will have its pressure reduced to 210 kPa in a similar pressure reduction facility to that described above. This new pipe will flow to the boilers and dryers.

The assessment of the individual, on-site gas supply pipes to the Co-Generation Plant and the boilers is performed in the PHA for the Co-Generation Plant.

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3.2 PIPELINE DIAMETER

Project Approval MP06_0228 for the Shoalhaven Starches Expansion Project made provision for a gas fired co-generation plant that would comprise two gas turbine generators that would deliver an anticipated net power output of 40 MW of power for the site.

One of the primary objectives of the Shoalhaven Starches Gas Pipeline Project was feed the gas fired co-generation plant.

At that time, the pipeline design parameters were as follows:

- Minimum inlet pressure from the EGP of 8,800 kPa;
- Minimum allowable pressure from the gas pressure reduction facility of 4,000 kPa; and
- Maximum gas flow of 25 TJ/day.

Based on the above parameters, a pipe diameter of 150 mm was adequate.

Shoalhaven Starches are presently seeking approval to modify the approved gas fired Co-Generation Plant under Mod 21. Shoalhaven Starches now propose to construct a new gas-fired Co-Generation Plant which will consist of two natural gas turbines that will generate an anticipated power output each of 30 MW, providing a total power to the site of 60 MW.

The increase in power output from the new gas fired Co-Generation Plant will require the following pipeline design parameters:

- Minimum inlet pressure from the EGP of 10,000 kPa;
- Minimum allowable pressure at the gas pressure reduction facility of 4,000 kPa for the turbines and 210 kPa for some of the other site users, e.g. dryers and boilers; and
- Maximum gas flow of 45 TJ/day.

Given the revised pipeline design parameters, the diameter of the underground pipe will now need to be 300 mm.

The increase in the diameter of the pipe will not, however, require any change to the anticipated trench dimensions that were envisaged under the original Project Approval.

4 HAZARD IDENTIFICATION

4.1 HAZARDOUS MATERIALS

The only hazardous material involved with the modifications is natural gas.

Natural gas is flammable, i.e. if released and ignited, there is a risk of jet fires, flash fires and explosions (if confined).

Natural gas is a Class 2.1 Dangerous Good (DG), i.e. a flammable gas.

Natural gas is a colourless hydrocarbon fluid mainly composed of the following hydrocarbons:

- Methane (typically 88.5% or higher);
- Ethane (typically 8%);
- Propane (typically 0.2%);
- Carbon dioxide (typically 2%); and
- Nitrogen (typically 1.3%).

For a typical natural gas, the TLV (threshold limit value) is approximately 1,000 ppm and the STEL (short term exposure limit) is 30,000 ppm (i.e. approaching 5 vol% which is the lower explosive limit).

The hydrocarbons are not considered to represent a significant environmental threat. Their hazard potential derives solely from the fact that they are flammable materials.

To enable ready leak detection, natural gas is normally odourised with mercaptans (sulphur containing hydrocarbons).

The flammability range is typically 5% to 15% v/v in air. The vapours are lighter than air and will normally disperse safely if not confined and/or ignited.

Products of combustion include carbon monoxide and carbon dioxide.

4.2 POTENTIAL HAZARDOUS INCIDENTS REVIEW

In accordance with the requirements of *Guidelines for Hazard Analysis*, (Ref 2), it is necessary to identify hazardous events associated with the facility's operations. As recommended in HIPAP 6, the PHA focuses on "atypical and abnormal events and conditions. It is not intended to apply to continuous or normal operating emissions to air or water".

In keeping with the principles of risk assessments, credible, hazardous events with the potential for off-site effects have been identified. That is, "slips, trips and falls" type events are not included nor are non-credible situations such as an aircraft crash occurring at the same time as an earthquake.

The identified credible, significant incidents (in particular, with the potential for off-site impacts) for the proposed modified pipeline are summarised in the Hazard Identification Word Diagram following (Table 1).

This diagram presents the causes and consequences of the events, together with major preventative and protective features that are to be included as part of the design.

Table 1 – Hazard Identification Word Diagram

Event Number	Hazardous Event	Causes	Consequences	Existing Safeguards - Prevention Detection Mitigation
1	Loss of containment of natural gas from the supply pipe or gas pressure reduction facility	Pipe failure, e.g. corrosion or weld defect, gasket failure, valve leak, impact, land subsidence, wash-away	If ignited, potential for a jet fire, flash fire or explosion (if confined) which can impact personnel and equipment	The pipe is to be protected from impact by locating it underground and providing barriers around the GPRF. Minimum flanges used. Pipe to be included in the hazardous zone study. Remote isolation of the natural gas is possible at the Meroo Meadow gas metering station. The natural gas supply pipe is to be pressure tested following construction and protected against corrosion by trilaminate coating and cathodic protection. The natural gas piping and equipment items are to be compliant with the Australian Standards, e.g. AS2885 and AS4041. This includes the controls identified in the approved PHA via an AS2885 Safety Management Study

Event Number	Hazardous Event	Causes	Consequences	Existing Safeguards - Prevention Detection Mitigation
2	Overpressure of the piping downstream of the gas pressure reduction station	Failure of the gas pressure reduction valves	Potential to overpressure the downstream piping leading to a failure. If ignited, potential for a jet fire, flash fire or explosion (if confined) which can impact personnel and equipment	Maintenance of all equipment associated with the pipeline. Redundant pressure reduction valves. Actuated high pressure emergency isolation valve prior to each gas pressure reduction facility. Remote isolation of the natural gas is possible at the Meroo Meadow gas metering station. Pressure safety valve downstream of each reduction facility (sized for valve leakage)

5 RISK ANALYSIS

The assessment of risks to both the public as well as to operating personnel around the proposed modified pipeline requires the application of the basic steps outlined in Section 1. As per HIPAP 6 (Ref 2), the chosen analysis technique should be commensurate with the nature of the risks involved. Risk analysis could be qualitative, semi-quantitative or quantitative.

The typical risk analysis methodology attempts to take account of all credible hazardous situations that may arise from the operation of processing plants etc.

Having identified all credible, significant incidents, risk analysis requires the following general approach for individual incidents:

$$\text{Risk} = \text{Likelihood} \times \text{Consequence}$$

The risks from all individual potential events are then summated to get cumulative risk.

For QRA (quantitative risk analysis) and hazard analysis, the consequences of an incident are calculated using standard correlations and probit-type methods which assess the effect of fire radiation, explosion overpressure and toxicity to an individual, depending on the type of hazard.

In this PHA, however, the approach adopted to assess the risk of the identified hazardous events is scenario-based risk assessment. The reasons for this approach are the distances from the proposed pipeline to residential and other sensitive land users are generally significant and there are only a few potential hazardous events, e.g. jet fires, flash fires and explosions, that can occur.

The risk criteria applying to developments in NSW are summarised in Table 2 on the following page (from Ref 3).

Table 2 - Risk Criteria, New Plants

Description	Risk Criteria
Fatality risk to sensitive uses, including hospitals, schools, aged care	0.5×10^{-6} per year
Fatality risk to residential and hotels	1×10^{-6} per year
Fatality risk to commercial areas, including offices, retail centres, warehouses	5×10^{-6} per year
Fatality risk to sporting complexes and active open spaces	10×10^{-6} per year
Fatality risk to be contained within the boundary of an industrial site	50×10^{-6} per year
Injury risk – incident heat flux radiation at residential areas should not exceed 4.7 kW/m^2 at frequencies of more than 50 chances in a million per year or incident explosion overpressure at residential areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year	50×10^{-6} per year
Toxic exposure - Toxic concentrations in residential areas which would be seriously injurious to sensitive members of the community following a relatively short period of exposure	10×10^{-6} per year
Toxic exposure - Toxic concentrations in residential areas which should cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community	50×10^{-6} per year
Propagation due to Fire and Explosion – exceed radiant heat levels of 23 kW/m^2 or explosion overpressures of 14 kPa in adjacent industrial facilities	50×10^{-6} per year

As discussed above, the consequences of the potential hazardous events are initially analysed to determine if any events have the potential to contribute to the above-listed criteria and hence worthy of further analysis. The potential hazardous events of interest in this PHA are jet and flash fires, and vapour explosions.

5.1 NATURAL GAS RELEASES – JET FIRES CONSEQUENCES

The jet fire consequence calculations for this revised PHA have been performed using TNO's EFFECTS program (Ref 4).

For hazard analysis of jet fires, each scenario defined by the analyst is modelled using an appropriate release rate equation based on the release situation and the initial state of the material. The flame lengths of the potential jet fires are then calculated based on parameters such as the release rate. The consequential impact value of interest at a particular location (i.e. radiant heat) can be obtained from the results.

Pipe details are summarised as follows:

- Diameter is 300 DN (nominal diameter) (the inside diameter is approximately 280 mm);
- Pipeline total length is 5.5 km. A catastrophic break at the Bomaderry area is assumed for modelling purposes as this location poses the maximum societal risk (the pipeline runs through farmland prior to Bomaderry);
- The maximum allowable operating pressure is taken to be 150 barg as it will representative the largest gas release and hence is worst case; and
- Operating temperature is assumed to be ambient (temperature changes have minimal impact on the results).

The pipeline failures analysed in this report are as follows:

- Pinhole (≤ 25 mm diameter);
- Small hole (> 25 to ≤ 75 mm diameter);
- Large hole (> 75 to ≤ 110 mm diameter); and
- Rupture (> 110 mm diameter).

The two latter cases, i.e. large hole sizes and rupture cases, are conservatively combined and assessed as rupture cases (for simplification purposes only). This will slightly overestimate the risk for the large hole sizes.

The analysis of the potential jet fires from the natural gas line failures is shown in Table 3. The initial release flowrates are provided. As the pipeline pressure decreases during the event, the flows will also decrease. Note that the rupture flow is also calculated from a one-sided release. The downstream section of the pipeline has little pressure support and hence will rapidly decrease in pressure. A horizontal jet (10 degrees off the horizontal) is also modelled to estimate the drop in radiant heat from the tip of the jet (i.e. along the long axis of the jet).

Table 3 – Jet Fire Modelling Results

Scenario	Length of Jet, m	Distance to Specified Radiant Heat Level, m		
		23 kW/m ²	12.6 kW/m ²	4.7 kW/m ²
Large Hole / Rupture (>75 mm diameter – rupture assumed):				
Natural Gas, 150 barg, 15°C, at 256 kg/s – vertical jet	115	Note 1	50	123
Natural Gas, 150 barg, 15°C, at 256 kg/s – horizontal jet (10 degrees off the horizontal)	171	For the horizontal jet case (Note 2), the radiant heat at a location away from the tip of the jet decreases from 150 kW/m ² to less than 12.6 kW/m ² over 36 m from the jet tip		
Small Hole (> 25 to ≤ 75 mm diameter – 75 mm assumed):				
Natural Gas, 150 barg, 15°C, at 69 kg/s – vertical jet	64	-	24	64
Natural Gas, 150 barg, 15°C, at 69 kg/s – horizontal jet (10 degrees off the horizontal)	96	For the horizontal jet case, the radiant heat at a location away from the tip of the jet decreases from 119 kW/m ² to less than 12.6 kW/m ² over 17 m from the jet tip		
Pinhole (≤ 25 mm diameter – 25 mm assumed):				
Natural Gas, 150 barg, 15°C, at 8 kg/s – vertical jet	25	-	6	22
Natural Gas, 150 barg, 15°C, at 8 kg/s – horizontal jet (10 degrees off the horizontal)	37	For the horizontal jet case, the radiant heat at a location away from the tip of the jet decreases from 94 kW/m ² to less than 12.6 kW/m ² over 5 m from the jet tip		

Notes:

1. Radiant heat is the heat flux received at ground level assuming a vertical flame from ground level. For a vertical jet, the predicted maximum ground level radiant heat is approximately 16 kW/m² (due to flame lift-off). This value will be increased if the jet is at an angle, i.e. closer to the horizontal.

See the last line of data in Table 3 for the maximum impact from a horizontal jet.

2. Horizontal jets from an underground pipe are not expected, however, the results are used (conservatively) for a jet inclined to the horizontal.

For assessment of the effects of radiant heat on people, it is generally assumed that if a person is subjected to 4.7 kW/m^2 of radiant heat and they can take cover within approximately 20 seconds then no serious injury, and hence fatality, is expected. However, exposure to a radiant heat level of 12.6 kW/m^2 can result in fatality for some people for limited exposure durations. Therefore, fatality from radiant heat exposure is of concern for radiant heat values above 12.6 kW/m^2 . Given the modelling results in Table 3, fatality is possibly for people closer than:

- 50 m for a vertical jet fire and 207 m (from the point of release) for a horizontal jet fire (large hole and rupture case);
- 24 m for a vertical jet fire and 113 m (from the point of release) for a horizontal jet fire (small hole case); and
- 6 m for a vertical jet fire and 42 m (from the point of release) for a horizontal jet fire (pinhole case).

This information is included in the risk analysis section later in this report.

Typical rules-of-thumb for property and equipment damage escalation are (Ref 5):

- Radiant heat exceeding 37.5 kW/m^2 for 10 minutes;
- Radiant heat above 23 kW/m^2 for longer durations; and
- Jet fire flame impingement on vessels or structural steel that are not protected for 15 minutes.

The modelled events have estimated jet fire lengths that can result in propagation to adjacent property and equipment items. This can be due to radiant heat from vertical or horizontal jet fires.

Given the results shown in Table 3, there is the potential for multiple injuries or fatalities if people are near to the break and/or significant property and equipment damage from a catastrophic pipe failure and corresponding jet fire. The likelihood of a potential jet fire is analysed later in this report to determine the risk.

5.2 NATURAL GAS RELEASES – FLASH FIRES CONSEQUENCES

Potential flash fires or vapour cloud explosions can occur from the natural gas pipe failures, i.e. due to delayed ignition.

A flash fire is the non-explosive combustion of a vapour cloud resulting from a release of flammable material into the open air. Generally vapour clouds only

explode in areas where turbulent transition develops and the flame speed needs to increase significantly to develop overpressures. This usually involves some degree of confinement. The main hazards from flash fires, however, are from thermal radiation and direct flame contact. The duration of flash fires is normally only a few tenths of a second (Ref 6).

The effect distance (i.e. due to radiant heat within the cloud) is typically estimated by performing a dispersion calculation to determine the maximum distance to the LEL (lower explosive limit). For flash fires, any person inside the flash fire cloud is assumed to be fatally injured. As flash fires are of limited duration then those outside the flash fire cloud have a high probability of survival without serious injury. Equipment and property damage is not a significant concern for flash fires as the duration is relatively short.

The analyses of a potential flash fire from failures of the pipeline for the main local wind / weather conditions are shown in the following three tables. The distances to LEL have been calculated using TNO's EFFECTS program.

Table 4 – Flash Fire Modelling Results – Large Hole and Rupture Case

Weather / Wind Conditions	Distance (m) to LEL	Total Explosive Mass (kg)
A2	200	14,000
B3	250	12,000
C5	280	8,000
D5	460	13,000
E3	830	45,000
F1.5	530	45,000

Table 5 – Flash Fire Modelling Results – Small Hole Case

Weather / Wind Conditions	Distance (m) to LEL	Total Explosive Mass (kg)
A2	89	1,700
B3	110	1,400
C5	120	980
D5	200	1,600
E3	450	5,700
F1.5	490	15,000

Table 6 – Flash Fire Modelling Results – Pinhole Case

Weather / Wind Conditions	Distance (m) to LEL	Total Explosive Mass (kg)
A2	24	55
B3	29	45
C5	32	30
D5	50	47
E3	110	170
F1.5	320	980

Note: The Pasquill atmospheric stability classes are used where F is the most stable (A is the most unstable class). The numbers after the stability classes represent the wind speed in m/s. See Appendix A for the local weather / wind data.

Given these potential impact distances then again multiple injuries and/or fatalities could be expected if the flash fire occurred in a location where people were present and did not escape.

5.3 NATURAL GAS RELEASES – VAPOUR CLOUD EXPLOSIONS CONSEQUENCES

Potential vapour cloud explosions can occur from flammable gas releases, i.e. delayed ignition with confinement. This results in overpressures that have the potential to injure people and damage property and the environment.

EFFECTS uses the Multi-Energy method for estimation of explosion effects. The key feature of the Multi-Energy method is that the explosion is not primarily defined by the fuel air mixture but by the environment in which the vapour disperses. Partial confinement is regarded as a major cause of blast in vapour cloud deflagrations. If there is no confinement, a flashfire (i.e. no overpressure effects) would occur rather than explosion.

Within the model, ignition is assumed to occur at the centre of the gas cloud formed.

The degree of confinement must be defined as an input to the model. Essentially, this is the proportion of the total mass in the cloud used in the dispersion and subsequent explosion calculation. For example, if 2,000 kg is entered as a total mass and 50% as confinement then 1,000 kg is the maximum amount that can

be included in the explosion calculation. The actual amount used in the Multi-Energy explosion model is calculated by the dispersion module.

For this hazard analysis, the percentage confinement value used is 20% as natural gas is a light gas, i.e. it disperses upwards, and the area surrounding the pipeline, in places, is only partially built-up, e.g. trees.

The initial strength of the blast is also variable, depending on the degree of confinement and on the reactivity of the gas. In the Multi-Energy method, the initial strength is represented by a series of curves relating overpressure to distance, where curve 1 means slow deflagration and curve 10 means detonation. An explosion curve number equal to 5 is used in the modelling (i.e. a deflagration as methane is not a strongly reactive gas).

For the release of natural gas, choked flow exists and rapid jet mixing with air occurs. Larger release durations have no significant impact on the size of the vapour cloud as steady state conditions are reached soon after the release occurs (i.e. the distance to the LEL does not change at steady state dispersion conditions).

The effects from explosion overpressures (Ref 3) are summarised in Table 7.

Table 7 – Effects of Explosion Overpressure

OVERPRESSURE, kPa	PHYSICAL EFFECT
3.5	90% glass breakage No fatality, very low probability of injury
7	Damage to internal partitions & Joinery 10% probability of injury, no fatality
14	Houses uninhabitable and badly cracked
21	Reinforced structures distort, storage tanks fail 20% chance of fatality to person in building
35	Houses uninhabitable, rail wagons & plant items overturned. Threshold of eardrum damage, 50% chance of fatality for a person in a building, 15% in the open
70	Complete demolition of houses Threshold of lung damage, 100% chance of fatality for a person in a building or in the open

The analysis of a potential vapour cloud explosion from the potential pipeline failures are shown in the following tables

Table 8 – Vapour Cloud Explosions Modelling Results – Large Hole and Rupture Case

Weather / Wind Conditions	Distance (m) to 21 kPa Explosion Overpressure	Distance (m) to 14 kPa Explosion Overpressure	Distance (m) to 7 kPa Explosion Overpressure
A2	60	97	193
B3	58	92	186
C5	48	81	162
D5	59	94	189
E3	88	143	287
F1.5	88	143	287

Table 9 – Vapour Cloud Explosions Modelling Results – Small Hole Case

Weather / Wind Conditions	Distance (m) to 21 kPa Explosion Overpressure	Distance (m) to 14 kPa Explosion Overpressure	Distance (m) to 7 kPa Explosion Overpressure
A2	6	47	95
B3	6	44	90
C5	Note 2	Note 2	Note 2
D5	6	47	95
E3	10	72	144
F1.5	14	98	200

Notes:

1. The distances are from the centre of the cloud.
2. There needs to be a minimum of 1 to 15 tes for ignition of a vapour cloud to result in an explosion (Ref 6) for non-reactive gases such as methane. Quantities that are lower than 1 te are therefore not modelled. This includes all the release cases for the pinhole failures.

As fatalities can be expected, particularly to those in-doors, from the 14 to 21 kPa overpressure range and higher, then these events have the potential for multiple serious injuries and/or fatalities. There is also the potential for property damage (e.g. broken windows) up to the 7 kPa overpressure contour, i.e. to distances of approximately 90 to 300 m from the centre of the cloud.

5.4 LIKELIHOOD AND RISK ANALYSIS

Data for overland pipeline failures is available from a number of sources but one of the most recent, comparable data sets is from the United Kingdom's Health and Safety Executive (HSE) (Ref 7).

The HSE have researched pipeline releases in the United Kingdom over a 45 year period. The following data summarises the HSE frequency data for releases from all causes for a DN300 Schedule 80 pipe.

The HSE data assumes the pipelines are in use 100% of the time.

The probabilities of ignition of flammable gas releases from gas pipelines are provided in AS2885.6 Table F2.

Table 10 – Pipeline Failure Rates and Ignition Probabilities

Release Case	Failure Rate		Probability of Ignition	Likelihood of Release and Ignition
	Times/km.yr	Times/m.yr		
Pinhole	4.3×10^{-5}	4.3×10^{-8}	0.035	1.5×10^{-9}
Small	4.9×10^{-6}	4.9×10^{-9}	0.075	3.7×10^{-10}
Large / Rupture	2.9×10^{-6}	2.9×10^{-9}	0.1	2.9×10^{-10}

Comments on the risk analysis as follows:

- Standard quantitative risk analysis (QRA) methodology is used, i.e. risk at a point is determined by multiplying the likelihood of an event by the consequence. The consequential impact is the probability of fatality for individual and societal risk calculations. This value is 1.0 for the events analysed in this PHA;
- The risk of each event that can cause fatality at the point of interest is then summated to get total risk;
- The point of assessment is orthogonal to the pipeline where all modelled events are expected to cause fatality. This point can be anywhere along the pipeline. In effect, this shows the maximum risk from the pipeline to this point. Any further away from this point then there will be fewer events

that can cause fatality, therefore, no further analysis at these greater distances is warranted (assuming the maximum calculated risk is below the HIPAP 4 risk criteria). This is a conservative approach as flame lift-off for jet fires may result in some scenarios not causing adverse impact;

- The probabilities of immediate and delayed ignitions are based on the data from the Energy Institute Report (Ref 8);
- Given there will be flow detection and automatic isolation then the release duration is taken as 5 minutes;
- The “Impact Direction Probability” in Table 11 is derived using the results of each modelled scenario. For example, the plume width for a gas release with a subsequent flash fire is used to determine the total probability of wind direction blowing the gas to the point of assessment. In Revision B of this report, a conservative value was chosen, however, the exact values (based on the modelling results) for wind direction have been included for each scenario in this version of the report;
- The “Impact Distance for Fatality” represents the length of pipeline where potential releases can occur that can result in fatality at the point of interest. The point of interest (or assessment) is orthogonal to the pipeline. There can be upstream and downstream releases that can also cause fatality at the point of interest. The modelling is used to determine how far upstream and downstream of this location that result in releases causing fatality at the point of interest. Any releases that are outside of this distance do not cause fatality at the point of interest and therefore do not need to be taken into consideration;
- The individual fatality risk is the likelihood of a release and ignition multiplied by the various probabilities and “Impact Distance for Fatality”; and
- Cumulative risk is the summated values for each risk contributor.

The risk of individual fatality is estimated in Table 11, i.e. the estimated individual fatality risk from jet fires, flash fires and explosions is approximately 5×10^{-8} per year. Therefore, all the HIPAP 4 risk criteria in Table 2 are satisfied given this low value.

The above low likelihood for a release and ignition supports the anecdotal evidence in Australia that gas and liquid pipelines built to the Australian Standards, e.g. AS2885, have a low failure rate. The low likelihood of releases and ignition plus construction to recognised codes confirms that the SFARP (So Far As Reasonably Practicable) principle is met.

Table 11 – Risk Results

	Likelihood of Rupture and Ignition, times/yr.m	Probability of Immediate Ignition and a Jet Fire	Probability of Delayed Ignition and a Flash Fire	Probability of Delayed Ignition and an Explosion	Weather / Wind	Total Weather / Wind Probability	Impact Direction Probability	Impact Distance for Fatality, m	Individual Fatality Risk, times per year	Comments
Large Releases and Ruptures:										
Jet Fire:	2.90E-10	0.3						118	1.03E-08	All releases, i.e. even vertically downward releases into the ground (the pipe will be underground), are considered to cause 100% fatality. The impact distance for fatality represents the potential releases along the pipeline that could adversely impact the analysis point of maximum risk. Releases further away, i.e. upstream and downstream along the pipeline, do not result in potential fatality (based on the modelling results)
Flash Fire:			0.4		A2	0.039	0.07	44	1.39E-11	The plume angles are determined from the modelling. The plume angle is the same as the wind direction that can impact the point of analysis, e.g. the probability that the wind is blowing towards the analysis point is 24 deg / 360 deg = 0.07
					B3	0.08	0.05	38	1.76E-11	
					C5	0.177	0.03	28	1.72E-11	
					D5	0.481	0.02	27	3.01E-11	
					E3	0.069	0.02	42	6.72E-12	
					F1.5	0.155	0.03	40	2.16E-11	
Explosion:				0.3	A2	0.039	0.25	194	6.58E-10	As overpressures are circular, take 0.25 for the weather / wind impact direction probability
					B3	0.08	0.25	184	1.28E-09	
Note: Impact distance doubled for overpressures diameter. (EFFECTS calculates the distance from the centre of the cloud to the overpressure of interest)					C5	0.177	0.25	162	2.49E-09	
					D5	0.481	0.25	188	7.87E-09	
					E3	0.069	0.25	286	1.72E-09	
					F1.5	0.155	0.25	286	3.86E-09	
Small Releases:										
Jet Fire:	3.68E-10	0.3						60	6.62E-09	
Flash Fire:			0.4		A2	0.039	0.07	22	6.97E-12	
					B3	0.08	0.05	18	8.35E-12	
					C5	0.177	0.03	13	8.01E-12	
					D5	0.481	0.02	13	1.45E-11	
					E3	0.069	0.02	20	3.20E-12	
					F1.5	0.155	0.02	27	9.71E-12	

	Likelihood of Rupture and Ignition, times/yr.m	Probability of Immediate Ignition and a Jet Fire	Probability of Delayed Ignition and a Flash Fire	Probability of Delayed Ignition and an Explosion	Weather / Wind	Total Weather / Wind Probability	Impact Direction Probability	Impact Distance for Fatality, m	Individual Fatality Risk, times per year	Comments
Explosion:				0.3	A2	0.039	0.25	94	3.19E-10	
					B3	0.08	0.25	88	6.12E-10	
					D5	0.481	0.25	94	3.93E-09	
					E3	0.069	0.25	144	8.64E-10	
					F1.5	0.155	0.25	196	2.64E-09	
Pinhole Releases:										
Jet Fire:	1.51E-09	0.3						20	9.03E-09	
Flash Fire:			0.7		A2	0.039	0.08	7	2.53E-12	
					B3	0.08	0.06	6	3.34E-12	
					C5	0.177	0.04	4	3.29E-12	
					D5	0.481	0.03	4	6.70E-12	
					E3	0.069	0.02	5	8.00E-13	
					F1.5	0.155	0.01	10	1.80E-12	
Total:	2.2E-09								5.23E-08	

5.5 PROPAGATION AND CUMULATIVE RISK

There are design and safety management system controls (summarised in Table 1) that are designed to prevent hazardous events occurring, primarily designing, operating and maintaining the pipe to AS2885. Should these prevention controls fail and an incident occur then propagation is possible for some events, e.g. due to radiant heat from jet or flash fires, or explosion overpressures.

Propagation from potential natural gas releases is a low likelihood event, e.g. the cumulative failure and ignition likelihood for all three scenarios from Table 11 is approximately 2.2×10^{-9} per m per year. Compliance with the Australian Standards ensures the risk of propagation incidents achieves AFARP.

Correspondingly, it is reasonable to conclude that the proposed gas pipeline does not make a significant contribution to the existing cumulative risk in the area.

5.6 SOCIETAL RISK

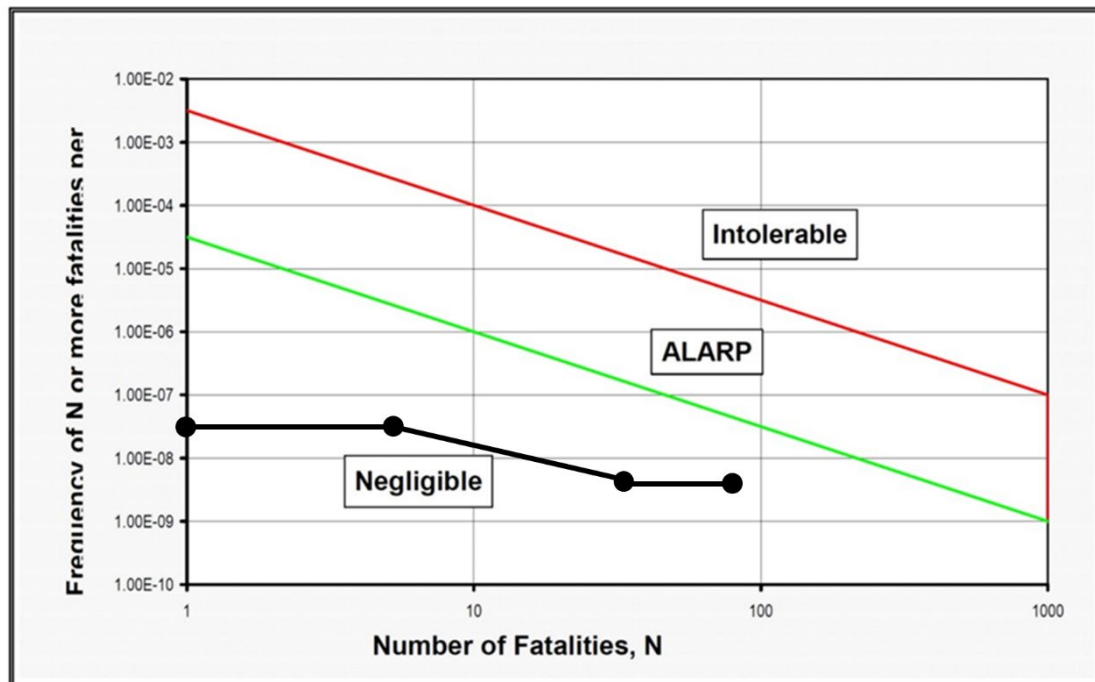
Societal risk results are usually presented as F-N curves which show the frequency of events (F) resulting in N or more fatalities. To determine societal risk, it is necessary to quantify the population within each zone of risk surrounding a facility. By combining the results for different risk levels, a societal risk curve can be produced.

Societal risk is normally calculated where the 1 pmpy contour (or calculated risk level) approaches closely to residential areas or sensitive land uses or when events with very large consequence distances are being assessed. Hence, the potential exists for multiple fatalities as a result of a single accident.

As the proposed natural gas pipeline runs underground through parts of Bomaderry then societal risk calculations have been performed. The population density for Bomaderry is approximately 9 persons per hectare (Ref 9). The impact areas were determined from each model in TNO's EFFECTS.

The societal risk curve from HIPAP 4 (Ref 3) is shown below with the estimated societal risk curve for the proposed pipeline (shown by the black line).

Figure 5 – Societal Risk Curve



As the estimated societal risk curve for the proposed pipeline is in the negligible region then societal risk is concluded to be acceptable. This is consistent with the historical safety of pipelines in Australia, e.g. AS2885 quotes there has not been any fatalities due to pipeline failures in Australia.

5.7 RISK TO THE BIOPHYSICAL ENVIRONMENT

The main concern for risk to the biophysical environment is generally with effects on whole systems or populations. For the proposed natural gas pipeline, there are no solid, liquid or gaseous effluents that could significantly impact the environment.

Whereas any adverse effect on the environment is obviously undesirable, the results of this study show that the risk of losses of containment is broadly acceptable.

6 CONCLUSION AND RECOMMENDATIONS

The risks associated with the proposed modified natural gas pipeline have been assessed and compared against the DoP risk criteria.

The results presented in this report show compliance with all risk criteria.

Societal risk, area cumulative and propagation risk, and environmental risk are also concluded to be acceptable.

The primary reason for the low risk levels from the natural gas pipeline is the low likelihood of significant pipe failures leading to off-site impact from jet or flash fires, or explosions. This is due, in part, to the design, operation and maintenance requirements of the Australian Standards (e.g. AS2885).

Based on the analysis in this PHA, there are no further recommendations to be made.

7 APPENDIX A – METEOROLOGICAL DATA

Preliminary Hazard Analysis, Shoalhaven Starches, Gas Pipeline Project

Appendix A - Meteorological Data

The following data is a summary of climate data obtained from the Bureau of Meteorology. The data summarises the local weather / wind conditions for various atmospheric stability classes and wind directions from 2010 to 2017.

	Stability Class / Wind Speed (m/s)						
Wind Direction	Percentages:						
	A2	B3	C5	D5	E3	F1.5	Totals:
N	1.5	2.2	1.4	3.9	0.5	5.8	15.4
NE	0.5	0.7	1.4	2.7	0.2	0.2	5.6
E	0.4	0.7	2.4	3.4	0.2	0.3	7.4
SE	0.3	0.6	1.6	3.6	0.2	0.5	6.8
S	0.2	0.6	2.4	10.8	0.5	0.8	15.4
SW	0.1	0.2	0.7	4.5	0.8	1.2	7.6
W	0.2	0.8	3.8	9.9	2.0	3.8	20.6
NW	0.6	2.0	3.9	9.3	2.3	2.9	21.1
Totals:	3.9	8.0	17.7	48.1	6.9	15.5	100

8 REFERENCES

- 1 URS Australia, *Shoalhaven Starches Pipeline Project (MP10-0108), Environmental Assessment - Preliminary Hazard Assessment*, 4 March 2011
- 2 Department of Planning and Infrastructure (NSW) *Hazardous Industry Planning Advisory Paper No 6 – Hazard Analysis*, January, 2011
- 3 Department of Planning and Infrastructure (NSW) *Hazardous Industry Planning Advisory Paper No 4 – Risk Criteria for Land Use Safety Planning*, January, 2011
- 4 TNO, *Models for the Calculation of Physical Effects*, 2005
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- 7 United Kingdom Health and Safety Executive, *Update of Pipeline Failure Rates for Land Use Planning Assessments*, 2015
- 8 UKOOA, *IP Research Report, Ignition Probability Review, Model Development and Look-Up Correlations*, January 2006
- 9 https://profile.id.com.au/s_bomaderry/population-density