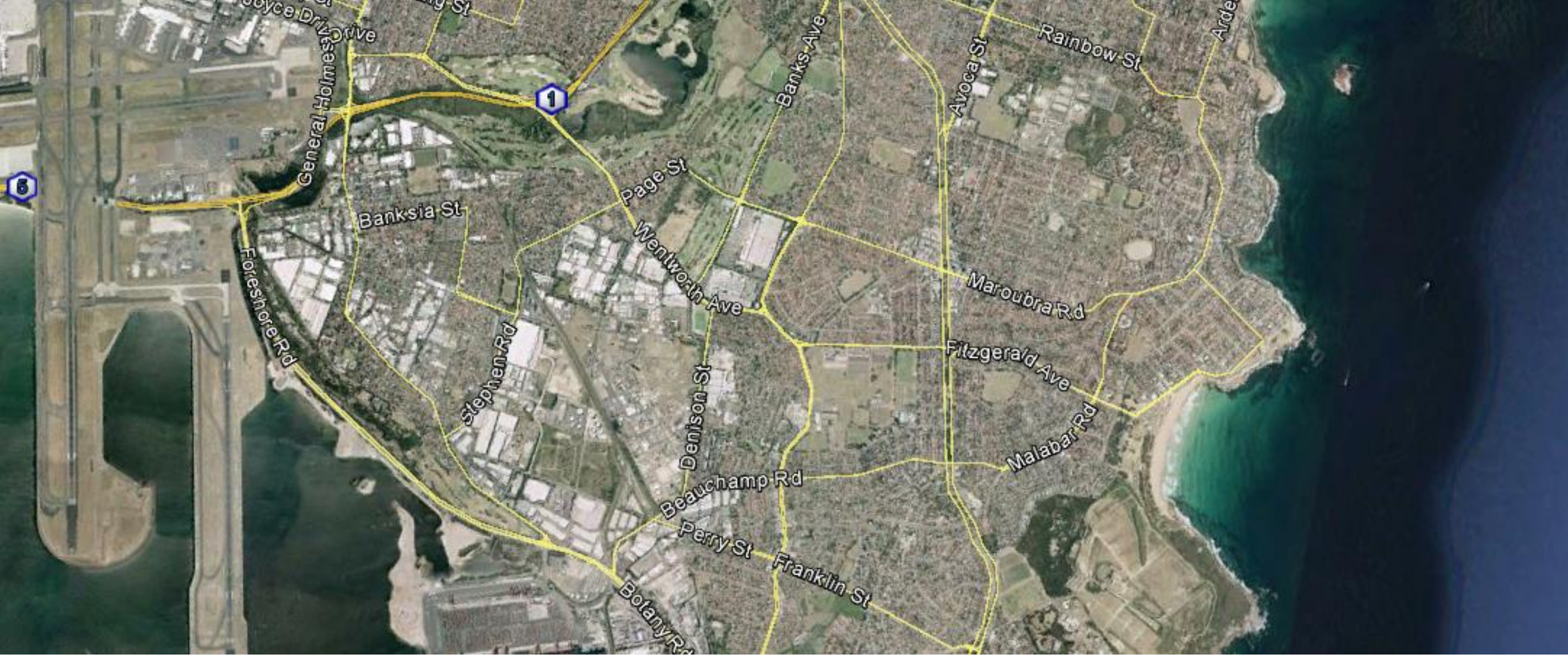

Dangerous Goods Transport QRA, Denison St, Hillsdale

Issued: 12th February, 2015

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Amendment Record

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01A	28/6/2014	Andrew Sutherland	Initial Draft	Simon Meiers
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03	12/2/2015	Mat Collin	Final revision following comments from stakeholders on draft Revision 02A	Howard Lister

Executive Summary

An application for development of a Bunnings Warehouse on Denison St, Hillsdale, is currently being considered by the Joint Regional Planning Panel (JRPP). To assist in the evaluation of the proposal, Scott Lister has undertaken, on behalf of the Department of Planning and Environment (DPE) and City of Botany Bay Council (CBBC), a Quantitative Risk Assessment (QRA) of the movement of Dangerous Goods (DG) along Denison St.

The purpose is to understand the level of risk associated with DG transport on Denison Street to inform determinations on the proposed Bunnings Warehouse as well as other potential future developments around the Botany Industrial Park (BIP). This responds to any potential concern that the number of people attracted to the area by the new store could result in unacceptable levels of risk due to the volume of DG traffic.

The study analysed DG movements along Denison St and cross referenced this with plant throughput data from the BIP. DG movements were then combined with vehicle crash rates to determine the likelihood of hazardous incident scenarios (fires, explosions, toxic gas releases). Using risk modelling software (Phast™ and Safeti™), the consequences of these scenarios were modelled and combined with likelihood data to generate detailed risk profiles for the area.

The results of the study show that the risks satisfy the adopted risk criteria for the study, which are based on those enunciated in the Department's Hazardous Industry Planning Advisory Paper No. 4, *Risk Criteria for Land Use Safety Planning* (HIPAP 4)). As such, it is concluded that risks associated with DG transport on Denison St should not present a barrier to the Bunnings development proceeding.

Recommendations from the study are:

- While this study has found that the risk criteria are met at the Bunnings site, it is recommended that the transport of dangerous goods in the study area be monitored with a view to updating this study at some future date, or in the event of a significant increase in the transport of dangerous goods in the study area.
- Botany Bay City Council should review the adequacy of existing emergency evacuation arrangements for Hensley Athletic Field to ensure that appropriate mitigation measures are implemented. Consideration should also be given to possible egress restrictions imposed by current fencing arrangement.
- Industrial or port related developments that would introduce significant increases in DG traffic around the BIP should include an assessment of the DG transport risks posed to surrounding land uses.
- City of Botany Bay Council (CBBC) should review its planning controls for the area, in light of this study, to ensure new development does not result in a significant exposure to risks from dangerous goods transport incidents. For example, it may be desirable to discourage intensification of residential development within areas with an individual fatality risk in excess of one chance in a million, as indicated in HIPAP 4, Section 2.5.2.1.

- Bunnings should consider the risks presented by the transport of Dangerous Goods in the facility design and preparing emergency response plans.

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Table of Acronyms

CBBC	City of Botany Bay Council
BIP	Botany Industrial Park
BLEVE	Boiling Liquid Expanding Vapour Explosion
DG	Dangerous Goods
DPE	NSW Department of Planning and Environment (formerly DP&I)
DP&I	Department of Planning and Infrastructure
EO	Ethylene Oxide
FN	Frequency of a Number
HIPAP	Hazardous Industry Planning Advisory Paper
LPG	Liquid Petroleum Gas
PGP	Polymer Grade Propylene
PO	Propylene Oxide
QRA	Quantified Risk Assessment
RMS	Roads and Maritime Services
SAFETI	Software for the Assessment of Fire Explosion and Toxic Impact
SEPP	State Environmental Planning Policy
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)

1. Introduction

An application for development of a Bunnings Warehouse on Denison St, Hillsdale, is currently being considered by the Joint Regional Planning Panel (JRPP). To assist in the evaluation of the proposal, Scott Lister have been commissioned by the Department of Planning and Environment (DPE) and City of Botany Bay Council (CBBC), to perform a Quantitative Risk Assessment (QRA) of the movement of Dangerous Goods (DG) along Denison St, Hillsdale, NSW.

The main contributors to DG movements along Denison Street are a combination of deliveries to and from the Botany Industrial Park (BIP) and Port Botany.

This study has created a quantified risk model of the risks from DG transport in Denison St. This allows risks to surrounding land uses posed by DG transport along Denison Street to be evaluated against criteria adopted for the study and so assist DPE and the City of Botany Bay Council (CBBC) in making decisions regarding the proposed Bunnings development and other future developments at sites along Denison Street.

1.1 Background

Bunnings have lodged an application for development of a Bunnings Warehouse for Denison St and this proposal is currently before the Joint Regional Planning Panel (JRPP). The DPE, CBBC and the JRPP seek to understand the level of risk associated with DG transport risk on Denison Street to further inform their determinations on the proposed Bunnings Warehouse and other future developments around the Botany Industrial Park.

There have been various QRA studies conducted for the BIP area. Most recently an updated QRA was performed in 2012 for the BIP [ref 3] and prior to that the then DP&I's Botany Randwick Land Use Safety Planning Study, 2001 [ref 1]. Consistent with the DPE's requirements neither of these studies considered the risks posed by the transport of dangerous goods (DG) through the area. A study on dangerous good transport from the expansion of the Port Botany container terminals was performed in 2003 [ref 5], but this was restricted to traffic associated with the container terminal. As a result the DG associated with the bulk liquid berths, Caltex Banksmeadow terminal and non-port DG imported to and exported from the BIP were outside the scope of the study.

With no prior comprehensive study of DG on Denison St this study is a first look at the issue. Further complicating the issue is the lack of risk criteria to evaluate risks of DG transport on surrounding land use areas.

In order to address concerns over DG risks to the Bunnings development in June and July of 2012 CBBC commissioned a study of the DG goods traffic levels in Denison St. This study provided a sample of the DG traffic broken down by vehicle type and DG class. Whilst useful concerns remained which in part has led to this study being commissioned.

1.2 Scope

The scope of this DG transportation study was to prepare a quantified risk model of the risks of DG transport along Denison Street and evaluate the risks against risk criteria. In more detail this involved;

- A review of previous relevant studies such as the study performed for the 2003 Port Expansion and the 2001 Botany Randwick Land Use Safety Study[1].
- Collecting DG transport statistics using categories to inform the assessment. This involved consulting with industries in the BIP on the DG goods logistics associated with their operations as well as using DG traffic data collected by the CBBC.
- Comparing and reconciling the updated DG transport statistics against the information provided for the Bunnings and Orica subdivision proposals.
- Considering future projections of traffic and DG transport.
- Determine crash rate and release rate data suitable for use in the QRA. Also develop crash rate modifiers for road class and features such as intersections.
- Developing representative material and release scenarios to cover the range of DG expected on Denison St.
- Modeling the route with the various DG loadings and crash rates in the SAFETI™ package. Generating individual risk contours, individual risk transects and FN curves (FN curves created for 1km sections following TNO purple book guidance).
- Developing proposed risk criteria based on existing criteria used in NSW and in Europe. Assessing individual fatality risk on the proposed Bunnings site and Hensley Athletics Field against the proposed risk criteria.
- Assessing societal risk posed by DG transport alone and in combination with the societal risk posed by the BIP.
- Documenting the analysis in a report. Discussing the significance of cumulative impacts when the DG transport risks are overlaid with the BIP QRA risk results.

2. Methodology

A simplified methodology employed in this assessment is summarised below in Figure 1. Each stage identified is discussed in more detail in the subsequent subsections.

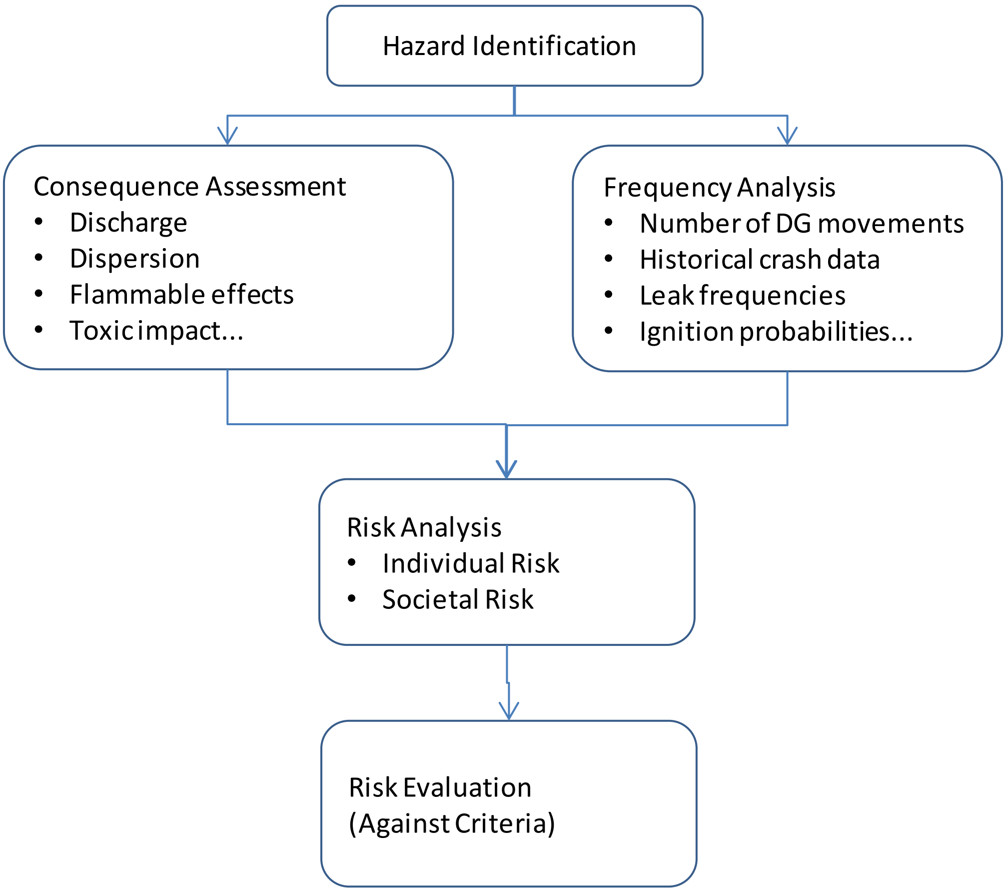


Figure 1 Risk Assessment Methodology

2.1 Hazard Identification

The QRA identified the hazards posed through the types and quantities of DG transported along Denison Street. From the hazard identification, release scenarios were identified and carried through to the risk analysis.

Sources of information for hazard identification were;

- The hazardous materials reported to be imported and exported from the BIP, as per the 2012 BIP QRA report [3],
- A survey of DG traffic commissioned by CBBC performed by Roar in June/July 2012[ref 7], which recorded levels of DG traffic according to placarded loads. This enabled an appreciation of the volumes of DG by general DG category moving in and out of the BIP as well as through traffic of DG coming to and from Port Botany,

- The 2003 Port Expansion QRA which provided an estimate of the types of DG moving from the container terminals at Port Botany for the then existing case and future projections, and
- Consultation with BIP operations to understand if volumes of DG had changed since the 2012 BIP QRA and the 2012 Roar traffic study.

These sources of information were combined to produce an overall appreciation of DG traffic by hazardous material. Bulk movements involving hazardous materials associated with the BIP are presented as Table 1:

Table 1 Bulk BIP Dangerous Goods Movements

Material	DG class	Hazardous Attributes
Polymer Grade Propylene (PGP)	2.1	Flammable gas, denser than air.
Liquid Petroleum Gas (LPG)	2.1	Hydrocarbon fluid composed predominantly of any of the following hydrocarbons or mixtures of any or all of them: propane (C_3H_8), propylene (C_3H_6), butane (C_4H_{10}) or butylenes (C_4H_8). Flammable gas, denser than air.
Ethylene Oxide	2.3, 2.1	Toxic gas with a perceptible (ether-like) odour. Flammable. Gas denser than air.
Propylene Oxide	3	Colourless with an ethereal odour. Miscible with water. Flammable liquid. Vapour denser than air.
Iso hexane	3	Flammable liquid. Vapour denser than air.
Hex-1-ene	3	Colourless liquid. Immiscible with water. Flammable liquid. Vapour denser than air.
Chlorine	2.3, 8	Non-flammable yellow-green gas, with a perceptible odour (pungent). Highly toxic. Corrosive in the presence of moisture. Much denser than air. Oxidizing agent which may cause fire with organic materials.
HCL	8	Colourless liquid. Aqueous solution of the gas hydrogen chloride. Highly corrosive to most metals. Vapour irritates mucous membranes.
Hypochlorite Solid	5.1	Solid with chlorine odour. Evolves very toxic and corrosive gases on contact with acid.
Hypochlorite Liquid	8	Liquid with chlorine odour. Evolves very toxic and corrosive gases on contact with acid. Mildly corrosive to most metals. Not to be transported in unlined metal drums.
Sodium Hydroxide (Caustic soda) Solid	8	White pellets, flakes, lumps or solid blocks. Deliquescent. In the presence of moisture corrosive to aluminium, zinc and tin. Reacts vigorously with acids. Reacts with ammonium

Material	DG class	Hazardous Attributes
		salts evolving ammonia gas. Causes severe burns to skin, eyes and mucous membranes.
Sodium Hydroxide (Caustic soda) Liquid	8	Colourless liquid. Corrosive to aluminium, zinc and tin. Reacts vigorously with acids. Reacts with ammonium salts evolving ammonia gas. Causes severe burns to skin, eyes and mucous membranes.

The less hazardous class 8 and class 5.1 materials were screened out from the analysis on the basis that releases would have limited impacts beyond the point of release. (A similar screening step was performed for the port expansion study [ref 5]). All the remaining materials in Table 1 were modelled as they are and not as a representative material.

The 2012 Roar traffic survey of DG for Denison St indicates that volumes of class 2.1 (flammable gases) and 3 (flammable liquids) in addition to the BIP DG traffic are moving along Denison St. These materials are assumed to be the LPG and petroleum products coming out of the bulk liquids area of Port Botany and Caltex Banksmeadow.

The Port Expansion DG transportation study [ref 5] provided details on the level of DG coming from the port container terminals (not the bulk liquids terminals). It also indicated what percentage of these goods would travel on Beauchamp Rd (1%) and then presumably Denison St. This level of DG traffic is shown as Table 2.Table 2 shows that in addition to the materials identified in Table 1 a small number of movements of explosives are possibly being transported along Denison St. The 2012 Roar study did not identify any class 1 materials, which is understandable due to their low number of annual movements (less than 1 in Table 2). Regardless, the contribution from these materials was included by adding the individual and societal risk from the Port Expansion study to the results of the model developed for this study.

Table 2 DG traffic on Beauchamp Rd From Port Expansion Study

Dangerous Goods Class	Description	Representative Material	Unit size and Number of Movements p.a.		
			NEQ<1 tonne	**NEQ 2 tonnes**	**NEQ 12 tonnes**
1	Explosives	TNT	Screened out	0.83	0.63
				1 Tonnes	20 Tonnes
2.1	Flammable Gases	Propane	Screened out		1.11
2.2	Non-flammable gases		Screened out		
2.3	Toxic Gases	Chlorine	Screened out	0.37	0
		Sulphur Dioxide	Screened out	0.32	0.05
		Ammonia	Screened out	0.89	0.37
3	Flammable liquids	Acrylonitrile	Screened out		
4.1	Flammable Solids	As per Class 3	Screened out		

Dangerous Goods Class	Description	Representative Material	Unit size and Number of Movements p.a. NEQ<1 tonne	NEQ 2 tonnes	NEQ 12 tonnes
4.2	Spontaneously Combustible		Screened out		
4.3	Dangerous When Wet	As per Class 3	Screened out		
5.1	Oxidising Materials	Ammonium Nitrate	Screened out	2.86	30.56
5.2	Organic Peroxides		Screened out		
6.1	Toxic Materials		Screened out		
7	Radioactive Materials		Please to refer to qualitative analysis		
8	Corrosive Materials	Hydrogen Fluoride	Screened out	0.13	0.2
9	Miscellaneous Materials				

2.1.1 Potential Scenarios

The range of DG transported on Denison St are described in Section 2.1 . The potential scenarios used for the analysis associated with the class 2.1, 2.3 and 3 materials being transported on Denison St are described here.

Class 2.1, Flammable Gases.

Class 2.1 such as LPG and PGP materials are transported as pressure liquefied gases. Damage to the vessel following a road accident or for other causes may lead to a rupture of the vessel or a leak.

In the case of a rupture, immediate ignition will result in the inventory of gas partially burning as a fireball with the remainder burning as a pool fire. If not immediately ignited the cloud of vapour will gradually disperse but will be heavier than air. If the flammable part of the cloud ignites a flash fire will result and can flash back to the remaining liquid and produce a pool fire. If the flash fire burns fast enough an explosion results.

Leaks from the vessel may be liquid,vapour or both, depending on the location of the hole (above or below the liquid level). If immediately ignited liquid leaks can produce a fireball, liquid jet fire or a pool fire. If immediately ignited vapour leaks can produce a fireball or a jet fire. If not immediately ignited the cloud of vapour will gradually disperse but will be heavier than air. If the flammable part of the cloud ignites a flash fire will result and can flash back to the remaining liquid and produce a jet fire or pool fire. If the flash fire burns fast enough an explosion results.

A pressure liquefied vessel may be impacted by a fire from another source, such as the adjacent vessel on a B-double or the leaking vessel itself. If the rate of heating of the vessel is greater than the rate of venting from the vessels relief value, the vessel can be weakened by the fire and become overpressurised. The resulting failure of the vessel and resulting fireball is referred to as a Boiling Liquid Vapour Cloud Explosion (BLEVE).

Class 2.3, Toxic Gases.

Class 2.3 materials such as chlorine are transported as pressure liquefied gases usually in drums, cylinders or isotainers. Damage to a drum or cylinder following a road accident or from other causes may lead to a rupture of the drum or cylinder or a leak.

In the case of a rupture the cloud of vapour will gradually disperse but may be heavier than air. High concentrations of vapour can persist for long distances downwind at ground level as the cloud disperses.

Leaks from the vessel may be liquid, vapour or both depending on the location of the hole. A liquid release will have a release rate many times higher than a vapour leak and so will create a bigger cloud of vapour. High concentrations of vapour can persist for long distances downwind at ground level as the cloud disperses.

Class 3, Flammable Liquids

Class 3 flammable liquids such as hexane, hexene and UnLeaded Petrol (ULP) are transported in top loading tankers, often with a series of separate tanks, which are unloaded through a bottom valve in the tank. A tanker carrying class 3 liquids that is involved in a road accident can release liquids through a puncture in a tank, or in the case of a rollover through a roof hatch opening. If this ignites a pool fire will form. If unignited, vapour can evaporate from the spill forming a flammable vapour cloud which will gradually disperse. If such a cloud ignites a flash fire will result and can flash back to the remaining liquid and produce a pool fire. If the flash fire burns fast enough an explosion results.

2.2 Frequency Analysis

The objective of the frequency analysis is to determine the frequency of each of the hazardous release scenarios identified in the hazard identification. The process undertaken was as follows;

- Selection of appropriate generic base incident frequencies for;
    - Releases whilst in transit;
    - Road transportation accidents;
    - Subsequent leaks from DG containers; and
    - Ignition probabilities.
- Analysis of the number of DG movements along Denison Street; and
- Analysis of the ratio of heavy crashes at main intersections and “mid-block” sections.

2.2.1 DG Traffic

Data on dangerous good traffic has come from three main sources, namely,

- The 2012 BIP QRA Appendices documenting plant throughput and tanker deliveries,
- The 2012 Roar Dangerous Goods Traffic Study
- Consultation with the members of BIP, Qenos, Huntsman and Orica, in March 2014.

The study consolidated this data by comparing the BIP QRA data on plant throughput with the Roar DG traffic survey data that was identified as entering and leaving the BIP through Gate 3. A reasonable correlation between the two sets of data was established, which is displayed in Table 3. The BIP QRA data overestimates the measured traffic by Roar except for class 3. This was attributed to Roar measuring movements associated with fuel tanker stabling operations which have now been discontinued.

Table 3 Comparison of Roar Data and BIP QRA Data on DG Traffic Entering & Leaving BIP Gate 3

Class	Roar Data [movements pa]	BIP QRA Data [movements pa]
3	2320	1124
2	7795	9302
8	14939	16200

In combination the BIP QRA and Roar data sets allowed the direction of the different classes of DG traffic to be established. The direction of movements in the Roar data is shown as Figure 2. Standout features of this data are:

- Large movements of class 3 movements moving north past gate 3, which are assumed to be full tankers leaving the bulk liquids area of Port Botany,
- Large movements of class 3 and class 2 movements moving south past gate 3, which are assumed to be empty tankers returning to the bulk liquids area of Port Botany,
- Large movements of class 2 and class 8 materials leaving the BIP at Gate 3 and heading north. The bulk of these class 2 materials are PGP. Much smaller amounts of class 2 materials leave Gate 3 and head south.
- Small movements of class 2 materials travel north past gate 3, but large movements travel south past gate three. This suggests that while many tankers, presumably empty, return to the bulk liquids area of the port via Denison St, they are travelling north, presumably full, on other routes.

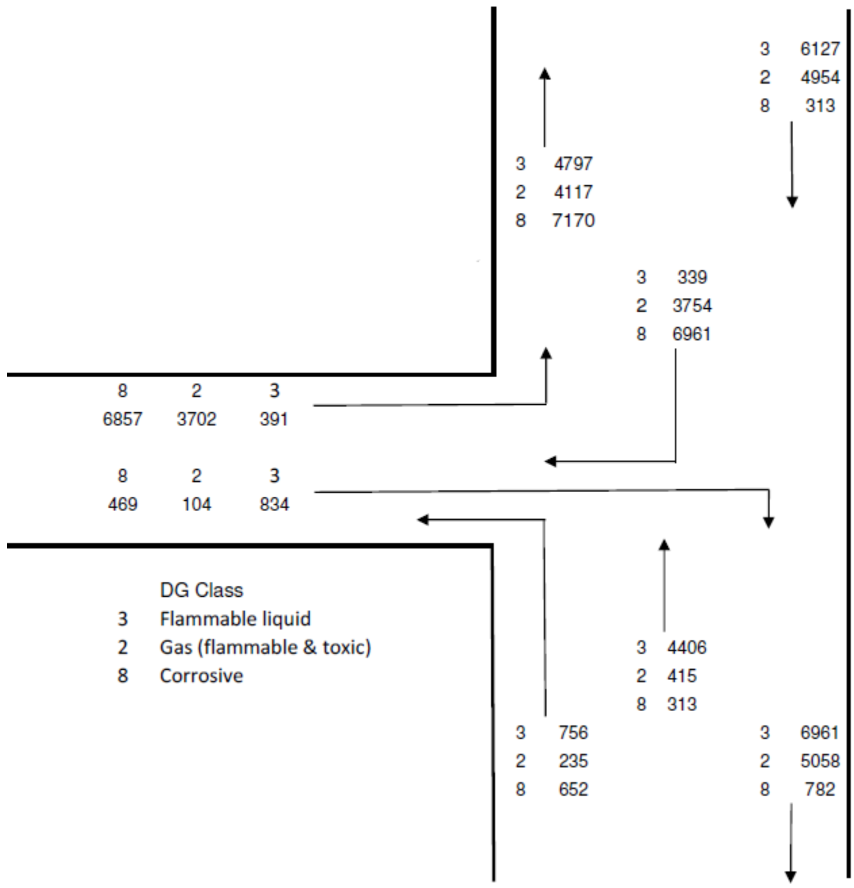


Figure 2 Annualised 2012 Levels of DG Traffic For Denison St

Further information on the analysis of DG movements along Denison Street are presented in Appendix A3.

2.2.2 Crash Rates and Release Frequencies

Historical heavy vehicle crash data for Denison St was obtained from Roads and Maritime Services (RMS) for the period June 2003 to June 2013. This data allowed a split of how many crashes occurred at main intersections and how many occurred “mid-block” between these intersections on Denison St. The analysis of the RMS data showed 66% occurred at main intersections and the remaining 33% occurred “mid-block”.

Combined crash rates and release frequencies were determined using general dangerous goods road vehicle data published by the International Oil and Gas Producers Association [ref 4]. This data source provides established release rates per vehicle kilometer for flammable liquid tankers and LPG tankers. (Note the rate is a combined crash rate and release rate). The LPG release frequencies and the flammable liquids release frequencies are the same as those used in the Port Expansion QRA [ref 5]. Class 3 movements were assigned the flammable liquid tanker release rates and the Class 2 movements were assigned the LPG tanker release rates.

For flammable liquids the crash and release rate data has frequencies for release cases of 5-15 kg, 15-150kg, 150-1500 kg and >1500 kg. For flammable gas tankers the crash and release rate data has frequencies for cases of a BLEVE, Cold Rupture (instant release), Large liquid space leak 50mm and Large vapour space leak 50mm. These release cases then formed an input into the consequence analysis.

Combining the DG road traffic data with the release rate data and intersection/non intersection data allowed frequencies of releases in all the release cases to be determined. 66% of the release frequency was allocated to the three main intersections (22% at each):

- Denison St and Beauchamp Rd; and
- Denison St and Wentworth Ave; and
- Denison St and BIP Gate 3.

The remaining release frequency was spread evenly along Denison St.

Further information on crash frequencies, release frequencies and ignition probabilities are presented in Appendix A2.

2.3 Consequence Analysis

The objectives of the consequence analysis is to;

- Identify the relevant toxic and flammable inventories;
- Analyse a representative set of release cases; and
- Determine the consequences of each release case with regards to their potential to cause fatality. The processes used to complete the analysis are:
- Discharge rate modelling;
- Dispersion modelling of toxic releases; and
- Fire and explosion impact modelling.

Release, dispersion and subsequent fire and explosion effect calculations are performed using SAFETI (Software for the Assessment of Fire Explosion and Toxic Impact) commercial software package. The SAFETI package models have been extensively validated and widely used throughout industry both in Australia and internationally.

A summary of how the various release cases have been modelled in the SAFETI package is provided in Table 4. Note that a reference material has not been used for the DG classes, instead each material has been modelled according to its own properties.

Table 4 Release Cases Modelled

Materials Modelled	Release Cases	Model Used
Class 3 Flammable liquids. **ULP, Hexane, Hexene, Propylene Oxide**	5-15 kg, 15-150kg, 150-1500 kg and >1500 kg	Instant release, with rainout. Pool Fire, Flash Fire, VCE.

Class 2.1 Flammable gases	BLEVE	Fireball Model
LPG,PGP Ethylene Oxide	Large 50mm bottom leak	Continuous release, with rainout. Fireball, Pool Fire, Jet Fire, Flash Fire, VCE Toxic impact of EO also modelled
	Large 50mm top leak	Continuous release, without rainout. Fireball, Jet fire, Flash Fire, VCE Toxic impact of EO also modelled
	Vessel Rupture	Instant release, with rainout. Fireball, Pool Fire, Jet Fire, Flash Fire, VCE Toxic impact of EO also modelled
Class 2.3 Toxic gases	50mm bottom leak	Impinging liquid jet, with rainout.
Chlorine	50mm top leak	Impinging gas jet, without rainout.
	Rupture	Instant release, with rainout.

2.4 Risk Analysis

The risk analysis is completed using SAFETI commercial software package. Two measures are used to display fatality risk, individual fatality risk contours and societal risk curves. Individual fatality risk is plotted according to;

- Release scenario frequency;
- Location of release;
- Ignition probability;
- Local meteorology; and
- Magnitude of consequence (thermal radiation, blast overpressure and toxic impact effects).

Two forms of ignition probabilities have been used, an immediate ignition probability and a delayed ignition probability. The immediate ignition probability relates to the how the mechanism causing the release may also ignite the release. The delayed ignition probability is dependent on the location of ignition sources. The delayed ignition model considered two main sources of delayed ignition, road vehicle traffic and residential populations. Details on these delayed ignition sources used are provided in Appendix A3.2.1.

Societal risk curves, also known as F-N curves, record the probability of multiple fatalities in the surrounding community. Societal risk curves and plotted using the same inputs as the individual fatality risk contours with the addition of population densities in the surrounding areas and additional assumptions such as vulnerability when indoors compared to outdoors. Data used for population densities for surrounding land use areas are presented in Appendix A2.

2.5 Risk Criteria

In order to evaluate risks at the risk assessment stage it is necessary to have risk criteria. Currently the DPE does not have risk criteria for transport of dangerous goods, and suitable criteria from other countries were not available.

Regulators have concluded that if a risk from a potentially hazardous situation is below most risks being experienced by the community, then that risk may be tolerated if as low as reasonably practicable. This is consistent with the basis of criteria setting used in HIPAP No. 4, as well as those adopted by most authorities nationally and internationally. Hence, for the purpose of this study, the NSW Risk Criteria for Land Use Safety Planning (HIPAP No. 4) [ref 6] for fixed potentially hazardous facilities were adopted for fatality risks. Consistent with worldwide practice and the approach adopted historically in NSW injury risk criteria were not adopted for the assessment of DGs transport risks, nor were injury risks analysed.

It should be noted, that the adoption of HIPAP4 fixed facility criteria for the assessment of DG transportation risks does not represent policy for the DPE, but was put forward as appropriate for the purpose of this study.

HIPAP No. 4 considers two categories of risk - individual risk and societal risk and suggests relevant criteria.

The individual risk criteria is a location specific individual risk criteria (LSIR) and have different values for different land uses, depending on the vulnerability of people present and their ability to escape. The individual fatality risk criteria for the various categories of land use are presented as Table 5 below.

Table 5 Individual Fatality Risk Criteria

Land Use	Suggested Criteria (risk in a million per year)
Hospitals, schools, child-care facilities, old age housing	0.5
Residential, hotels, motels, tourist resorts	1
Commercial developments including retail centers, offices and entertainment centers	5
Sporting complexes and active open space	10
Industrial	50

HIPAP 4 differentiates between existing land use situations and new situations as it acknowledges that it is not always possible for existing industry and surrounding developments to meet the same target risk criteria as new industrial developments. As such specific guidance is provided for these situations.

Figure 3 shows the indicative NSW risk criteria for societal risk published in HIPAP No. 4, in the form of an F-N curve (Frequency of occurrence F of Number of N or more fatalities). The area between the ‘unacceptable’ and ‘acceptable’ risk regions is referred to as the ALARP (As Low As Reasonably Practicable) region. For risks to be tolerated in this region all practical risk reduction measures must be implemented. Below the ALARP region the risks are considered to be tolerable (acceptable) as further “reasonably practical” measures are considered to be unlikely.

It is noted that the indicative NSW risk criteria for societal risk published in HIPAP No. 4 uses the same criteria as that published in the 2001 DP&I’s Botany Randwick Land Use Planning Study[1]. Whilst the DPE’s criteria for societal risk are “indicative”, it has been agreed with DPE that the societal risk criteria depicted in Figure 3 shall be used for the purpose of this study.

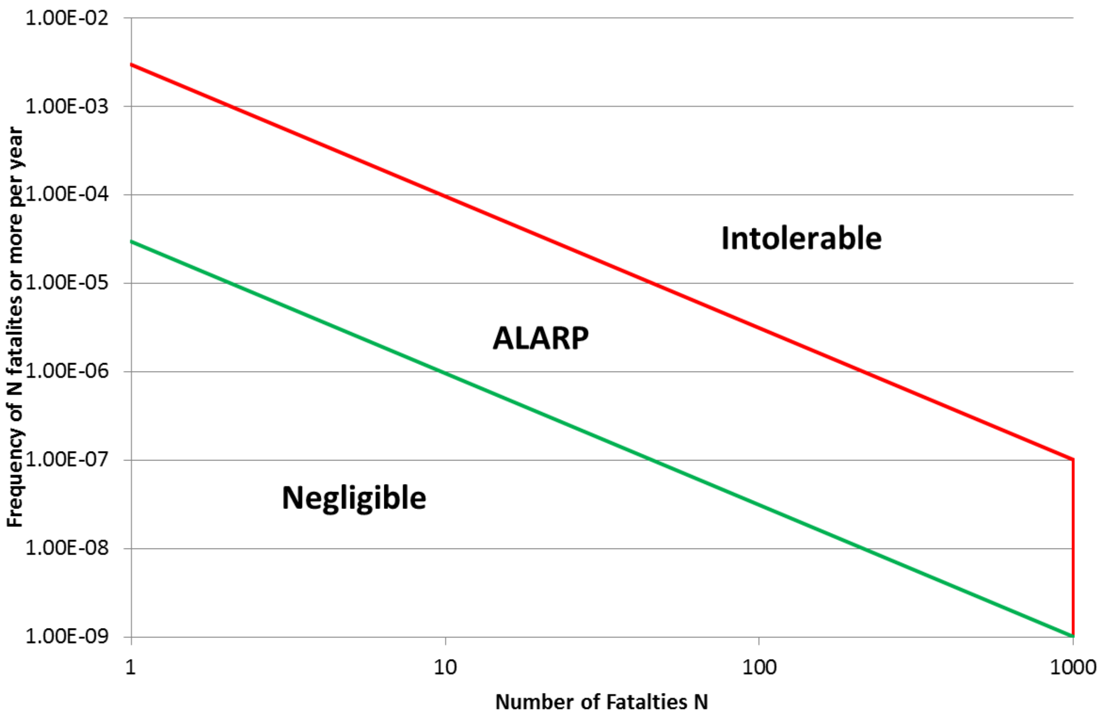


Figure 3 Indicative Societal Risk Criteria

3. Results

Risk results have been determined for two cases, a 2012 worst case and a 2014 current case. The 2012 worst case represents BIP plant import and export of DG by road for 2012, plus additional traffic moving north and south to the bulk liquids part of Port Botany, as measured by the 2012 ROAR traffic survey (whilst titled the worst case it is the actual case for 2012).

The 2014 current case uses the same DG traffic data as the worst case except the number of PGP traffic movements from Qenos which reflects their current production. Consultation with Qenos has indicated that due to a change in the availability of feedstock caused by the closure of the Shell Clyde refinery and the reduction in customer demand generated by the closure of LyondellBasell's polypropylene production facility the volume of class 2.1 materials being exported has significantly decreased (greater than 85%). This 2014 current case is representative of the current risk posed by DG movements along Denison St.

3.1 Discussion

3.1.1 Individual risk from DG transport

The location of the proposed Bunnings development is indicated in Figure 12 in Appendix A1. The Bunnings development is classified as a commercial development. Therefore the location specific individual risk criterion to be satisfied for a commercial development is a risk of fatality of 5 chances in a million (5E-6) per year.

The 2012 worst case individual risk contours are shown in Figure 4, and the 2014 current case individual risk contours are presented in Figure 5.

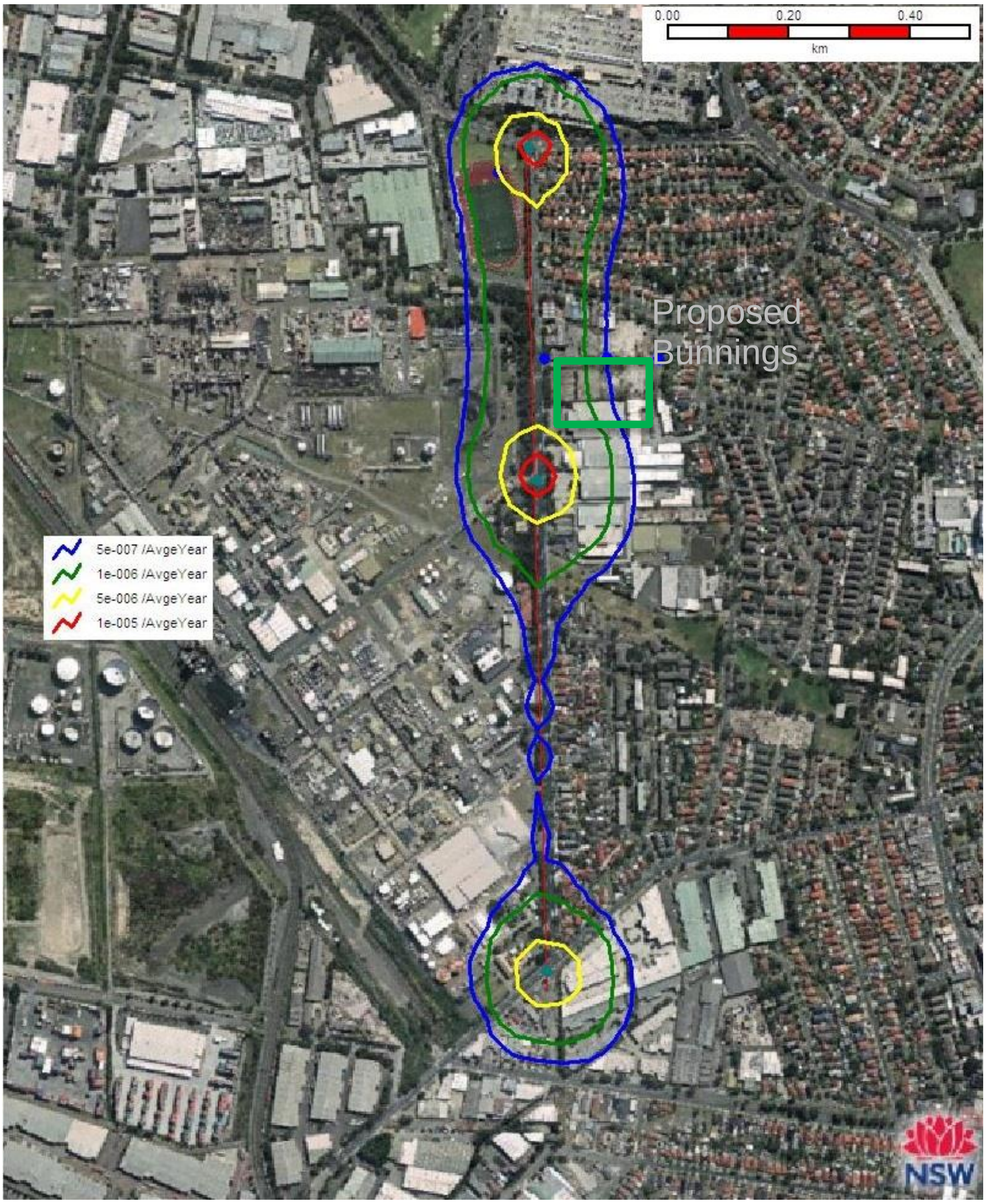
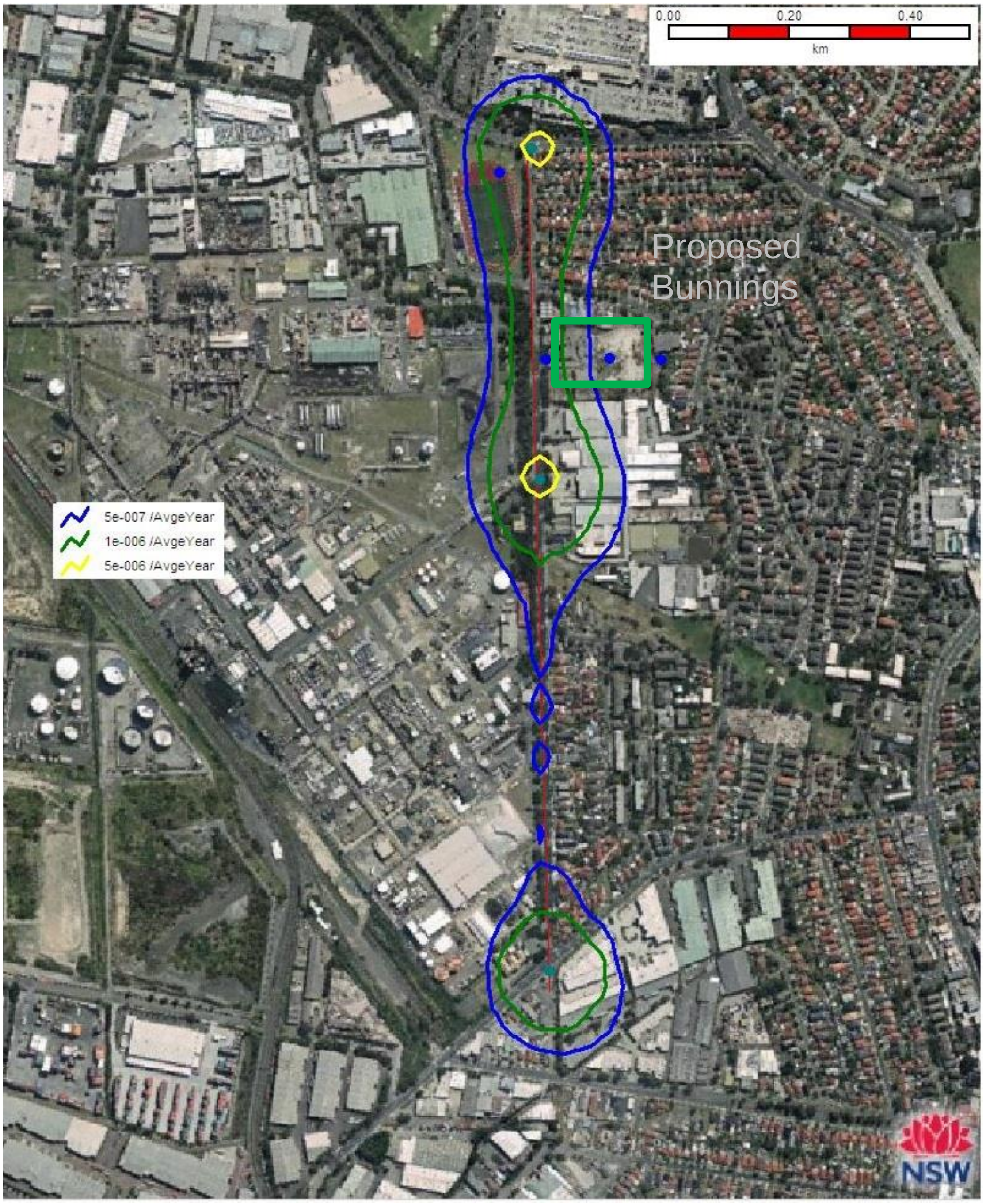


Figure 4 Location Specific Individual Fatality Risk – 2012 Worst case

Figure 5 Location Specific Individual Fatality Risk – 2014 Current Case



As would be expected with the reduction in PGP movements, Figure 5 shows a significant reduction in the footprint of the individual risk contours compared to the 2012 worst case. The 10 chances in a million (1E-5 red line) per year of fatality contour is eliminated from the contour plot, and there is a significant reduction in the 5 chances in a million (5E-6 yellow line) per year fatality risk contour. There is a similar but less pronounced reduction in the 1 in a million (1E-6 green line) per year and 0.5 in a million (5E-7 blue line) fatalities per year contours. This is due to the dominance of chlorine release scenarios in the medium and far field fatality risk. The frequency of chlorine movements has not been changed from the base to the reduced case.

It is evident in Figure 4 and Figure 5 that the 5 chances in a million per year (5E-6 yellow line) fatality contour does not encroach onto proposed Bunnings development site. Investigation of the major risk contributors indicates that the near field fatality risk at the Bunnings site is driven by a release of PGP with early ignition and the resultant fireball. The PGP release cases account for over 65% of the near field fatality risk. The far field consequences are driven by chlorine gas toxic impacts. Chlorine gas release cases account for over 97% of far field fatality risk. (i.e. at the extremity of the contours presented).

The 2014 current case results contains no areas of individual fatality risk above 5 in a million per year over residential land uses but there are some areas above one in a million. Whilst not relevant for existing land use situations Council and the DPE should consider the magnitude of the risk in any future land use planning assessments for new developments.

3.1.2 Denison St DG and BIP Individual Risks at Bunnings

The case of the combining the risks of the BIP (i.e. fixed facilities) and DG on Denison St (i.e. transport) has been modelled. Risks at the western side of the Bunnings development are based on the BIP QRA [ref 3]. Individual risks for the specific locations of the western side of the Bunnings site facing the BIP are presented as Figure 6, for both the BIP, DG in Denison St and the combined result. It shows that for the combined results (for both DG traffic cases considered - worst case 2012 and current case 2014), the individual risk criteria is satisfied. The maximum risk at the Bunnings site is 3.4 chances in a million per year which is less than the 5 chances in a million per year criterion for commercial development.

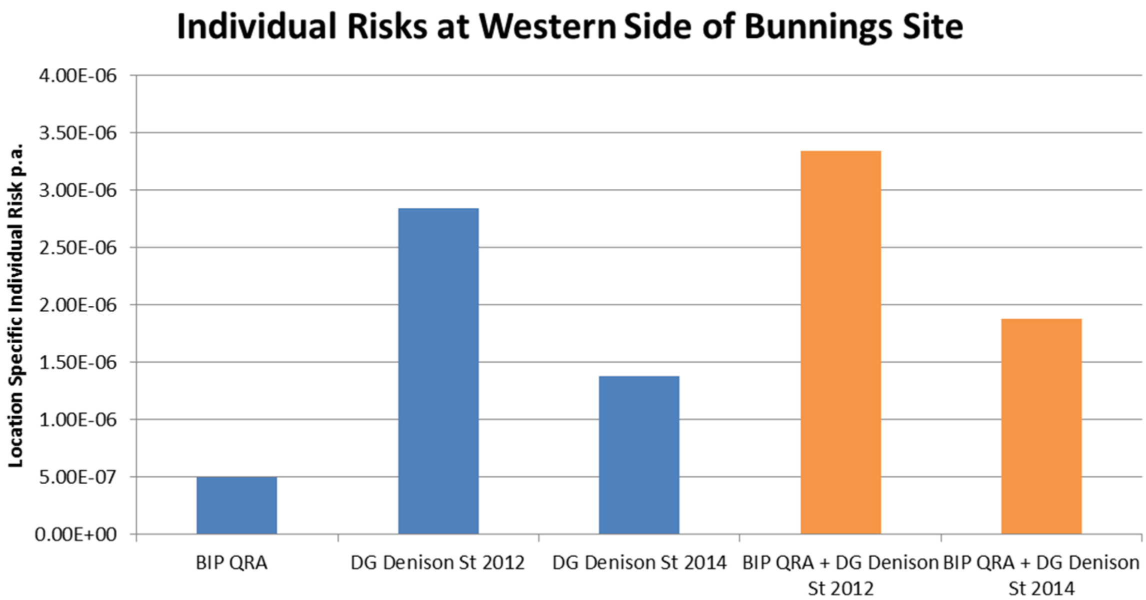


Figure 6 Individual risks at Western Side of Bunnings Site

3.1.3 Incremental Societal Risk

In accordance with HIPAP 4, when there is a significant intensification of population around an existing hazardous facility the incremental societal risk must be assessed. This is done by calculating the societal risk FN curve for the population of the new development alone. HIPAP 4 suggests that if the new development on its own does not present a risk greater than the "negligible" zone then "development should not be precluded". The incremental societal risk associated with the proposed Bunnings development for the 2014 current case is presented as Figure 7.

The results show that for the 2014 current case the curve for the proposed Bunnings entirely falls within the negligible region and the proposed Bunnings development should hence not be precluded based on increased societal risk.

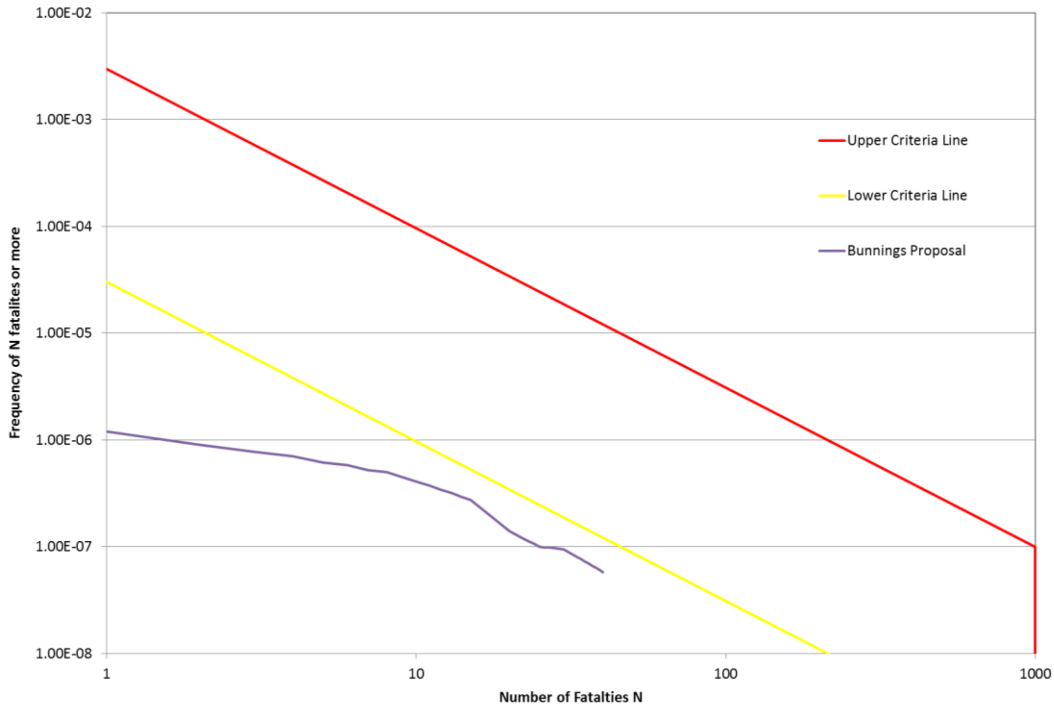


Figure 7 Incremental Societal Risk Based on 2014 Current Case

At the time of conducting the study a number of future development proposals were identified by CBBC. These projects are summarised as :

Table 6 Current Development Proposals Before Council In The Vicinity of the Study Area

No.	Site	Zone	Proposal
1	BATA Site, Banks Avenue, Heffron Road & Bunnerong Road, Eastgardens	R3 Medium Density Residential and B4 Mixed Use under Botany bay LEP 2013	2000 residential units Up to 5000m2 retail floor space Up to 30,000m2 business (office) floor space
2	No. 39 Rhodes Street and the rear part of 47 Rhodes Street Hillsdale.	R3 Medium Density Residential and B4 Mixed Use under Botany bay LEP 2013	DA13/279 lodged with Council for the demolition of all structures and the construction of 3 residential flat buildings with a total of 246 units Building Heights – 7 to 9 storeys)
3	14 Beauchamp Road, Banksmeadow	IN1 General Industrial under SEPP (Port Botany & Port Kembla) 2013.	Waste Transfer Station
4	32 Page Street, Pagewood	R3 Medium Density Residential under Botany Bay LEP 2013.	Residential development consisting of 262 residential units
5	Orica 20 lot subdivision	IN1 General Industrial under SEPP (Port Botany & Port Kembla) 2013.	DA approved by Land and Environment Court on 13/09/2012 for 20 lot subdivision
6	Denison Street sites	R2 Low Density Residential	Capable of having a secondary dwelling under SEPP (Affordable Housing) on each lot

All these future potential developments have been modelled individually and do not breach the incremental societal risk criteria for the 2014 current case and were included in the 2014 current case societal risk FN curve

3.1.4 Overall Societal Risk

Societal risk is a measure of the cumulative risk of multi-fatality accidents. It is represented as a FN curve, that is the frequency F of a particular number of fatalities N or more. To calculate societal risk data on populations surrounding potential accidents is needed. The population data used in this study is presented in Appendix A2.4. The societal risk calculation has included nearby industrial populations in addition to all other population categories as detailed in Appendix A, Section 2.4.

The societal risk curves for the 2012 worst case for DG transport alone and for DG transport in combination with the BIP QRA are shown in Figure 8 and Figure 9 respectively. The societal risk curve representing the 2014 current case societal risk is shown in Figure 10. The 2014 current case combined BIP and DG transport societal risk curve is shown in Figure 11.

Figure 8 illustrates that the societal risk for the 2012 worst case lies in the middle to upper part of the ALARP region. This indicates that according to the criteria the movement of DG along Denison St is acceptable provided that all reasonably practicable risk reduction measures have been implemented. The combination of the societal risk generated from DG movement and the BIP, shown in Figure 9, indicates a very small rise in the overall societal risk profile.

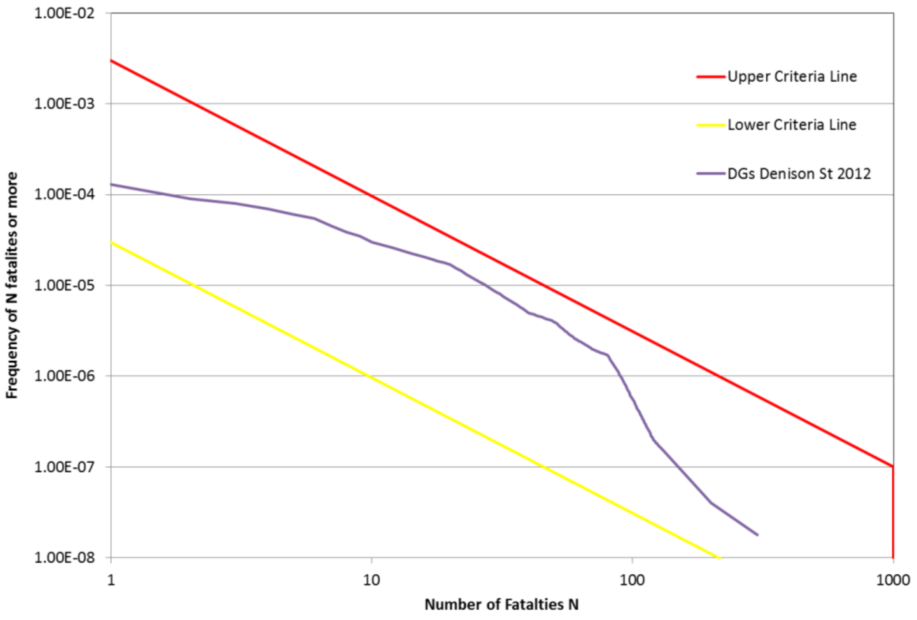


Figure 8 FN Curve – Denison St DG Traffic Data – 2012 Worst case

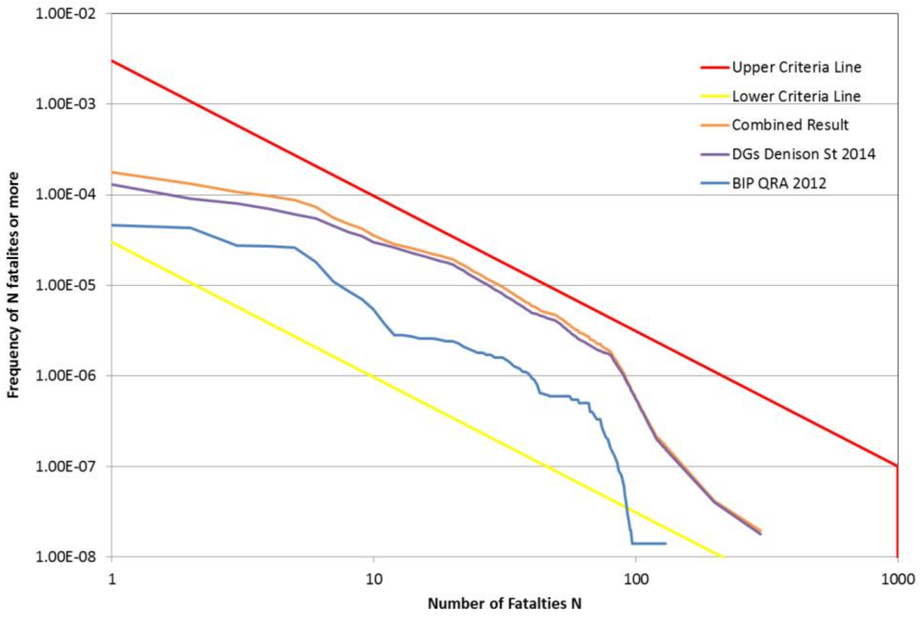


Figure 9 FN Curve – Combined BIP QRA and Denison St DG Movements –2012 Worst case

As in the case for the 2012 worst case curve, the societal risk generated by the 2014 Current Case falls within the ALARP region of the societal risk criteria. The combined societal risk generated by the BIP and DG movements along Denison St likewise falls within the ALARP region. This indicates that the risk is acceptable provided all reasonably practicable measures are taken to reduce the risk.

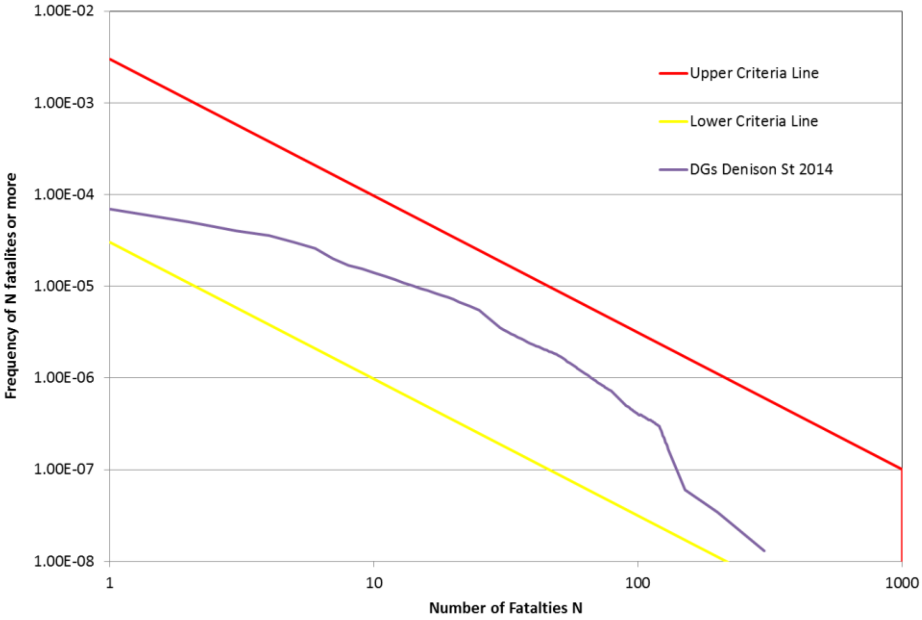


Figure 10 FN Curve Based - 2014 Current Case

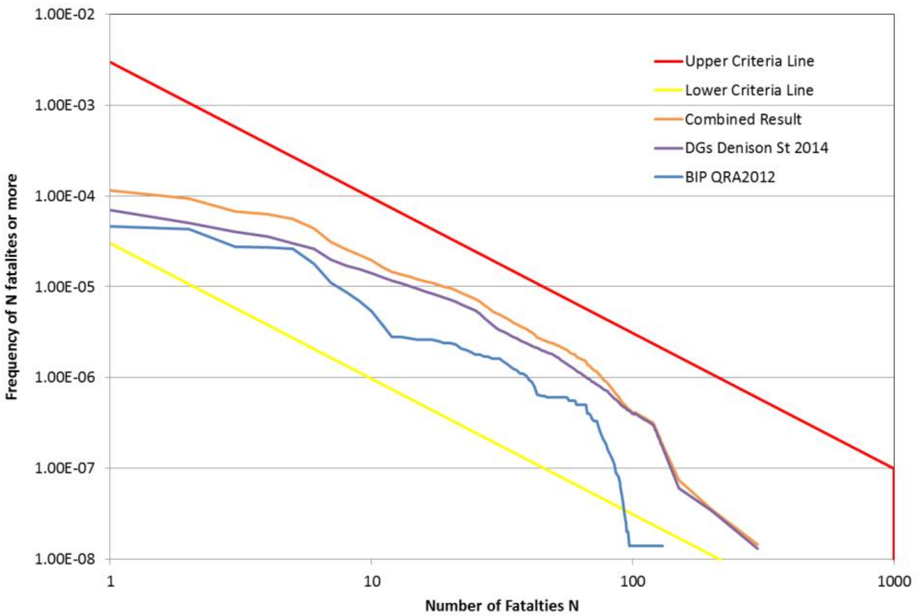


Figure 11 FN Curve – Combined BIP QRA and Denison St DG Movements Based on 2014 Current Case

4. Conclusion

An application for development of a Bunnings Warehouse on Denison St, Hillsdale, is currently being considered by the Joint Regional Planning Panel (JRPP). To assist in the evaluation of the proposal, Scott Lister has undertaken, on behalf of the Department of Planning and Environment (DPE) and City of Botany Bay Council (CBBC), a Quantitative Risk Assessment (QRA) of the movement of Dangerous Goods (DG) along Denison St.

The purpose is to understand the level of risk associated with DG transport on Denison Street to inform determinations on the proposed Bunnings Warehouse as well as other potential future developments around the Botany Industrial Park (BIP). This responds to any potential concern that the number of people attracted to the area by the new store could result in unacceptable levels of risk due to the volume of DG traffic.

The study analysed DG movements along Denison St and cross referenced this with plant throughput data from the BIP. DG movements were then combined with vehicle crash rates to determine the likelihood of hazardous incident scenarios (fires, explosions, toxic gas releases). Using risk modelling software (Phast™ and Safeti™), the consequences of these scenarios were modelled and combined with likelihood data to generate detailed risk profiles for the area.

The results of the study show that the risks satisfy the adopted risk criteria for the study, which are based on those presented in the Department's Hazardous Industry Planning Advisory Paper No. 4, *Risk Criteria for Land Use Safety Planning* (HIPAP 4)). A number of cases have been explored such as,

- Higher than current levels of PGP being transported,
- Addition of the BIP risks (individual and societal) to the transport risks to estimate the overall risks, and
- Sensitivity analysis of the societal risks (taking into account the impact of increase of the population as a result of future developments)

For all of the above cases the risk criteria are satisfied. As such, it is concluded that risks associated with DG transport on Denison St and the BIP should not present a barrier to the Bunnings development proceeding.

5. Recommendations

Recommendations from the study are:

- While this study has found that the risk criteria are met at the Bunnings site, it is recommended that the transport of dangerous goods in the study area be monitored with a view to updating this study at some future date, or in the event of a significant increase in the transport of dangerous goods in the study area.
- City of Botany Bay Council should review the adequacy of existing emergency evacuation arrangements for Hensley Athletic Field to ensure that appropriate

mitigation measures are implemented. Consideration should also be given to possible egress restrictions imposed by current fencing arrangement.
- Industrial or port related developments that would introduce significant increases in DG traffic around the BIP should include an assessment of the DG transport risks posed to surrounding land uses.
- City of Botany Bay Council (CBBC) should review its planning controls for the area, in light of this study, to ensure new development does not result in a significant exposure to risks from dangerous goods transport incidents. For example, it may be desirable to discourage intensification of residential development within areas with an individual fatality risk in excess of one chance in a million, as indicated in HIPAP 4, Section 2.5.2.1.
- Bunnings should consider the risks presented by the transport of Dangerous Goods in the facility design and preparing emergency response plans.

6. References

[1] Department of Urban Affairs & Planning, Botany /Randwick Industrial Area Land Use Safety Study, Overview Report, ISBN 0 7347 0173 X, 2001

[2] Department of Urban Affairs & Planning, “Port Botany Land Use Safety study – Overview Report”, ISBN 0 7310 89847, 1996

[3] Sherpa Consulting, Confidential Appendices of the Quantified Risk Assessment, Main Report, Botany Industrial Park, NSW Department of Planning, 2012.

[4] International Association of Oil and Gas Producers (OGP) Risk Assessment Data Directory, Land Transport Accident Statistics, Report No. 434 – 9, March 2010.

[5]Qest Consulting, “Port Botany Expansion Preliminary Hazard Analysis for Sydney Ports” June 2003.

[6] Department of Planning and Industry,”Hazardous Industry Planning Advisory Paper No 4 Risk Criteria for Land Use Safety Planning (HIPAP 4), January 2011, ISBN 978-0-73475-923-8.

[7] Roar, Survey of Dangerous Goods Traffic Denison St Hillsdale, June/July 2012.

[8] VROM “Guideline for quantitative risk assessment” ’Purple book’ CPR 18E

[9] HSE Research Report 226 “Development of a method for the determination of on-site ignition probabilities” 2004

A1 Background Information

A1.1 Site Location

The study site for this QRA is Denison Street, Hillsdale, NSW. Denison Street is approximately 3.7km east of Sydney Airport. Denison Street is approximately 1.3km long with the study site being bordered by Beauchamp Rd in the south and Wentworth Ave in the north. Denison Street has a speed limit of 60km/hr. Figure 12 below shows Denison Street, the proposed location of the Bunnings development and Hensley Athletics Field.

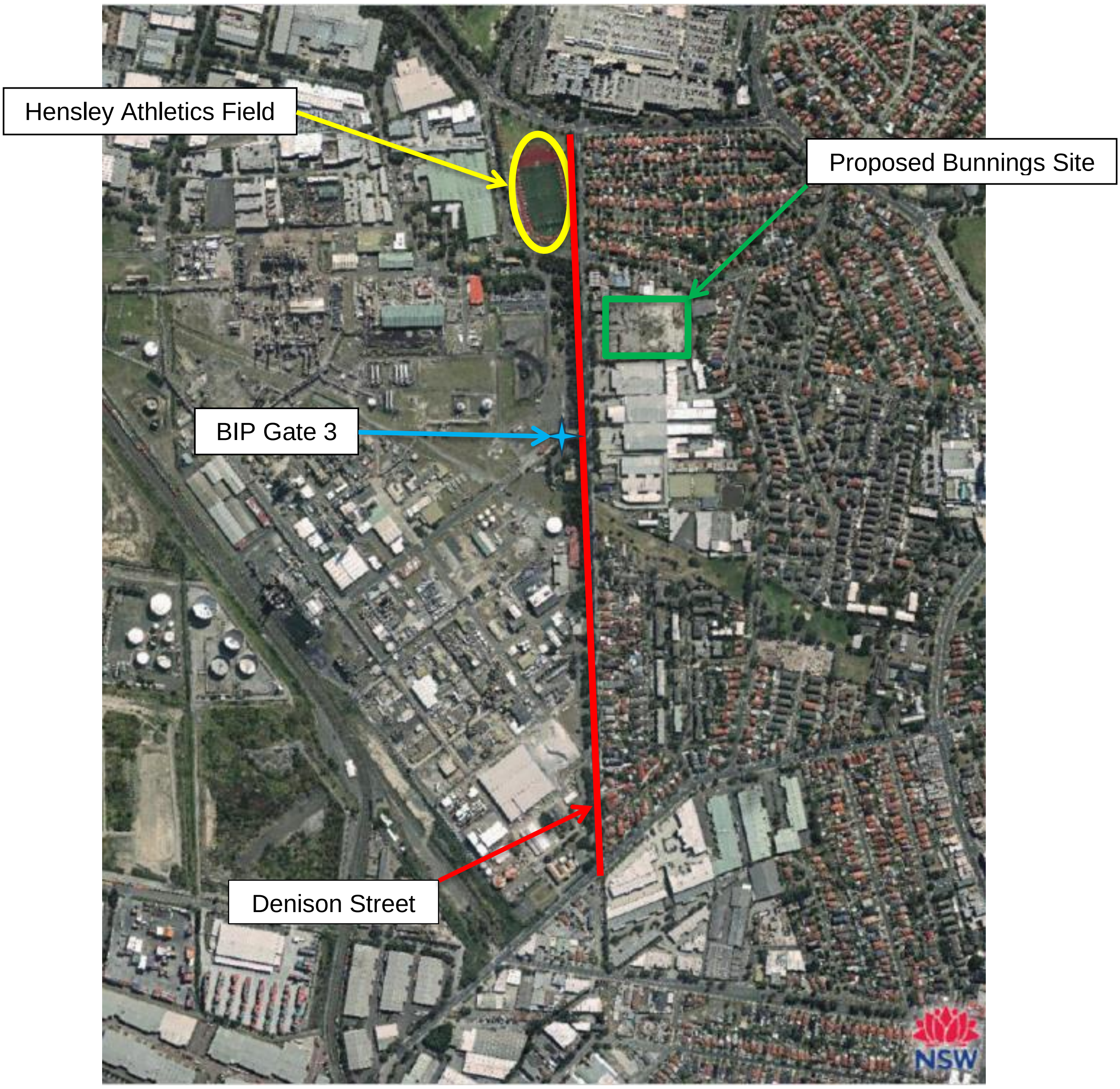


Figure 12 Study Site Location

A2 Assumptions Register

A2.1 Dangerous Goods Traffic

Data on dangerous goods traffic has come from three main sources, namely,

- The 2012 BIP QRA Appendices documenting plant throughput and tanker deliveries,
- The 2012 Roar Dangerous Goods Traffic Study
- Consultation with Qenos, Huntsman and Orica in March 2014.

The 2012 BIP QRA dangerous good traffic data is summarised as Table 7.

Table 7 BIP QRA 2012 Dangerous Goods Traffic

Plant	DG Class	Deliveries (pa)	Delivery size (tonnes)	Total Throughput (tpa)
Olefins				
	Class 2.1	4380	32	58400
Surfactants				
	Class 2.1	50	16	800
	Class 3	230	16	3680
Alkatuff				
	Class 3	332	37.2	7251.6
Chlor - Alkali				
	Class 2.3 & 8	8321	10 to 20	128609

The Roar Traffic Study of 2012 surveyed dangerous good traffic on Denison St for a two week period in July 2012. The survey categorised dangerous goods loads by the Australian dangerous goods classification, as determined by the placard the load was carrying. As such the study did not distinguish between fully loaded, partly loaded and empty vehicle.

The Roar study did however capture the direction of DG vehicles movements along Denison St, as well as the DG vehicles entering and leaving BIP (through Gate 3). As such this enabled traffic associated with the BIP to be separated from other DG traffic, which is most likely to be associated with the Port activities. Also based on the Roar data and information gained from consultation with BIP, it was possible to estimate the number and direction of the empty vehicles. The ROAR data, factored up to yearly movements, is presented as Figure 13. This also shows what proportion of DG vehicles heading north and south are full and are empty.

An assumption was made that DG vehicles not associated with the BIP were associated with the Port bulk liquid terminals and the Banksmeadow fuel distribution centre. Therefore on this basis the vehicles travelling south (to the Port Botany) were empty and vehicles travelling north were full. Empty class 3 tankers will still have a heel of liquid and empty class 2 tankers will have a heel of liquid as well as gas. For this reason they were not screened out but were modelled specifically.

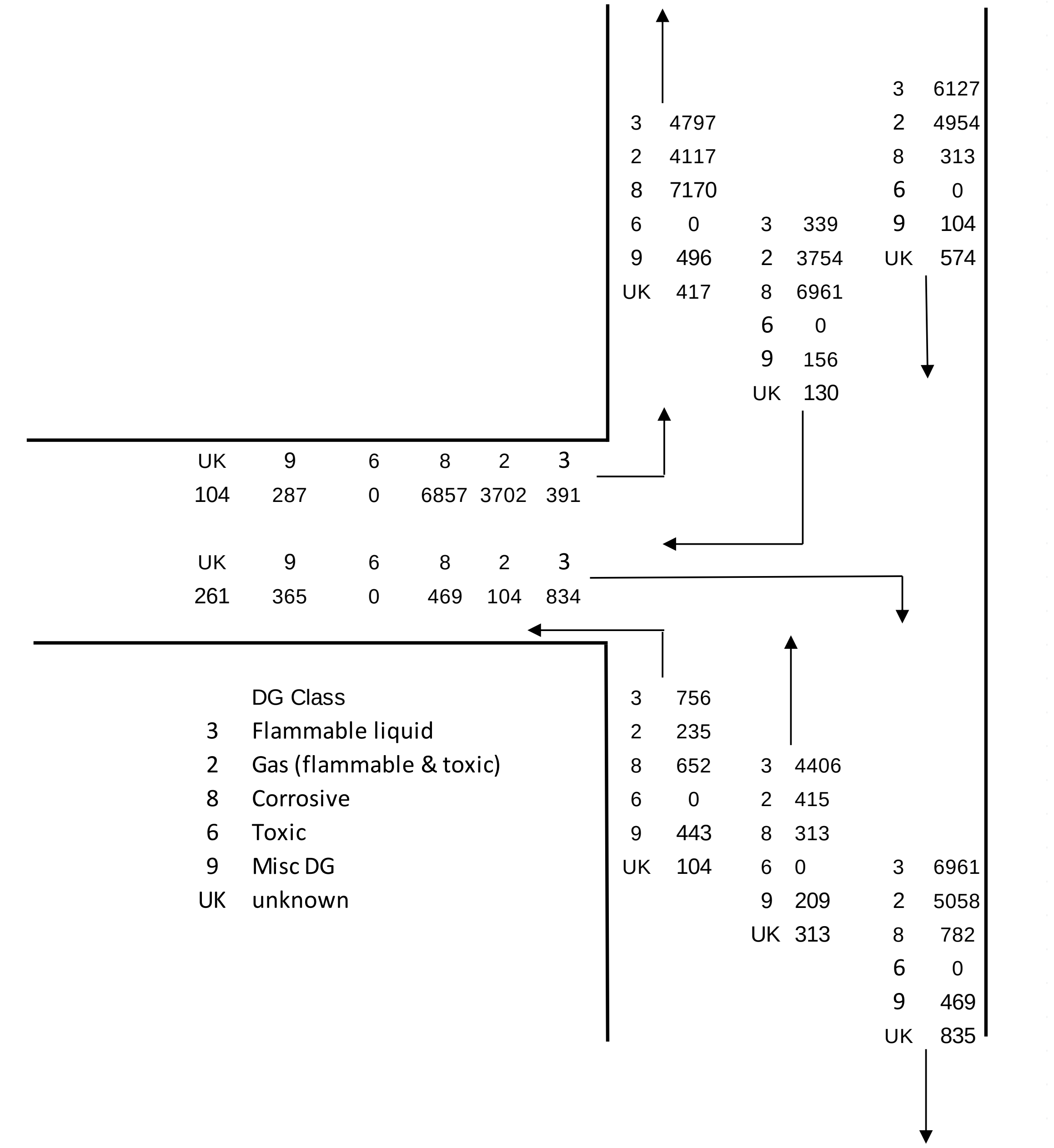


Figure 13 DG Movements Denison St As Surveyed By Roar 2012

The BIP QRA 2012 DG traffic data and the Roar 2012 Denison St DG data were combined to give an indication of the total DG traffic on the street. The combined data is presented as Table 8.

The actual DG movements associated with Qenos activities for the last 12 months were supplied by the company. It is evident that the class 2.1 movements are 85% less than the movements assumed in the 2012 BIP QRA. This is due to

- the closure of LyondellBassell'; and
- loss of feedstock after the closure of both refineries in NSW.

Therefore the actual 2014 class 2.1 movements have been used to estimate the risks in the "2014 current case". This data is presented as Table 9. Within the QRA model Class 2.1 and Class 2.3 DGs have been modelled separately based on their properties and breakdowns of their movements obtained from the BIP QRA appendices [ref 3].

Table 8 2012 Scenario Inferred Dangerous Goods Traffic

Full			**Empty**		
Direction	**Class**	**Movements [pa]**	**Direction**	**Class**	**Movements [pa]**
Heading north of gate 3 full			**Heading north of gate 3 empty**		
	2	4453		**3**	180
Heading north full			**Heading south empty**		
	2	415		2	4954
	3	4406		3	6127
Heading north to gate 3 full			**Heading south to gate 3 empty**		
	3	388		2	4142
Heading south of gate 3 full			**Heading south of gate 3 empty**		
	2	200		3	382
Heading south to gate 3 full			**Heading north to gate 3 empty**		
	3	174		2	509

Table 9 2014 Scenario Inferred Dangerous Goods Traffic

Full			**Empty**		
Direction	**Class**	**Movements [pa]**	**Direction**	**Class**	**Movements [pa]**
Heading north of gate 3 full			**Heading north of gate 3 empty**		
	2	1416		**3**	180
Heading north full			**Heading south empty**		
	2	415		2	4954
	3	4406		3	6127
Heading north to gate 3 full			**Heading south to gate 3 empty**		
	3	388		2	1325
Heading south of gate 3 full			**Heading south of gate 3 empty**		
	2	106		3	382
Heading south to gate 3 full			**Heading north to gate 3 empty**		
	3	174		2	196

A2.2 Frequency Assessment

A2.2.1 Release Frequency Data

Release frequencies were determined by combining traffic movements with general dangerous good road vehicle data published by the International Oil and Gas Producers Association [ref 4], which are the same as those used by Qest in their Port Expansion QRA [ref 5].

LPG release frequencies used are presented as Table 10, and flammable liquid frequencies are presented as Table 11. The LPG tanker release frequencies were used for other pressure liquefied gases, such as PGP and Chlorine.

Table 10 OGP Flammable Liquid Tanker Release Frequencies

Release Size	Frequency per km
5-15 kg	6.00E-09
15-150kg	2.60E-08
150-1500 kg	7.00E-09
>1500 kg	2.10E-08

Table 11 OGP LPG Tanker Release Frequencies

Release	Frequency per km
BLEVE	2.70E-12
Cold Rupture (instant release)	2.60E-09
Large liquid space leak 50mm	1.80E-08
Large vapour space leak 50mm	2.10E-09

A2.2.1 Ignition Probability

Two forms of ignition probabilities have been used, an immediate ignition probability and a delayed ignition probability. The immediate ignition probability relates to the how the mechanism causing the release may also ignite the release. The delayed ignition probability is dependent on the location of ignition sources. The delayed ignition model considered two main sources of delayed ignition, road vehicle traffic and residential populations.

For the immediate ignition probability the same value used in the Port Expansion QRA [ref 5] of 30% was used, in order to provide consistency.

The delayed ignition probability is dependent on the location of ignition sources. The model considered two main sources of delayed ignition, road vehicle traffic and residential populations. The whole length of Denison St was treated as a vehicle based ignition source, based on the traffic level. Populated areas were as per the numbers used in the societal risk calculations.

The delayed ignition model in Safeti model uses a combination of a probability the source is present (eg a road vehicle is in the flammable vapour cloud) and the “ignition effectiveness”. The “purple book” [ref 8] gives a value of “ignition effectiveness” of 0.4 for motor vehicles and 0.01 per person. A HSE research report [ref 9] gives a range of 0.05 to 0.5 for motor vehicles. The approximate mid-point of this range, 0.2, was used for the ignition source strength. While the Port Expansion QRA [ref 5] also used ignition sources for delayed ignition, the strength of such sources used was not provided.

Table 12 Framework ranking system for ignition sources

Category (strength of source)	Examples of ignition sources	Ignition probability
Certain	Pilot light Open flare	1
Strong	Electric motors Hot work	> 0.5
Medium	Vehicles Faulty wiring	0.5 > p > 0.05
Weak	Electrical appliances Mechanical sparks	< 0.05
Negligible	Intrinsically safe equipment Radio frequency sources	0

A2.3 Meteorlogical Conditions

A2.3.1 Weather Conditions

Meteorological data used in the study is the same used in the BIP QRA [ref 5], to ensure consistency.

The BIP QRA used meteorological data from Sydney Airport as an input for the gas dispersion modelling. Data from 1999-2004 from the Bureau of Meteorology (BOM) was categorized with six wind / weather combinations (wind speed / Pasquill stability category) and 12 directional categories. In general the most stable meteorological conditions (F stability) leads to the largest dispersion footprint for toxic releases. Stability class descriptions are presented in Table 13.

Table 13 Pasquill Atmospheric Stability Categories

Class	Type	Description
A	Very Unstable	Daytime – sunny, light winds
B	Unstable	Daytime – moderately sunny, light to moderate winds
C	Lightly Unstable	Daytime – moderate winds, overcast or windy and sunny
D	Neutral	Daytime – windy and overcast or Night-time - windy
E	Stable	Night-time - moderate winds with little cloud or light winds with more clouds
F	Very Stable	Night-time - light wind, little cloud

Based on the data provided from the BIP QRA a wind rose has been produced as shown in Figure 14.

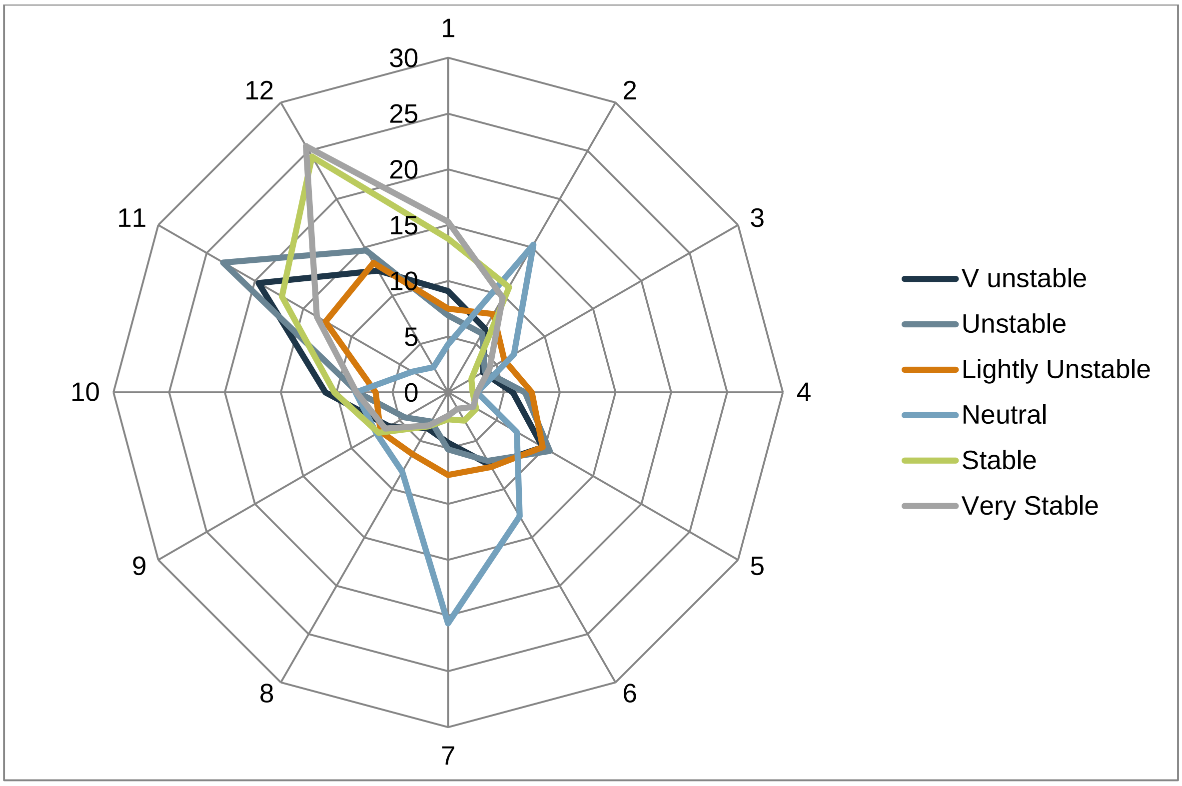


Figure 14 Wind Direction Probabilities for Selected Atmospheric Stability Conditions

A2.3.2 Atmospheric Conditions

The following ambient atmospheric conditions have been used for this study:

Atmospheric Pressure	101.325kPa
Air Surface Temperature	20°C
Atmospheric Humidity	70%
Surface Roughness Factor	0.5

Significance/likely effect on study outcome:

The following items affect the outcome of the study:

- Atmospheric pressure is used to determine the properties of the atmosphere for the dispersion and discharge calculation.
- Atmospheric temperature is used to determine the properties of the atmosphere for the dispersion and discharge calculation.
- Air surface temperature is used to calculate how much heat is transferred from the air surface into the gas cloud.
- Relative humidity is used to determine the properties of the atmosphere in all discharge and dispersion calculation especially materials that react with H_2O.

- Solar radiation flux represents the amount of heat radiation received by a pool from the sun for the pool vapourisation calculation.
- Surface roughness describes the roughness of the surface over which the cloud is dispersing (i.e. Greater roughness, more mechanical turbulence, greater dispersion).

A surface roughness of 0.5 m has been chosen as it is the recommended value for parkland, bushes, and numerous obstacles. This is considered to be conservative given the built up nature of the surrounding area. Note the higher categories of surface roughness for “suburb” and “city centre” in Table 14.

Table 14 Categories of Surface Roughness

Class	Short description of terrain	z0 (m)
1	open water, at least 5 km	0.0002
2	mud flats, snow; no vegetation, no obstacles	0.005
3	open flat terrain; grass, few isolated objects	0.03
4	low crops; occasional large obstacles, x/h > 20 [1]	0.1
5	high crops; scattered large obstacles, 15 < x/h < 20 [1]	0.25
6	parkland, bushes; numerous obstacles, x/h < 15 [1]	0.5
7	regular large obstacle coverage (suburb, forest) [2]	1
8	city centre with high- and low-rise buildings [2])	3

1 x is a typical upwind obstacle distance and h the height of the corresponding major obstacles.

2 These values are rough indications. The use of an aerodynamic roughness length, z0, does not account for the effects of large obstacles.

A2.4 Population data

Societal risk calculations require data on populations within range of the impact distances associated with potential major accidental events.

For this study two sets of data were collected, a day population and a night population.

For night populations the data has been sourced from Australian Bureau of Statistics (ABS), 2011 Census of Population and Housing, Place of Usual Residence database. Additionally the BIP night shift population was added and a cleaning/security population added for Eastgardens. Developments currently before council were also considered (refer to Table 6). The data is presented graphically as Figure 15 Day Population Data Used in Studyand Figure 16.

For day populations the data is sourced from NSW Bureau of Transport Statistics Journey to Work data. This is based on 2011 ABS census data. This has a number of additions made to it, being;

- 20% of night time residential population was assumed present during the day,
- A 200 person average population assumed for Bunnings,
- A 100 person population assumed Hensley athletic field.

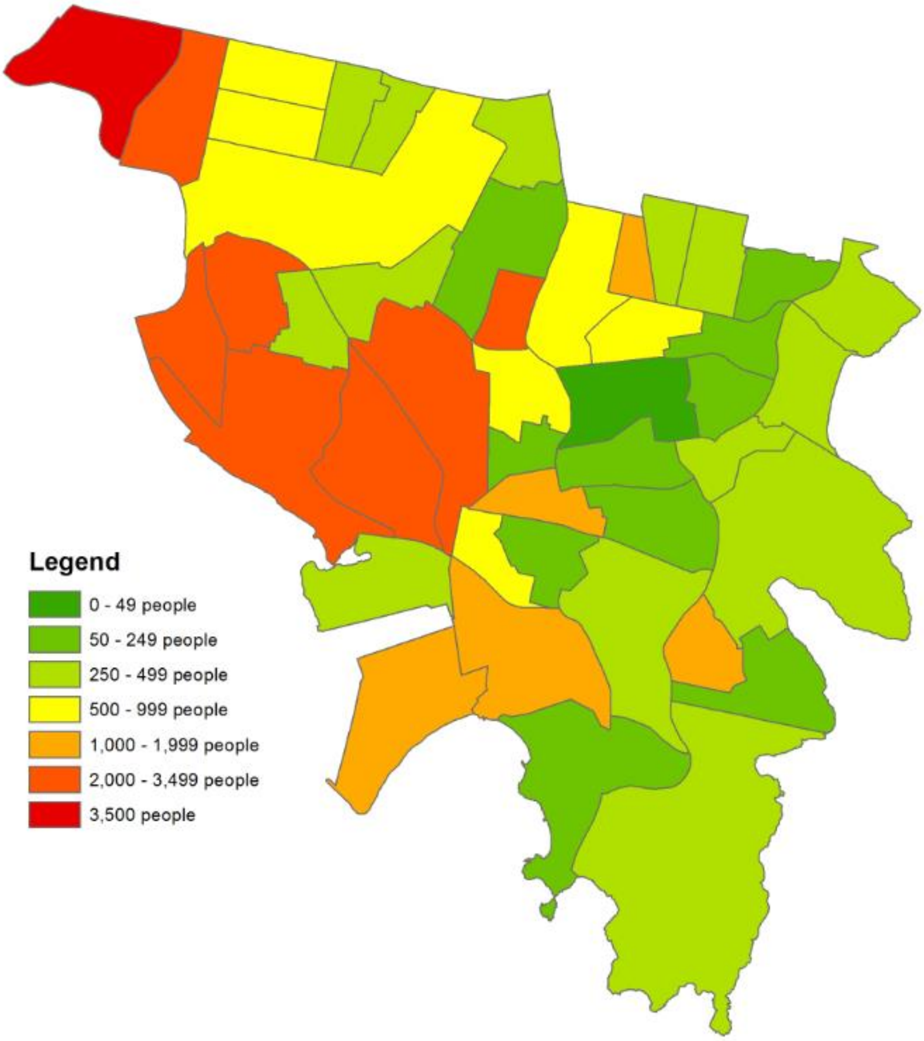


Figure 15 Day Population Data Used in Study

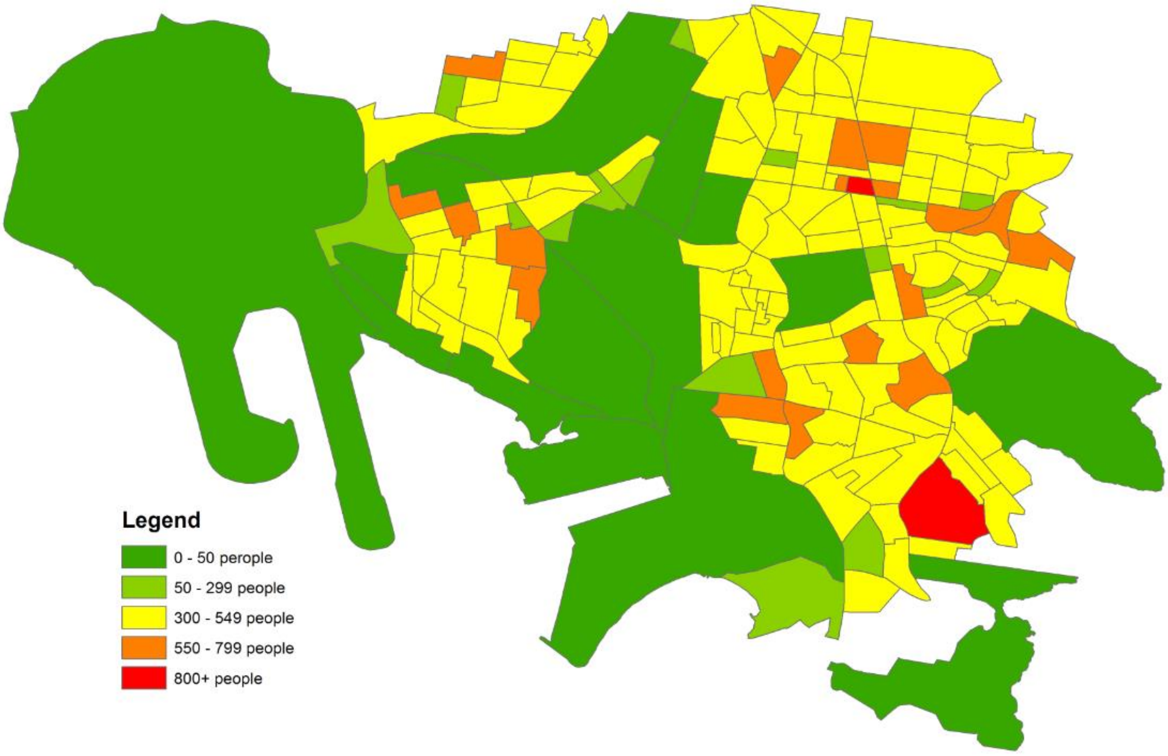


Figure 16 Night Population Data Used in Study

A2.5 Consequence and Vulnerability Assumptions

Societal risk calculations require assumptions on what proportion of populations are indoors and what population are outdoors. Note that such assumptions do not apply to individual risk calculations, where it is assumed that people are outside at the point of interest.

A standard assumption for residential and commercial areas of 90% of the population indoors and 10% outdoors has been made.

Assumptions as to what degree buildings provide protection from fires, explosions, toxic clouds etc. are also required. Assumptions used in the analysis are presented in Table 15.

Table 15 Societal Risk Vulnerability Assumptions

Human Impact	(End Point) Impact Criteria	Vulnerability Parameters	Notes and References
Explosion (Heavy Blast)	Heavy blast damage – R1 (equated to 350 mbarg)	Outdoors – 0.3	Where heavy building damage occurs, fatalities outdoors are likely to result from being close to collapsing buildings or being hit by missiles.
		Indoors – 1.0	The likelihood of fatalities inside heavily damaged buildings is high.
Explosion (Light Blast)	Light blast damage – R1 to R2 (equated to 100 mbarg)	Outdoors – 0.1	People outside are less likely than those inside to suffer fatality due to building damage.
		Indoors – 0.3	Some fatalities are likely to result indoors from building damage.
Flash Fire	50% LFL effect zone	Outdoors – 1.0	People outside may be engulfed by the fire; historically most fatalities in such fires has been inhalation of hot combustion gases, hence the default value assumed is for 100% fatalities, irrespective of protective outer clothing worn (PPE) or potential to rapidly find shelter
		Indoors – 0.1	A flash fire is only likely to cause fatalities indoors if the building is set on fire or else hot combustion gases enter the building.
Fireball / BLEVE	Thermal dose criterion (equivalent to 12.5kW/m^2 for 20s)	Outdoors – 0.7	The dose criterion, equivalent to 250kJ/m^2 (or 12.5kW/m^2 for 20 seconds) is consistent with a high level of fatalities, but not 100% since some people may be shielded by buildings or shelters, or by PPE, or may be able to rapidly find shelter.
		Indoors – 0.2	Personnel indoors will be probable fatalities if they have line of sight to the fireball, i.e. through a window or open door

Human Impact	(End Point) Impact Criteria	Vulnerability Parameters	Notes and References
Jet or Pool Fire	12.5kW/m^2 radiation level	Outdoors – 0.7	The fraction located outdoors killed by a jet flame is high. People caught within the flame will die immediately while there could be some survivors among those affected by the heat radiation level of 12.5kW/m^2. The same default level is assumed for pool fires.
		Indoors – 0.1	The fraction killed inside buildings subjected to jet flame (or pool fire) impingement and heat radiation is 0.1. This accounts for an interior building fire in which personnel may be trapped.
Toxic Effects	Toxic dose and probit equation calculation.	Outdoors – 0.9 x probit	The default value of 0.9 applied with respect to toxic effects is the fraction of the fatality rate calculated by the probit function. That is, a further factor (0.9) is applied to the theoretical effect zone derived from the toxic dose and probit equations.
		Indoors – 0.1 x probit	In the safe way as above, a factor of 0.1 is applied to the 'probit' effect zone as the default estimate of the fraction of exposed personnel indoors that will be killed. However, this calculation is only applied if the option to calculate air entrainment and indoors toxicity within SAFETI is not applied.

The range of susceptibility of a population to a harmful substance can be expressed mathematically as a dose - response function. The dose - response function shows the percentage of the population that will suffer a defined level of harm (normally death) when it is exposed to a specific dose. The probability function of the dose response relationship can be converted to a straight line by converting it to a probit. The probit as the following form for a toxic substance:

Pr = A + B ln(Dose) and Dose = $\int C^n \, dt$

Where

Pr is the probability of the specified level of harm

A, B, and n are constants for a given toxic substance

C is the concentration of the toxic substance

Probit equations for toxics used are the standard ones used in Safeti which for chlorine, the value of the constants used are A = -4.81, B = 0.5 and n = 2.75.