Commercial in Confidence

Preliminary Hazard Analysis

1130 Gooloogong Road, Grenfell, NSW 2810

Report Number: 370726-GrenfellPoultry-LotePHA-RevD

Date: 22/11/2021

Client: Baiada Properties Pty Limited

Conditions of Use

Contact Information

Lote Consulting Pty Ltd

Sydney
Gough Whitlam Plaza
Suite 3, Level 1
20-22 Wentworth Street
Parramatta NSW 2150
Australia

Postal Address
PO Box W33
Westfield Parramatta, NSW 2150
Australia

T: 1300 761 744
F: +61 2 8004 6843
E: info@loteconsulting.com

ABN 75 166 888 544

Quality Information

Ref: 370726-GrenfellPoultry-LotePHA-RevD

Revision History:

Revision	Revision Date	Details	Document Details		
			Prepared	Reviewed	Authorised
A	16/08/2021	PHA draft for design team review.	Sarah Torrington	Renton Parker NER CPEng Christopher Koch	Dr S A Magrabi Director NER CPEng
B	7/09/2021	Updated based on Client Comments.	Sarah Torrington Renton Parker NER CPEng	Dr S A Magrabi	Dr S A Magrabi Director NER CPEng
C	12/10/2021	Updated bird numbers.	Christopher Koch	Dr S A Magrabi	Dr S A Magrabi Director NER CPEng
C	12/10/2021	Updated based on DPIE comments	Sarah Torrington Renton Parker NER CPEng	Christopher Koch	Dr S A Magrabi Director NER CPEng

Report Reading Guide

The scope of this Preliminary Hazard Analysis (PHA) is to assess the risks posed by the storage of DGs on the Baiada Poultry Farm located at 1130 Gooloogong Road, Grenfell, NSW 2810 to determine whether the storage of DGs may result in offsite impacts. This PHA is divided into the following sections:

EXECUTIVE SUMMARY

1.0 INTRODUCTION

2.0 METHODOLOGY

3.0 SITE DESCRIPTION

4.0 HAZARD IDENTIFICATION

5.0 CONSEQUENCE ANALYSIS

6.0 FREQUENCY ANALYSIS

7.0 CONCLUSIONS AND RECOMMENDATIONS

8.0 VALIDITY AND LIMITATIONS

The project stakeholders will have varying degrees of involvement in the PHA with an interest in different sections. It is recommended that each stakeholder read the entire document, paying particular attention to the sections indicated in Table A.

Table A – Recommended reading guide table for project stakeholders

Stakeholder	Executive Summary	1	2	3	4	5	6	7	8	9
Client	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Architect	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Certifying Authority	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Project Manager	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Services Engineers	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fire Brigades	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Managing Contractor	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sub-Contractor	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table of Contents

Background 6
Conclusions 6
Report Outcomes 6
1 INTRODUCTION 8
1.1 Background 8
1.2 Objectives 8
1.3 Scope of Services 8
1.4 Abbreviations 9
2 METHODOLOGY 10
2.1 Multi-Level Risk Assessment 10
2.2 Risk Assessment Study Approach 11
3 SITE DESCRIPTION 12
3.1 Site Location 12
3.2 Adjacent land Uses 12
3.3 General Description 12
3.4 Quantities of Dangerous Goods Stored and Handled 14
3.5 Aggregate Quantity Ratio 14
4 HAZARD IDENTIFICATION 15
4.1 Introduction 15
4.2 Properties of Dangerous Goods 16
4.3 Hazard Identification 16
4.4 LPG Tank Release and Environmental Impact 17
4.5 LPG Tank Release, Ignition and Pool Fire 17
4.6 LPG Tank Release, Ignition and Flash Fire or Explosion 17
4.7 LPG Tank Release, Ignition and Jet Fire 18
4.8 LPG Tank Jet Fire and Tanker BLEVE 18
4.9 LPG Tank Jet Fire and Tank Shell BLEVE 18
4.10 Chemical Store DG Spill and Environmental Impact 18
4.11 Chemical Store Flammable Liquid Spill, Ignition and Pool Fire 19
4.12 Chemical Store Flammable Liquid Pool Fire, Incident Propagation and Full Building Fire 19
5 CONSEQUENCE ANALYSIS 20
5.1 Incidents Carried Forward for Consequence Analysis 20
5.2 LPG Tank Release, Ignition and Jet Fire 20
5.3 LPG Tank Jet Fire and Tanker BLEVE 21

5.4 LPG Tank Jet Fire and Tank Shell BLEVE 21
6 FREQUENCY ANALYSIS 23
6.1 Incidents Carried Forward for Frequency Analysis 23
7 CONCLUSIONS AND RECOMMENDATIONS 24
7.1 Conclusions 24
7.2 Recommendations 24
8 VALIDITY AND LIMITATIONS 25
APPENDIX A – HAZARD IDENTIFICATION TABLE 26
A1. Hazard Identification Table 26
APPENDIX B – CONSEQUENCE ANALYSIS 28
B1. Incidents Assessed in Detailed Consequence Analysis 28
B2. Spreadsheet Calculator (SSC) 28
B3. Jet Fire Modelling 31
B4. BLEVE Modelling 31
B5. LPG Tank Release, Ignition and Jet Fire 32
B6. LPG Tank Jet Fire and Tanker BLEVE 33
B7. Above Ground LPG Tank Jet Fire and Tank Shell BLEVE 33

Executive Summary

Background

Baiada Properties Pty Limited (Baiada) has proposed to develop four new poultry farms at 1130 Gooloogong Road, Grenfell, NSW 2810. The proposed development is identified under Item 21 Intensive Livestock Agriculture within Schedule 3 of the Environmental Planning and Assessment Regulation (EPAR) 2000[1] and is therefore regarded as a State Significant Development (SSD). As such, it is necessary to prepare an Environmental Impact Statement (EIS) in accordance with the State Environmental Planning Policy (State and Regional Development) 2011[2].

As part of the EIS, the site was assessed against the State Environmental Planning Policy No. 33 (SEPP33) – Hazardous and Offensive Developments[3] to provide a preliminary hazard screening for submission with the Development Application (DA). The assessment determined that the site would be regarded as potentially hazardous and therefore the SEPP 33 policy applies to the site. Hence, it is necessary to prepare a Preliminary Hazard Analysis (PHA) to assess whether the storage of DGs on the site might result in hazardous impacts to surrounding land.

Lote Consulting Pty Ltd (Lote), have been appointed by Baiada Properties to prepare a PHA for submission with the DA. This document provides Lote's PHA of the proposed Grenfell poultry farm at 1130 Gooloogong Road, Grenfell, NSW 2810.

Conclusions

A hazard identification table was developed for the facility to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The consequence analysis showed that no scenarios had the potential to impact offsite. As such, frequency analysis was not conducted as the probability of a fatality at the site boundary was already minimised to within the acceptable risk criteria.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria. Hence, the facility would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

Report Outcomes

a) The area immediately surrounding the LPG tanks shall be designed in accordance with AS/NZS 1596:2014.

b) All areas containing dangerous goods shall be zoned in accordance with the requirements of AS/NZS 60079.10.1:2009.

c) All electrical equipment located within hazardous areas shall comply with AS/NZS 600079.14:2017.

d) A no smoking policy and placarding in accordance with AS/NZS 1940-2017 shall be provided in the vicinity of all dangerous goods stores.

e) The safeguards outlined in Table A1 in Appendix A – Hazard Identification Table shall be implemented including but not limited to:

   i. Installation of proprietary ARMCO barriers or equivalent to protect tanks from impact.

   ii. Hydrant protection as per AS 2419.1:2005.

   iii. Provision of spill kits and staff training for spill response.

1 New South Wales Government, "Environmental Planning and Assessment Regulation 2000," New South Wales Government, Sydney, 2000.
2 New South Wales Government, "State Environmental Planning Policy (State and Regional Development) 2011," New South Wales Government, Sydney, 2011.
3 NSW Department of Planning and Environment, "Applying SEPP33 – Hazardous and Offensive Developments," NSW Department of Planning and Environment, Sydney, 2011.

f) Notwithstanding the conclusions following this analysis of the facility, if the poultry farms are relocated as part of design review, a reassessment of the site facility risk contours shall be conducted in the form of a Final Hazard Analysis (FHA) prior to construction of the DG related elements of the design.

1 Introduction

1.1 Background

Baiada Properties Pty Limited (Baiada) has proposed to develop four new poultry farms at 1130 Gooloogong Road, Grenfell, NSW 2810. The proposed development is identified under Item 21 Intensive Livestock Agriculture within Schedule 3 of the Environmental Planning and Assessment Regulation (EPAR) 2000[4] and is therefore regarded as a State Significant Development (SSD). As such, it is necessary to prepare an Environmental Impact Statement (EIS) in accordance with the State Environmental Planning Policy (State and Regional Development) 2011[5].

As part of the EIS, the site was assessed against the State Environmental Planning Policy No. 33 (SEPP33) – Hazardous and Offensive Developments[6] to provide a preliminary hazard screening for submission with the Development Application (DA). The assessment determined that the site would be regarded as potentially hazardous and therefore the SEPP 33 policy applies to the site. Hence, it is necessary to prepare a Preliminary Hazard Analysis (PHA) to assess whether the storage of DGs on the site might result in hazardous impacts to surrounding land.

Lote Consulting Pty Ltd (Lote), have been appointed by Baiada Properties to prepare a PHA for submission with the DA. This document provides Lote's PHA of the proposed Grenfell poultry farm at 1130 Gooloogong Road, Grenfell, NSW 2810.

1.2 Objectives

The objectives of the PHA project for the proposed Baiada Poultry farm at 1130 Gooloogong Road, Grenfell include:

- Complete the PHA according to the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis[7];
- Assess the PHA results using the criteria in HIPAP No. 4 – Risk Criteria for Land Use Planning[8]; and
- Demonstrate compliance of the site with the relevant codes, standards and regulations (i.e., NSW Planning and Assessment Regulation 1979, WHS Regulation, 2017[9].

1.3 Scope of Services

The scope of work is for the development of a PHA for the proposed Baiada poultry farm at 1130 Gooloogong Road, Grenfell, NSW 2810 to determine whether the storage of DGs might result in hazardous offsite impacts. The scope does not include any other sites, nor the preparation of any other planning studies should they be required.

4 New South Wales Government, "Environmental Planning and Assessment Regulation 2000," New South Wales Government, Sydney, 2000.
5 New South Wales Government, "State Environmental Planning Policy (State and Regional Development) 2011," New South Wales Government, Sydney, 2011.
6 NSW Department of Planning and Environment, "Applying SEPP33 – Hazardous and Offensive Developments," NSW Department of Planning and Environment, Sydney, 2011.
7 Department of Planning, "Hazardous Industry Planning Advisory Paper No. 6 - Guidelines for Hazard Analysis," Department of Planning, Sydney, 2011.
8 Department of Planning, "Hazardous Industry Planning Advisory Paper No. 4 - Risk Criteria for Land Use Safety Planning," Department of Planning, Sydney, 2011.
9 SafeWork NSW, "Work Health and Safety Regulation," SafeWork NSW, Lisarow, 2017.

1.4 Abbreviations

Abbreviation	Description
ADG	Australian Dangerous Goods Code
AS	Australian Standard
CBD	Central Business District
DA	Development Application
DGs	Dangerous Goods
DPE	Department of Planning and Environment
EPAR	Environmental Planning and Assessment Regulation
FHA	Final Hazard Analysis
HIPAP	Hazardous Industry Planning Advisory Paper
HSE	Health and Safety Executive
PFD	Probability of Failure on Demand
PHA	Preliminary Hazard Analysis
Pmpy	Per million per year
SEP	Surface Emissive Power
SEPP	State Environmental Planning Policy
SMSS	Storage Mode Sprinkler System
SSC	Spread Sheet Calculator
SSD	State Significant Development
VF	View Factor

2 Methodology

2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach[10] published by the NSW Department of Planning and Environment, has been used as the basis for the study to determine the level of risk assessment required. The approach considered the development in context of its location, the quantity and type (i.e. hazardous nature) of Dangerous Goods stored and used, and the facility's technical and safety management control. The Multi-Level Risk Assessment Guidelines are intended to assist industry, consultants and the consent authorities to carry out and evaluate risk assessments at an appropriate level for the facility being studied.

There are three levels of risk assessment set out in Multi-Level Risk Assessment which may be appropriate for a PHA, as detailed in Table 2-1.

Table 2-1: Level of Assessment PHA

Level	Type of Analysis	Appropriate If:
1	Qualitative	No major off-site consequences and societal risk is negligible
2	Partially Quantitative	Off-site consequences but with low frequency of occurrence
3	Quantitative	Where 1 and 2 are exceeded

The Multi-Level Risk Assessment approach is schematically presented in Figure 2-1.

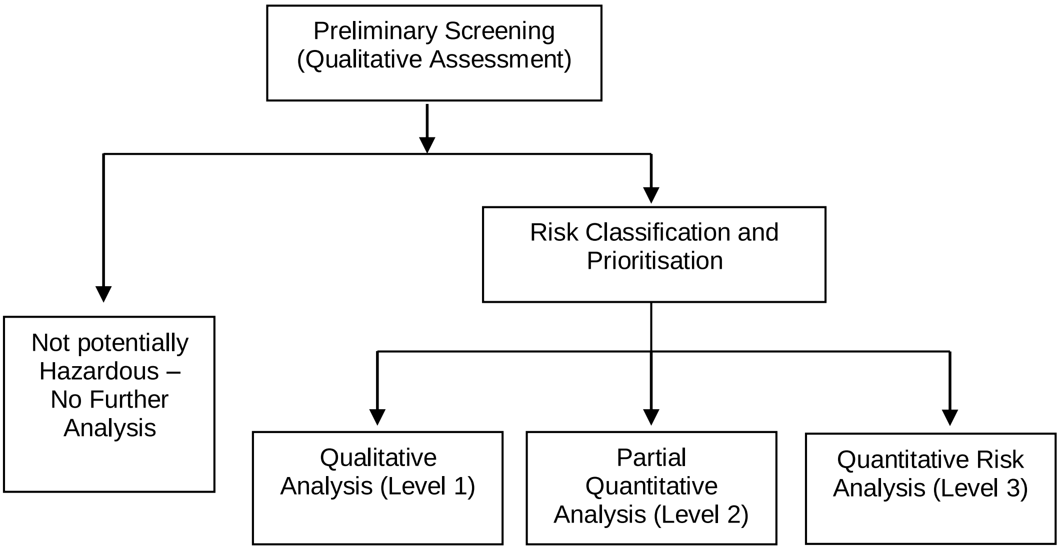


Figure 2-1: The Multi-Level Risk Assessment Approach

Based on the type of DGs to be used and handled at the proposed facility, a Level 2 Assessment was selected for the site. This approach provides a qualitative assessment of those DGs of lesser quantities and hazard, and a quantitative approach for the more hazardous materials to be used on-site. This approach is commensurate with the methodologies recommended in "Applying SEPP 33" Multi Level Risk Assessment approach[11].

10 Department of Planning, Multi-Level Risk Assessment, Sydney: Department of Planning, 2011.
11 NSW Department of Planning and Environment, "Applying SEPP33 – Hazardous and Offensive Developments," NSW Department of Planning and Environment, Sydney, 2011.

2.2 Risk Assessment Study Approach

The methodology used for the PHA is as follows:

Hazard Analysis – A detailed hazard identification was conducted for the site facilities and operations. Where an incident was identified to have a potential off-site impact, it was included in the recorded hazard identification word diagram (Appendix A). The hazard identification word diagram lists incident type, causes, consequences and safeguards. This was performed using the word diagram format recommended in HIPAP No. 6[12].

Each postulated hazardous incident was assessed qualitatively in light of proposed safeguards (technical and management controls). Where a potential offsite impact was identified, the incident was carried into the main report for further analysis. Where the qualitative review in the main report determined that the safeguards were adequate to control the hazard, or that the consequence would obviously have no offsite impact, no further analysis was performed. Section 4.1 of this report provides details of values used to assist in selecting incidents required to be carried forward for further analysis.

Consequence Analysis – For those incidents qualitatively identified in the hazard analysis to have a potential offsite impact, a detailed consequence analysis was conducted. The analysis modelled the various postulated hazardous incidents and determined impact distances from the incident source. The results were compared to the consequence criteria listed in HIPAP No. 4[13]. The criteria selected for screening incidents is discussed in Section 4.1.

Where an incident was identified to result in an offsite impact, it was carried forward for frequency analysis. Where an incident was identified to not have an offsite impact or a simple solution was evident (i.e. move the proposed equipment further away from the boundary), the solution was recommended and no further analysis was performed.

Frequency Analysis – In the event a simple solution for managing consequence impacts was not evident, each incident identified to have potential offsite impact was subjected to a frequency analysis. The analysis considered the initiating event and probability of failure of the safeguards (both hardware and software). The results of the frequency analysis were then carried forward to the risk assessment and reduction stage for combination with the consequence analysis results.

Risk Assessment and Reduction – Where incidents were identified to impact offsite and where a consequence and frequency analysis was conducted, the consequence and frequency analysis for each incident were combined to determine the risk which was then compared to the risk criteria published in HIPAP No. 4[13]. Where the criteria were exceeded, a review of the major risk contributors was performed, and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

Reporting – on completion of the study, a draft report was developed for review and comment by Baiada. A final report will then be developed, incorporating the comments provided by Baiada, for submission to the Regulatory Authority.

12 Department of Planning, "Hazardous Industry Planning Advisory Paper No. 6 - Guidelines for Hazard Analysis," Department of Planning, Sydney, 2011.

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

3 Site Description

3.1 Site Location

The proposed Baiada poultry farm is to be located at 1130 Gooloogong Road, Grenfell, NSW 2810 which is approximately 100 km South-West of Orange in rural NSW. Figure 3-1 shows the regional location of the site in relation to Orange. The site layout is provided in Figure 3-2 and Figure 3-3.

Figure 3-1 – Baiada Poultry Farm Regional Location (Source Google Maps)

3.2 Adjacent land Uses

The land is located in a rural area surrounded on all sides by pasture/agricultural land. The Wallan Creek intersects the property and runs south to north across the site.

3.3 General Description

The proposed Baiada poultry farm will comprise four (4) farms with 10 sheds per farm, giving a total of 40 poultry sheds. The site has an area of 708.75 ha and has been previously cleared for historical agriculture use. Each farm will house the following number of birds with a maximum quantity of 570,000 birds as advised by the Client:

i. Farm 1 (Rearer) – 153,000
ii. Farm 2 (Production) – 132,000
iii. Farm 3 (Production) – 132,000
iv. Farm 4 (Rearer and Production) – 153,000

The proposed farm is intended to produce fertile eggs which are then hatched at a company hatchery offsite and will be grown at company broiler farms (meat chickens) across NSW. In addition to the poultry sheds, there will be other ancillary buildings and infrastructure including manager residences, water tanks, access roads and other services. Each farm will contain between one to three LPG tanks and there will be a chemical store housing other DGs such as cleaning products.

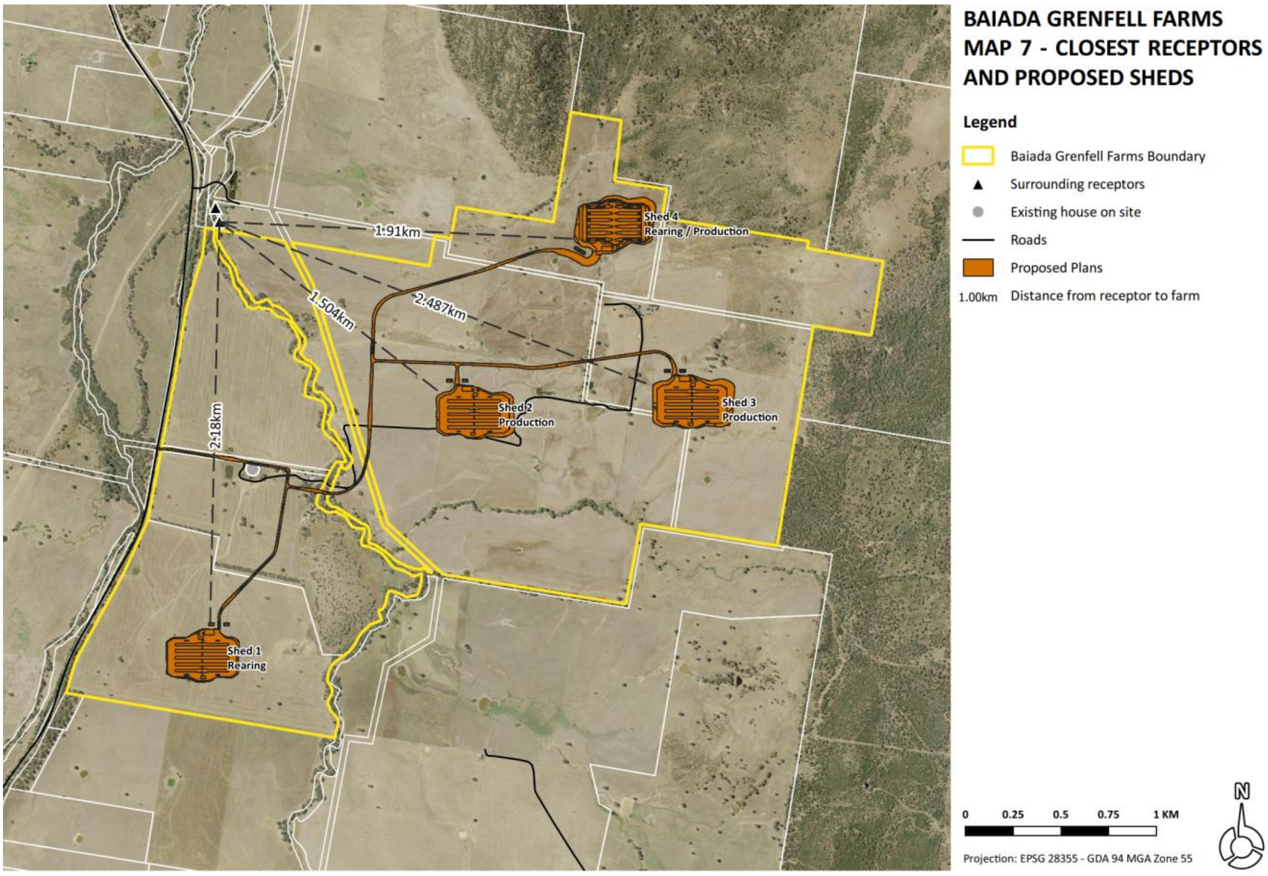


Figure 3-2 - Proposed Site Layout

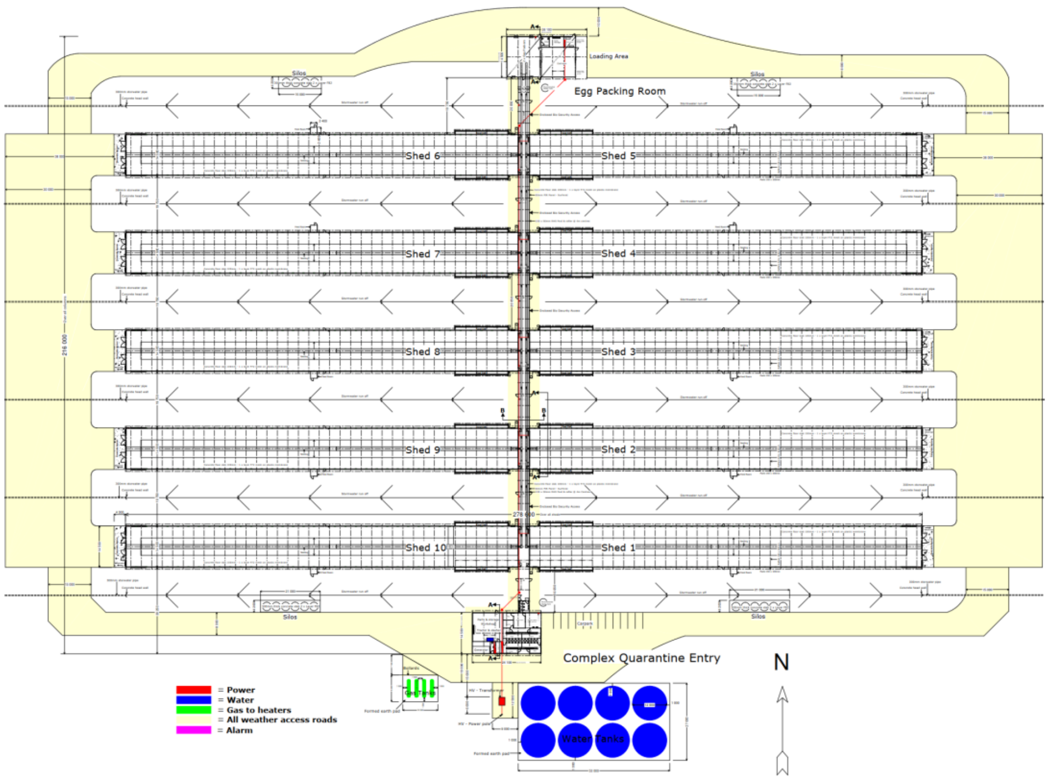


Figure 3-3 – Poultry Shed Detailed Layout

3.4 Quantities of Dangerous Goods Stored and Handled

The DGs to be stored on the proposed Baiada poultry farm are detailed in Table 3-1.

Table 3-1: Quantities of DGs to be Stored

Class	PG	Description	Quantity (L or kg)
2.1	n/a	8 x 7,000 L LPG Tanks	56,000 L
2.1	n/a	LPG (aerosols)	1.8 kg
3	II	Unleaded petrol	40 L
5.1	II	Hyperox	40 L
9	III	Prolong	1 kg
Combustible Liquid	III	Diesel	100 L

3.5 Aggregate Quantity Ratio

Where more than one class of DGs are stored and handled at the site, and aggregate quantity ratio (AQR) exists. This ratio is calculated using **Equation 3-1**.

$$AQR = \frac{q_x}{Q_x} + \frac{q_y}{Q_y} + [\ldots] + \frac{q_n}{Q_n}$$ **Equation 3-1**

Where:

x,y […] and n are the dangerous goods present

q_x, q_y, […] and q_n is the total quantity of dangerous goods x, y, […] and n present.

Q_x, Q_y, […] and Q_n is the individual threshold quantity for each dangerous good of x, y, […] and n

Where the AQR exceeds a value of 1, the site would be considered a Major Hazard Facility (MHF). The threshold quantities for each class are taken from the NSW Work Health and Safety Regulation[14]. These are summarised in Table 3-2, noting that Class 9 substances are not subject to MHF.

Table 3-2: Major Hazard Facility Thresholds

Class	Packing Group	Description	Threshold (tonnes)	Storage (tonnes)
2.1	n/a	LPG	200	28.6*
3	II	Unleaded petrol	50,000	0.04
5.1	II	Hyperox	200	0.04

*Taking the density of LPG as 510 kg/m^3

A review of the commodities stored indicates that only Class 2.1, 3 and 5.1 materials are assessable against the MHF thresholds. Therefore, substituting the storage masses into Equation 3-1, the AQR is calculated as follows:

$$AQR = \frac{28.6}{200} + \frac{0.04}{50{,}000} + \frac{0.04}{200} = 0.14$$

The AQR is less than 1; hence, the facility would not be classified as an MHF.

14 SafeWork NSW, "Work Health and Safety Regulation," SafeWork NSW, Lisarow, 2017.

4 Hazard Identification

4.1 Introduction

A hazard identification table has been developed and is presented at Appendix A. This table has been developed following the recommended approach in Hazardous Industry Planning Advisory Paper No. 6, Hazard Analysis Guidelines[15]. The Hazard Identification Table provides a summary of the potential hazards, consequences and safeguards at the site. The table has been used to identify the hazards for further assessment in this section of the study. Each hazard is identified in detail and no hazards have been eliminated from assessment by qualitative risk assessment prior to detailed hazard assessment in this section of the study.

In order to determine acceptable impact criteria for incidents that would not be considered for further analysis due to limited impact offsite the following approach has been applied:

- Fire Impacts - It is noted in Hazardous Industry Planning Advisory Paper (HIPAP) No. 4[16] that a criterion is provided for the maximum permissible heat radiation at the site boundary (4.7 kW/m^2) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in a heat radiation less than 4.7 kW/m^2 at the site boundary are screened from further assessment.

  Those incidents exceeding 4.7 kW/m^2 at the site boundary are carried forward for further assessment (i.e. frequency and risk). This is a conservative approach, as HIPAP No. 4[16] indicates that values of heat radiation of 4.7 kW/m^2 should not exceed 50 chances per million per year at sensitive land uses (e.g. residential). It is noted that the closest residential property is 1.5 km from the site and is located in a rural land zone. As HIPAP No. 4 considers the risk posed to higher density residential areas, by selecting 4.7 kW/m^2 as the consequence impact criteria at the site boundary the assessment is considered conservative.

- Explosion - It is noted in HIPAP No. 4[16] that a criterion is provided for the maximum permissible explosion over pressure at the site boundary (7 kPa) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, incidents that result in an explosion overpressure less than 7 kPa at the site boundary are screened from further assessment. Those incidents exceeding 7 kPa at the site boundary are carried forward for further assessment (i.e. frequency and risk). Similarly to the heat radiation impact discussed above, this is conservative as the 7 kPa value listed in HIPAP No. 4 relates to higher density residential areas which are not present around the site.

- Toxicity – Toxic substances have not been proposed to be stored at the site. However, toxic gases may be generated as a result of combustion and therefore this has been assessed within this report.

- Property Damage and Accident Propagation - It is noted in HIPAP No. 4[16] that a criterion is provided for the maximum permissible heat radiation/explosion overpressure at the site boundary (23 kW/m^2 / 14 kPa) above which the risk of property damage and accident propagation to neighbouring sites must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk to incident propagation, for this study, incidents that result in a heat radiation less than 23 kW/m^2 and explosion over pressure less than 14 kPa at the site boundary are screened from further assessment. Those incidents exceeding 23 kW/m^2 at the site boundary are carried forward for further assessment with respect to incident propagation (i.e. frequency and risk).

- Societal Risk – HIPAP No. 4[16] discusses the application of societal risk to populations surrounding the proposed potentially hazardous facility. It is noted that HIPAP No. 4 indicates that where a development proposal involves a significant intensification of population in the vicinity of such a facility, the change in societal risk needs to be taken into account. In the case of the Baiada poultry farm, there is no significant intensification of population around the proposed site. Additionally, the closest residential land is 1.5 km away however it is situated in a rural land zone so exists as an isolated property and not a high density residential area. Therefore, societal risk has not been considered in the assessment.

---

15 Department of Planning, "Hazardous Industry Planning Advisory Paper No. 6 - Guidelines for Hazard Analysis," Department of Planning, Sydney, 2011.

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

4.2 Properties of Dangerous Goods

The type of DGs and quantities stored and used at the site has been described in Section 3. Table 4-1 provides a description of the DGs, including the DG Class and the hazardous material properties of that Class.

Table 4-1: Properties* of the Dangerous Goods and Materials Stored at the Site

Class	Hazardous Properties
2.1 – Flammable Gas	Class 2.1 includes flammable gases which are ignitable when in a mixture of 13 per cent or less by volume with air or have a flammable range with air of at least 12 percentage points regardless of the lower flammable limit. Ignited gas may result in explosion or flash fire. Where gas released under pressure from a hole in a pressurised component is ignited, a jet fire may occur.
3 – Flammable Liquids	Class 3 includes flammable liquids which are liquids, or mixtures of liquids, or liquids containing solids in solution or suspension (for example, paints, varnishes, lacquers, etc.) which give off a flammable vapour at temperatures of not more than 60ºC closed-cup test or not more than 65.6ºC open-cup test. Vapours released may mix with air and if ignited, at the right, concentration will burn resulting in pool fires at the liquid surface
5.1 – Oxidising Substances	Class 5.1 materials will not combust but these materials include substances which can in a fire event, liberate oxygen and could accelerate the burning of other combustible or flammable materials. Releases to the environment may cause damage to sensitive receptors within the environment.
9 – Miscellaneous DGs	Class 9 substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not covered by other classes. Releases to the environment may cause damage to sensitive receptors within the environment.
C1/C2	C1/C2 products are not classified as DGs; however, they are combustible liquids. Therefore, it may sustain combustion although initial ignition is difficult due to the high flash point of the material. Combustible liquids do not generate flammable vapours which eliminates the potential for flash fire or explosions to occur when confined.

* The Australian Code for the Transport of Dangerous Goods by Road and Rail[17]

4.3 Hazard Identification

Based on the hazard identification table presented in Appendix A, the following hazardous scenarios have been developed:

- LPG Tank Release and Environmental Impact
- LPG Tank Release, Ignition and Pool Fire
- LPG Tank Release, Ignition and Flash Fire or Explosion
- LPG Tank Release, Ignition and Jet Fire
- LPG Tank Jet Fire and Tanker BLEVE
- LPG Tank Jet Fire and Tank Shell BLEVE
- Chemical Store DG Spill and Environmental Impact
- Chemical Store Flammable Liquid Spill, Ignition and Pool Fire

17 National Transport Commission (NTC), "Australian Code for the Transport of Dangerous Goods by Road & Rail, 7th Edition," 2011.

- Chemical Store Flammable Liquid Pool Fire, Incident Propagation and Full Building Fire

Each identified scenario is discussed in further detail in the following sections.

4.4 LPG Tank Release and Environmental Impact

In the event of a small leak from a vessel or pipework a pool of LPG may form when the rate of evaporation of LPG is less than the flow rate of LPG from the leak, although it is noted that due to pressure of the tank any release will likely flash to vapour rather than pooling. Nonetheless, if the LPG pool were large enough, this may flow into waterways nearby. A leak sufficient to cause a release that exceeds the evaporation rate to develop a pool large enough to flow out of the immediate area and cause environmental impact is extremely unlikely to occur. This is substantiated by numerous similar sized LPG tanks installed throughout Australia with very low incidences of leaks and fires occurring from such installations. Furthermore, as the liquid flows it will absorb heat from the ground where it will evaporate into a vapour. With sufficient time, all vapour will evaporate leaving no trace of the LPG within the terrestrial environment.

Additionally, the area immediately surrounding the LPG tanks is designed in accordance with AS/NZS 1596:2014[18] to minimise the potential for both a leak to occur and any incidents to result from a potential leak. Hence, as the potential for this event to occur is low and the environmental impact is not considered to be significant as the LPG will evaporate, this incident has not been carried forward for further analysis.

4.5 LPG Tank Release, Ignition and Pool Fire

In the event of a small leak from a vessel or pipework a pool of LPG may form when the rate of evaporation of LPG is less than the flow rate of LPG from the leak. If the pool were to ignite, an LPG pool fire would occur which may impact over the site boundary.

A leak sufficient to cause a release that exceeds the evaporation rate to develop a pool large enough to ignite is considered a low risk. Noting the area is zoned per the requirements of AS/NZS 60079.10.1:2009[19], which is substantiated by numerous similar sized LPG tanks installed throughout Australia with very low incidences of leaks and fires occurring from such installations. In addition, the radiant heat from a fire would be unlikely to be sufficient to impact over the site boundary at a level exceeding 4.7 kW/m^2 based upon the tank locations.

As the potential for a leak and LPG pool and subsequent ignition to occur is incredibly low and there are unlikely to be offsite radiant heat impacts, this incident has not been carried forward for further analysis.

4.6 LPG Tank Release, Ignition and Flash Fire or Explosion

As the site LPG is depleted, it will be refilled by a delivery tanker at the site. During loading of the tank there is the potential for the hose to rupture which may be the result of a puncture of the hosing or deterioration through general wear and tear. It is considered that the hoses are inspected monthly and pressure tested annually in accordance with the Australian Dangerous Goods (ADG[20]) Code.

Notwithstanding this, there is the potential for a hose to become damaged between inspection and test periods which may lead to sufficient deterioration resulting in a hose rupture when transferring pressurised LPG. Excess flow and non-return valves will isolate the flow of LPG. However, if these fail in addition to a hose rupture, LPG will be released resulting in an LPG vapour cloud. The operator may be able to respond and isolate the LPG transfer by activating an emergency stop button located on the tanker.

If the operator is incapacitated or unable to stop the transfer, the LPG will continue to flow developing a substantial cloud which may contact an ignition source and ignite and would result in a flash fire or explosion. It is noted the area is unconfined. Hence, the occurrence of an explosion is unlikely and the ignition would likely result in a flash fire.

The potential for a fatality to occur offsite as a result of a flash fire is not considered credible. As LPG is a dense gas, any release will spread along at ground level and due to the open nature of the site it will not accumulate to a level where a person will be fully engulfed; hence, a fatality offsite is unlikely to occur. Furthermore, the site boundary is a substantial distance from where the tanks are stored allowing substantial time for dispersion of the LPG prior to impacting over the site boundary. However, it is considered that site personnel caught in the immediate vapour cloud will result in a fatality.

18 Standards Australia, AS/NZS 1596:2014 - The Storage and Handling of LP Gas, Sydney: Standards Australia, 2014.
19 Standards Australia, AS/NZS 60079.10.1:2009 - Explosive Atmospheres Part 10.1: Classification of Areas, Explosive Gas Atmospheres, Sydney: Standards Association of Australia, 2009.
20 Road Safety Council, The Australian Code for the Transport of Dangerous Goods by Road and Rail Edition 7.4, Canberra: Road Safety Council, 2016.

AS/NZS 1596:2014[21] has been developed with reference to the likely impact scenarios from storage of LPG in various tank sizes. Review of Table 6.1 of AS/NZS 1596:2014[21] indicates for a 7.5 kL tank the separation distance to a protected place is 6 m. Therefore, the standard would consider that in open air, events resulting from a release from the tank would be unlikely to significantly impact at a distance greater than 6 m.

A catastrophic failure of an LPG tank (i.e. rupture and full release of LPG) is considered low due to the manufacturing and regular testing of pressure vessels according to AS 1210:2010[22]. It is noted that this is based on the reported failure catastrophic failure rate for LPG tank ruptures being 2x10^{-6} per tank per year[23]. Thus, it is not expected to occur within a tank's useful lifetime.

As the area is unconfined, the location of the tank provides adequate separation to the site boundary and protected places, it is considered that a fatality would not result from this incident. Hence, this incident has not been carried forward for further analysis.

4.7 LPG Tank Release, Ignition and Jet Fire

As with Section 4.6, there is the potential for a significant LPG release during transfer if the hose were to rupture. If the vapour cloud were ignited, it would burn back to the release point and subsequently form a jet fire. If the source of release is not stopped, the jet fire may cause significant impact to personnel, property or equipment on site and over the site boundary. Hence, this incident has been carried forward for further analysis.

4.8 LPG Tank Jet Fire and Tanker BLEVE

Similarly, to the scenario described in Section 4.7, the hose may rupture during LPG transfer resulting in a jet fire. If this jet fire were aimed at the delivery tanker, the tanker shell would begin to heat, transferring the heat into the LPG within the tank which would begin to vaporise and increase the pressure within the tanker. At the design pressure of the tank, the pressure relief valve will begin to lift to relieve pressure within the tanker.

As the liquid level within the tanker drops, the impact zone of the jet fire may impact the vapour space in the tanker. The vapour will absorb less energy than the liquid which will result in localised heating of the tanker shell at the point of the jet fire impact. This may compromise the structural integrity of the tanker shell which may rupture resulting in a blast overpressure as the vessel fails and formation of an LPG vapour cloud which may also ignite resulting in a vapour cloud explosion known as a Boiling Liquid Expanding Vapour Explosion (BLEVE). This incident has been carried forward to assess the potential impact zone.

4.9 LPG Tank Jet Fire and Tank Shell BLEVE

Similarly, to the scenario described in Section 4.7, the hose may rupture during LPG transfer resulting in a jet fire. If this jet fire were aimed at the tank itself or another tank located nearby, the tank shell would begin to heat, transferring the heat into the LPG within the tank which would begin to vaporise and increase the pressure within the tank which may result in a BLEVE as described in Section 4.8. Hence, this incident has been carried forward for further analysis.

4.10 Chemical Store DG Spill and Environmental Impact

The Chemical Store contains DGs in small packages with a maximum package volume within the store of 20 L. There is the potential for a spill to occur if the packages were dropped or mishandled, which could result in a release of DGs and an environmental spill. An environmental release of DGs into local waterways could have serious impacts on local flora and fauna.

In order for the spill to have an off-site impact, a loss of containment is required within the store which is able to flow into the local water system. The potential for a loss of containment of sufficient size to result in such an impact has been eliminated by the small individual package volumes. In the event that a spill was to occur, it would readily be cleaned up and thus, no environmental impact would be expected to occur. Therefore, as any potential releases will not have offsite impacts, this scenario has not been carried forward for further analysis.

21 Standards Australia, AS/NZS 1596:2014 - The Storage and Handling of LP Gas, Sydney: Standards Australia, 2014.
22 Standards Australia, "AS 1210:2010 - Pressure Vessels," Standards Australia, Sydney, 2010.
23 HSE – Failure Rates and Event Data for use within Land Use Planning Risk Assessments

4.11 Chemical Store Flammable Liquid Spill, Ignition and Pool Fire

There is the potential for flammable liquids to be released in the Chemical Store if the packages were dropped or mishandled. In the event that a liquid pool forms and ignites, a fire would occur within the store. In order for the fire to have an offsite impact, it would need to propagate beyond the store and impact surrounding land.

The store of flammable liquids is classified as a minor store per AS 1940:2017 which reflects the low risk posed by stores containing low volumes of Class 3 substances. Additionally, the risk of a fire has been mitigated by controlling ignition sources in and around the flammable liquids and providing ventilation which reduces the accumulation of vapours within the area. These controls include a hazardous area classification in accordance with AS/NSZ 60079.10.1:2009[24], compliant electrical equipment in accordance with AS/NZS 600079.14:2017[25], a no smoking policy and placarding in accordance with AS/NZS 1940-2017[26].

If these controls were to fail and a pool fire occurred, it would be easily suppressed by first aid firefighting equipment which is available in the store. Furthermore, the store is located away from the site boundary which would further supress the radiant heat experienced offsite. Hence, as no offsite impact would be expected to occur this incident has not been carried forward for further analysis.

4.12 Chemical Store Flammable Liquid Pool Fire, Incident Propagation and Full Building Fire

As discussed in Section 4.11, the potential for a flammable liquid spill to result in a fire is extremely low. This is attributable to the minor quantities of flammable materials kept, the ignition controls in place and the availability of first aid firefighting equipment which would be sufficient to extinguish any fire which did occur. Therefore, as the initiating event is not considered a credible scenario, there would be no incident propagation which would result in a full building fire. Hence, this incident has not been carried forward for further analysis.

24 Standards Australia, AS/NZS 60079.10.1:2009 - Explosive Atmospheres Part 10.1: Classification of Areas, Explosive Gas Atmospheres, Sydney: Standards Association of Australia, 2009.
25 Standards Australia, AS/NZS 60079.14:2017 - Explosive Atmospheres Part 14: Electrical Installations, Design, Selection and Erection, Sydney: Standards Australia, 2017.
26 Standards Australia, AS 1940-2017 - Storage and Handling of Flammable and Combustible Liquids, Sydney: Standards Australia, 2017.

5 Consequence Analysis

5.1 Incidents Carried Forward for Consequence Analysis

The following incidents were identified to have potential to impact offsite:

- LPG Tank Release, Ignition and Jet Fire
- LPG Tank Jet Fire and Tanker BLEVE
- LPG Tank Jet Fire and Tank Shell BLEVE

Each incident has been assessed in the following sections.

5.2 LPG Tank Release, Ignition and Jet Fire

There is the potential for a hose to rupture and release high pressure LPG if the excess flow valve on the tanker fails and operator intervention does not occur. If this stream ignited, a jet fire could occur. A detailed analysis has been conducted in Appendix B5 for this scenario which indicates the jet fire would have an impact of distance of 38.4 m. The impact distances for this incident are shown in Figure 5-1, noting that this incident could occur at any one of the eight tanks which are stored on site.

There are several protection systems to prevent hose rupture including hose pressure testing and inspections, non-return valves on the tank and vehicle, excess flow valves on the tanker, earthing connections, and ignition source controls. Therefore, it is unlikely that a release of LPG would occur and subsequently ignite.

The incident does not impact over the site boundary and there are no areas where people may congregate within the impact contour. Therefore, this incident has not been carried forward for further assessment.

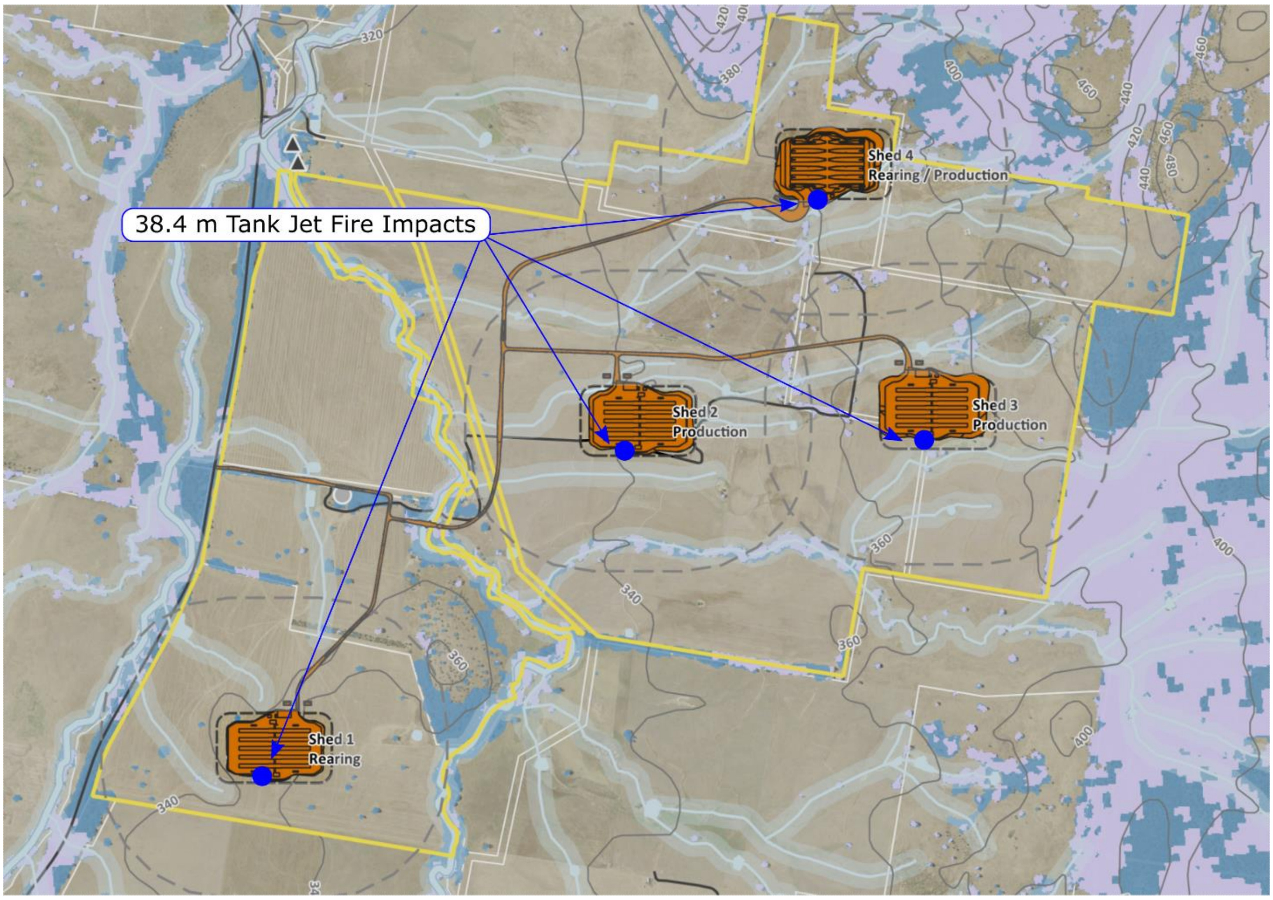


Figure 5-1: LPG Tank Jet Fire Distances

5.3 LPG Tank Jet Fire and Tanker BLEVE

In the event of a jet fire and impingement on the delivery tanker there is potential for the LPG in the tanker to boil escalating to a BLEVE if intervention measures fail. A detailed analysis has been conducted in Appendix B6 which indicates the diameter of the BLEVE would be 164.5 m and would last for 10 seconds. The impact distances for this incident are shown in Figure 5-2, noting that this incident could occur at any one of the eight tanks which are stored on site.

Similar to the jet fire scenario, several layers of protection are required to fail before the initiating event could occur. In addition, the jet fire would need to be impinged on the tanker before it could BLEVE which takes considerable time as the LPG must boil off such that the liquid level is below the impact point. Additionally, the incident does not impact over the site boundary at any of the LPG Tank locations, nor are there any areas where people may congregate within the impact contour. Therefore, this incident has not been carried forward for further assessment.

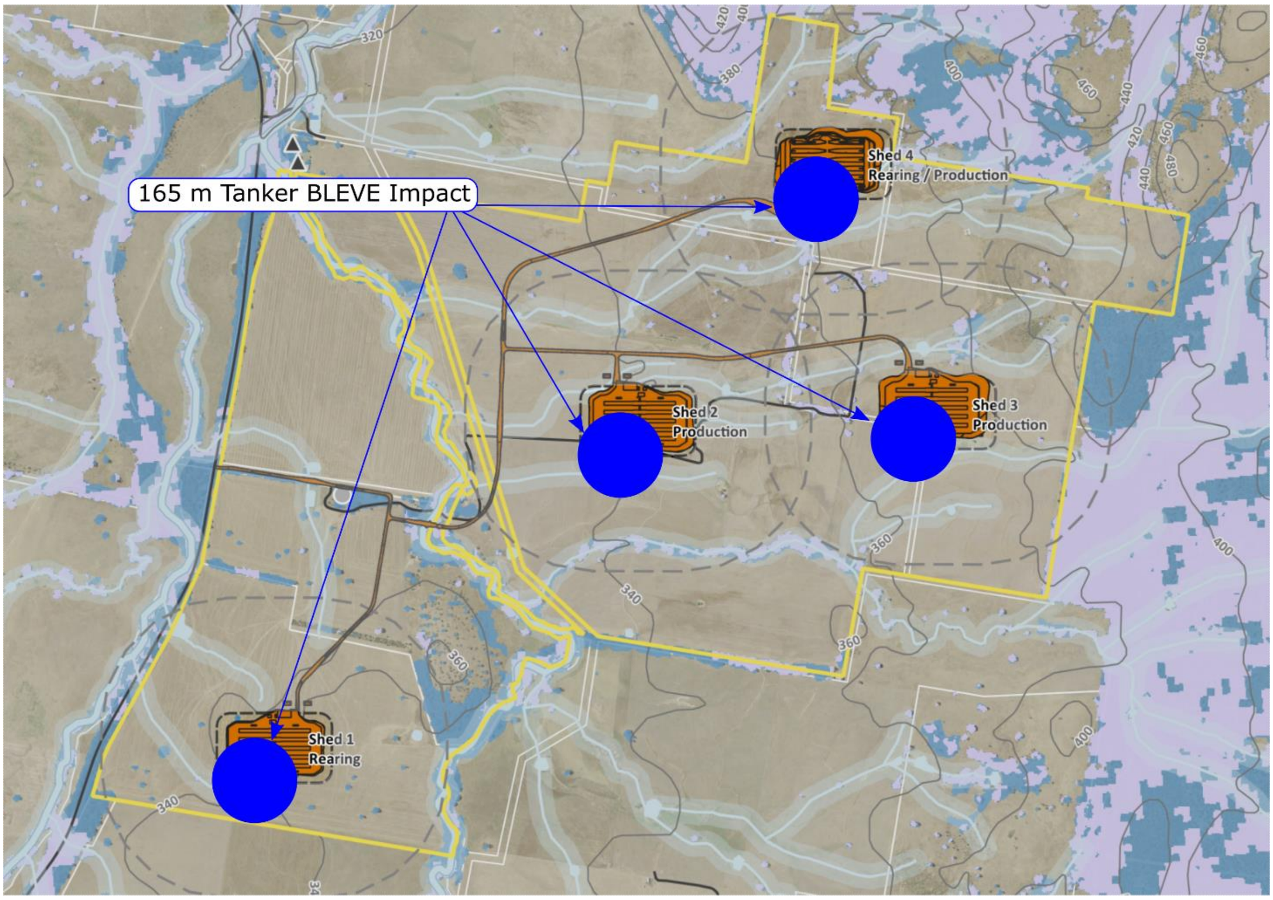


Figure 5-2: LPG Tanker BLEVE Impact Distances

5.4 LPG Tank Jet Fire and Tank Shell BLEVE

In the event of a jet fire and impingement on the LPG tank there is potential for the LPG in the tank to boil escalating to a BLEVE if intervention measures fail. A detailed analysis has been conducted in Appendix B7 which indicates the diameter of the BLEVE would be 92.5 m and would last for 7 seconds. The impact distances for this incident are shown in Figure 5-3, noting that this incident could occur at any one of the eight tanks which are stored on site.

Similar to the jet fire scenario, several layers of protection are required to fail before the initiating event could occur. In addition, the jet fire would need to be impinged on the LPG tank before it could BLEVE which takes considerable time as the LPG must boil off such that the liquid level is below the impact point. Additionally, the incident does not impact over the site boundary at any of the LPG Tank locations, nor are there any areas where people may congregate within the impact contour. Therefore, this incident has not been carried forward for further assessment.

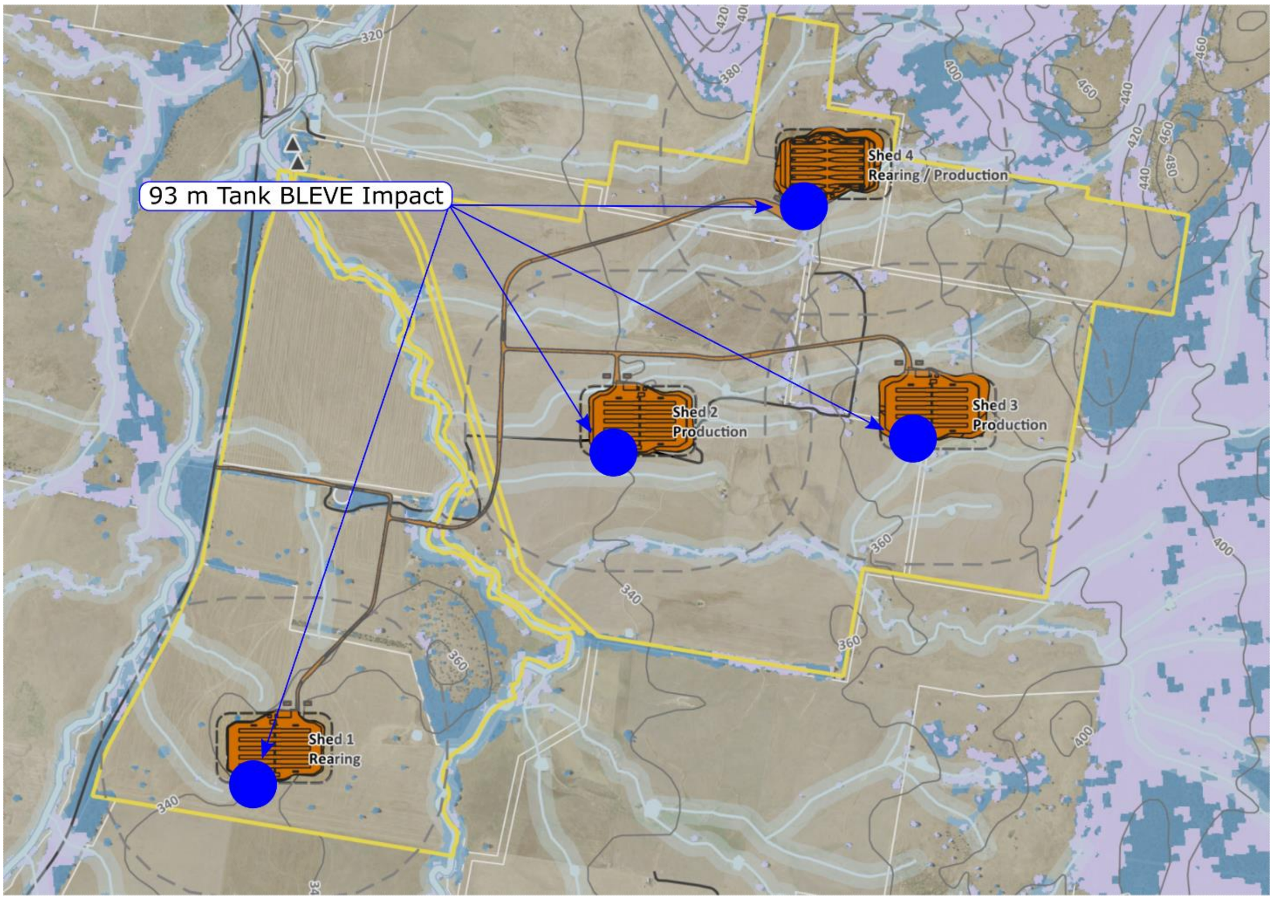


Figure 5-3: LPG Tank BLEVE Impact Distances

6 Frequency Analysis

6.1 Incidents Carried Forward for Frequency Analysis

No incidents were identified to impact offsite; hence, no items were carried forward for frequency analysis.

7 Conclusions and Recommendations

7.1 Conclusions

A hazard identification table was developed for the facility to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The consequence analysis showed that no scenarios had the potential to impact offsite. As such, frequency analysis was not conducted as the probability of a fatality at the site boundary was already minimised to within the acceptable risk criteria.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the facility would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

7.2 Recommendations

a) The area immediately surrounding the LPG tanks shall be designed in accordance with AS/NZS 1596:2014.

b) All areas containing dangerous goods shall be zoned in accordance with the requirements of AS/NZS 60079.10.1:2009.

c) All electrical equipment located within hazardous areas shall comply with AS/NZS 600079.14:2017.

d) A no smoking policy and placarding in accordance with AS/NZS 1940-2017 shall be provided in the vicinity of all dangerous goods stores.

e) The safeguards outlined in Table A1 in Appendix A – Hazard Identification Table shall be implemented including but not limited to:

   i. Installation of proprietary ARMCO barriers or equivalent to protect tanks from impact.

   ii. Hydrant protection as per AS 2419.1:2005.

   iii. Provision of spill kits and staff training for spill response.

f) Notwithstanding the conclusions following this analysis of the facility, if the poultry farms are relocated as part of design review, a reassessment of the site facility risk contours shall be conducted in the form of a Final Hazard Analysis (FHA) prior to construction of the DG related elements of the design.

8 Validity and Limitations

The reader's attention is drawn to the following limitations with respect to the Preliminary Hazard Assessment (PHA) undertaken in this report:

a) This report has been prepared in accordance with the scope of services described in the contract or agreement between Lote Consulting and the Client.

b) The report relies upon data, surveys, measurements and results taken at or under the particular times and conditions specified herein.

c) Changes to circumstances or facts after certain information or material has been submitted may impact on the accuracy, completeness or currency of the information or material.

d) This report has been prepared solely for use by the Client. Lote Consulting accepts no responsibility for its use by other parties without the specific authorization of Lote Consulting.

e) Lote Consulting reserves the right to alter, amend, discontinue, vary or otherwise change any information, material or service at any time without subsequent notification.

f) Reports marked 'Draft' are subject to change and Lote accepts no liability pending release of the final version of the report.

g) All access to, or use of, the information or material is at the user's risk and Lote Consulting accepts no responsibility for the results of any actions taken on the basis of information or material provided, nor for its accuracy, completeness or currency.

h) Any change in building, occupant or fuel conditions from those considered in this report, or any deviation from the implementation of the fire safety strategy outlined in this report, may result in outcomes not anticipated by the proposed strategy and should be reviewed.

i) It is considered that the scope of works arising from this report and limitations of this report are read, understood and implemented. Lote shall be contacted in relation to any queries on the report content and takes no responsibility for misinterpretation of the report content by others.

j) The architectural and engineering drawings referenced or listed in this report have been utilised for purposes of formulating and assessing the site as nominated in this Report. Lote have not reviewed the drawings for compliance with the BCA, Australian Standards or the Dangerous Goods Guidelines.

Appendix A – Hazard Identification Table

A1. Hazard Identification Table

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
Above Ground LPG Tanks (Farm 1, 2, 3, and 4)	• Release of LPG from tank filling • Tank leak (valves and fittings) • Vehicle collision and tank puncture • Over-pressurisation and pressure relief activation	• Formation of a vapour cloud, delayed ignition and explosion • Immediate ignition resulting in jet fire • Jet fire impingement on tank shell resulting in BLEVE • Jet fire impingement on delivery tanker resulting in BLEVE	• Natural ventilation • System designed in accordance with AS/NZS 1596:2014 • ARMCO barriers to protect from impact • Operator can stop source of release (emergency stop during filling) • Separation distances complying with AS/NZS 1596:2014 • First attack firefighting equipment available (fire extinguishers and hose reels) and operators trained in first attack firefighting • Hydrant protection as per AS 2419.1:2005. • Control of ignition sources according to AS/NZS 60079.14:2017[27] • Ignition source control placarding, complying with AS/NZS 1596:2014[28] • Fire and Rescue may respond faster than BLEVE escalation
DG Spill in Chemical Store	• Release of Class 3, 5.1, 9 or combustible liquid	• Release and environmental impact	• Minor storage quantities and all packages containing small volumes

27 Standards Australia, AS/NZS 60079.14:2017 - Explosive Atmospheres Part 14: Electrical Installations, Design, Selection and Erection, Sydney: Standards Australia, 2017.
28 Standards Australia, AS/NZS 1596:2014 - The Storage and Handling of LP Gas, Sydney: Standards Australia, 2014.

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
			• Storage in accordance with AS/NZS 3833:2007[29] • Spill kit and staff trained in spill response
		• Release, ignition of Class 3 substance and pool fire • Incident propagation involving oxidising substances and combustible liquids	• Ignition control in accordance with AS/NZS 60079.14:2007[27] • Separation of DGs in accordance with AS/NZS 3833:2007[29] • First attack firefighting equipment available and staff trained in proper use

29 Standards Australia, "AS/NZS 3833:2007 - Storage and Handling of Mixed Classes of Dangerous Goods, in Packages and Intermediate Bulk Containers," Standards Australia, Sydney, 2007.

Appendix B – Consequence Analysis

B1. Incidents Assessed in Detailed Consequence Analysis

The following incidents were assessed for consequence impacts:

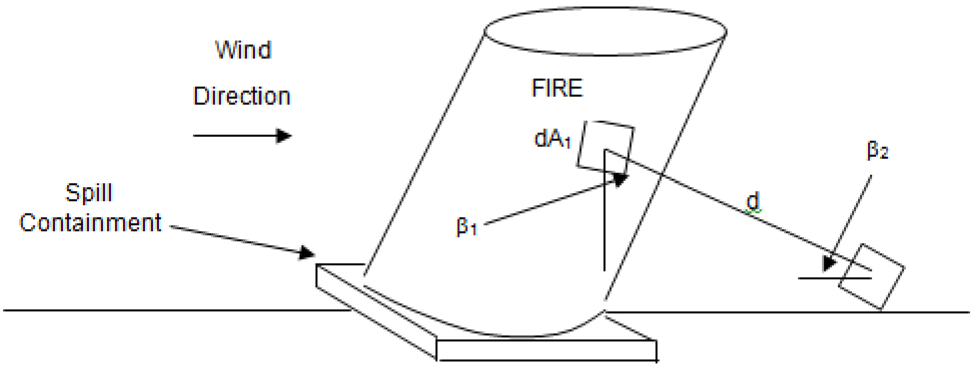
- LPG Tank Release, Ignition and Jet Fire
- LPG Tank Jet Fire and Tanker BLEVE
- LPG Tank Jet Fire and Tank Shell BLEVE

Each incident has been assessed in the following sections.

B2. Spreadsheet Calculator (SSC)

The SSC is designed on the basis of finite elements. The liquid flame area is calculated as if it is a circle to find the radius for input into the SSC model.

The SSC is designed on the basis of finite elements. The liquid flame area is calculated as if it is a circle to find the radius for input into the SSC model. Appendix Figure B-1 shows a typical pool fire, indicating the target and fire impact details.



Appendix Figure B-1: Heat Radiation on a Target from a Cylindrical Flame

A fire in a bund or at a tank roof will act as a cylinder with the heat from the cylindrical flame radiating to the surrounding area. A number of mathematical models may be used for estimating the heat radiation impacts at various distances from the fire. The point source method is adequate for assessing impacts in the far field; however, a more effective approach is the view factor method, which uses the flame shape to determine the fraction of heat radiated from the flame to a target. The radiated heat is also reduced by the presence of water vapour and the amount of carbon dioxide in air. The formula for estimating the heat radiation impact at a set distance is shown in Equation B-1[30].

$$Q = EF\tau$$ **Equation B-1**

Where:

- Q = incident heat flux at the receiver (kW/m^2)
- E = surface emissive power of the flame (kW/m^2)
- F = view factor between the flame and the receiver
- τ = atmospheric transmissivity

30 I. Cameron and R. Raman, Process Systems Risk Management, San Diego: Elsevier, 2005.

The calculation of the view factor (F) in Equation B-1 depends upon the shape of the flame and the location of the flame to the receiver. F is calculated using an integral over the surface of the flame, S[30]. The formula can be shown as:

$$F = \int\int_S \frac{\cos\beta_1 \cos\beta_2}{\pi d^2}$$ **Equation B-2**

Equation B-2 may be solved using the double integral **or** using a numerical integration method in spread sheet form. This is explained below.

For the assessment of pool fires, a Spread Sheet Calculator (SCC) has been developed, which is designed on the basis of finite elements. The liquid flame area is calculated as if the fire is a vertical cylinder, for which the flame diameter is estimated based on the fire characteristics (e.g. contained within a bund). Once the flame cylindrical diameter is estimated, it is input into the SSC model. The model then estimates the flame height, based on diameter, and develops a flame geometric shape (cylinder) on which is performed the finite element analysis to estimate the view factor of the flame. Appendix Figure B-1 shows a typical pool fire, indicating the target and fire impact details.

The SSC integrates the element dA_1 by varying the angle theta θ (the angle from the centre of the circle to the element) from zero to 90º in intervals of 2.5 degrees. Zero degrees represents the straight line joining the centre of the cylinder to the target (x0, x1, x2) while 90º is the point at the extreme left-hand side of the fire base. In this way the fire surface is divided up into elements of the same angular displacement. Note the tangent to the circle in plan. This tangent lies at an angle, gamma, with the line joining the target to where the tangent touches the circle (x4). This angle varies from 90º at the closest distance between the liquid flame (circle) and the target (x0) and gets progressively smaller as θ increases. As θ increases, the line x4 subtends an angle phi Φ with x0. By similar triangles we see that the angle gamma γ is equal to 90- θ - Φ . This angle is important because the sine of the angle give us the proportion of the projected area of the plane. When γ is 90º, sin(γ) is 1.0, meaning that the projected area is 100% of the actual area.

Before the value of θ reaches 90º the line x4 becomes tangential to the circle. The fire cannot be seen from the rear and negative values appear in the view factors to reflect this. The SSC filters out all negative contributions.

For the simple case, where the fire is of unit height, the view factor of an element is simply given by the expression in Equation B-3 (Derived from Equation B-2):

$$VF = \Delta A \frac{\sin\gamma}{\pi \times X4 \times X4}$$ **Equation B-3**

Where ΔA is the area of an individual element at ground level.

Note: the denominator (π. x4. x4) is a term that describes the inverse square law for radiation assumed to be distributed evenly over the surface of a sphere.

Applying the above approach, we see the value of x4 increase as θ increase, and the value of sin(γ) decreases as θ increase. This means that the contribution of the radiation from the edge of the circular fire drops off quite suddenly compared to a view normal to the fire. Note that the SSC adds up the separate contributions of Equation B-3 for values of θ between zero until x4 makes a tangent to the circle.

It is now necessary to do two things: (i) to regard the actual fire as occurring on top of a fire wall (store) and (ii) to calculate and sum all of the view factors over the surface of the fire from its base to its top. The overall height of the flame is divided into 10 equal segments. The same geometric technique is used. The value of x4 is used as the base of the triangle and the height of the flame, as the height. The hypotenuse is the distance from target to the face of the flame (called X4'). The angle of elevation to the element of the fire (alpha α) is the arctangent of the height over the ground distance. From the cos(α) we get the projected area for radiation. Thus there is a new combined distance and an overall equation becomes in Equation B-4 ((Derived from Equation B-3):

$$VF = \Delta A \frac{\sin\gamma \times \cos\alpha}{\pi \times X4 \times X4}$$ **Equation B-4**

The SCC now turns three dimensional. The vertical axis represents the variation in θ from 0 to 90º representing half a projected circle. The horizontal axis represents increasing values of flame height in increments of 10%. The average of the extremes is used (e.g. if the fire were 10 m high then the first point would be the average of 0 and 1 i.e. 0.5 m), the next point would be 1.5 m and so on).

Thus, the surface of the flame is divided into 360 equal area increments per half cylinder making 720 increments for the whole cylinder. Some of these go negative as described above and are not counted because they are not visible. Negative values are removed automatically.

The sum is taken of the View Factors in Equation B-3. Actually, the sum is taken without the ∆A term. This sum is then multiplied by ∆A which is constant. The value is then multiplied by 2 to give both sides of the cylinder. This is now the integral of the incremental view factors. It is dimensionless so when we multiply by the emissivity at the "face" of the flame (or surface emissive power, SEP), which occurs at the same diameter as the fire base (pool), we get the radiation flux at the target.

The SEP is calculated using the work by Mudan & Croche[31 & 32] which uses a weighted value based on the luminous and non-luminous parts of the flame. The weighting is based on the diameter and uses the flame optical thickness ratio where the flame has a propensity to extinguish the radiation within the flame itself. The formula is shown in Equation B-5.

$$SEP = E_{max}e^{-sD} + E_s(1 - e^{-sD})$$ **Equation B-5**

Where:

E_{max} = 140

S = 0.12

E_s = 20

D = pool diameter

The only input that is required is the diameter of the pool fire and then estimation for the SEP is produced for input into the SSC.

The flame height is estimated using the Thomas Correlation[31] which is shown in Equation B-6.

$$H = 42d_p\left[\frac{\dot{m}}{\rho_a\sqrt{gd_p}}\right]^{0.61}$$ **Equation B-6**

Where:

d_p = pool diameter (m)

ρ_a = density of air (1.2 kg/m^3 at 20^{o}C)

$\dot{m}$ = burning rate (kg/m^2.s)

g = 9.81 m/s^2

The transmissivity is estimated using Equation B-7[31].

$$\tau = 1.006 - 0.01171(\log_{10} X(H_2O) - 0.02368(\log_{10}X(H_2O))^2 - 0.03188(\log_{10} X(CO_2) + 0.001164(\log_{10}X(CO_2))^2$$ **Equation B-7**

Where:

- τ = Transmissivity (%)
- X(H_2O) = $\frac{R_H \times L \times S_{mm} \times 2.88651 \times 10^2}{T}$
- X(CO_2) = $\frac{L \times 273}{T}$

and

- R_H = Relative humidity (% expressed as a decimal)

31 I. Cameron and R. Raman, Process Systems Risk Management, San Diego: Elsevier, 2005.
32 F. P. Lees, Loss Prevention in the Process Industries, London: Butterworth-Heinemann, 2005.

- L = Distance to target (m)
- S_{mm} = saturated water vapour pressure in mm of mercury at temperature (at 25ºC S_{mm} = 23.756)
- T = Atmospheric temperature (K)

B3. Jet Fire Modelling

The flow rate of a liquid from a hole may be calculated from Equation B-8[33].

$$m = C_d A(2\rho\Delta P)^{0.5}$$ **Equation B-8**

Where:

- m = Mass flow rate (kg/s)
- C_d = Discharge coefficient (0.6 for irregular holes)
- A = area of the orifice (m^2)
- ρ = Density of the material (kg/m^3)
- ΔP = Pressure difference across the orifice (Pa).

The flame length and width, as a result of a release, can be estimated from the empirical formula published by Lees[34]. The equations for the length and width are shown in Equation B-9 and Equation B-10.

$$L = 9.1{G_L}^{0.5}$$ **Equation B-9**

Where:

- L = Length (m)
- G_L = Mass flow rate (kg/s)

$$W = 0.25L$$ **Equation B-10**

Where:

- W = Width (m)
- L = Length (m)

B4. BLEVE Modelling

The diameter of the fireball and the duration of the BLEVE may be estimated using the following formulae[33]:

$$D = 6.48m^{0.325}$$ **Equation B-11**

$$t = 0.852m^{0.25}$$ **Equation B-12**

Where:

- D = diameter of the fire ball (m)
- m = mass of LPG in the tank (kg)
- t = duration of the BLEVE (seconds)

33 I. R. R. Cameron, Process Systems Risk Management, Sydney: Elsevier Academic Press, 2005.
34 F. P. Lees, Loss Prevention in the Process Industries, London: Butterworth-Heinemann, 2005.

Table B-1 provides noteworthy heat radiation values and the corresponding physical effects of an observer exposed to these values[35].

Table B-1: Heat Radiation and Associated Physical Impacts

Heat Radiation (kW/m^2)	Impact
35	• Cellulosic material will pilot ignite within one minute's exposure • Significant chance of a fatality for people exposed instantaneously
23	• Likely fatality for extended exposure and chance of a fatality for instantaneous exposure • Spontaneous ignition of wood after long exposure • Unprotected steel will reach thermal stress temperatures which can cause failure • Pressure vessel needs to be relieved or failure would occur
12.6	• Significant chance of a fatality for extended exposure. High chance of injury • Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure • Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure
4.7	• Will cause pain in 15-20 seconds and injury after 30 seconds exposure (at least second-degree burns will occur)
2.1	• Minimum to cause pain after 1 minute

B5. LPG Tank Release, Ignition and Jet Fire

A hose rupture could occur and ignite which would result in a jet fire. To estimate the dimensions of a jet fire, the flow rate of the liquid from the hose must be estimated. The following data was input into Equation B-8 to estimate the flow rate through the ruptured hose:

- C_d = Discharge coefficient (0.6 for irregular holes)
- A = 50 mm hose = $\frac{\pi D^2}{4} = \frac{\pi \times 0.050^2}{4} = 0.002\ m^2$
- ρ = 510 kg/m^3
- ΔP = 8.6 bar = 860000 Pa

Substituting the information into Equation B-8 gives a flow rate of 34.8 kg/s.

$$m = 0.6 \times 0.002 \times (2 \times 510 \times 860000)^{0.5} = 35.5\ \frac{kg}{s}$$

Now, a liquid LPG release would be too fuel dense to ignite as it would be above the LEL so the only portion that could ignite would be the liquid that vaporises upon release. Assuming a flash fraction of 50%, the vapour flow rate from the release would be 0.5 x 35.5 = 17.8 kg/s.

Substituting the mass flow rate of vapour into Equation B-9 gives a jet fire length of 38.4 m.

$$L = 9.1 \times 17.8^{0.5} = 38.4\ m$$

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

B6. LPG Tank Jet Fire and Tanker BLEVE

In the event of a jet fire and impingement on the delivery tanker there is potential for the LPG in the tanker to boil escalating to a BLEVE if intervention measures fail. In order to model the most sever credible situation, it is assumed that impingement will occur at the 100% fill level of the tanker and that the tanker holds a maximum 21 tonnes of LPG.

Inputting the mass into Equation B-11 and Equation B-12 yields an impact diameter of 164.5 m and a resonance time of 10 seconds.

$$D = 6.48 \times 1{,}148^{0.325} = 164.5\ m$$

$$t = 0.852 \times 1{,}148^{0.25} = 10\ s$$

B7. Above Ground LPG Tank Jet Fire and Tank Shell BLEVE

In the event of a jet fire and impingement on the LPG tank there is potential for the LPG in the tank to boil escalating to a BLEVE if intervention measures fail. In order to model the most sever credible situation, it is assumed that impingement will occur at the 100% fill level of the tank. The tank holds 7,000 L and based on the density of LPG is 510 kg/m^3, therefore, the mass of LPG involved in the BLEVE is 3,570 kg.

Inputting the mass into Equation B-11 and Equation B-12 yields an impact diameter of 92.5 m and a resonance time of 7 seconds.

$$D = 6.48 \times 1{,}100^{0.325} = 92.5\ m$$

$$t = 0.852 \times 1{,}100^{0.25} = 6.6\ s$$