QUANTITATIVE RISK ASSESSMENT 2018

BOTANY INDUSTRIAL PARK (BIP)

REPORT

BOTANY INDUSTRIAL PARK PTY LTD

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ABBREVIATIONS

ABS	Australian Bureau of Statistics
ADG	Australian Dangerous Goods (Code)
AEGL	Acute Emergency Guideline Level
ALA	Air Liquide Australia
ALARP	As Low As Reasonably Practicable
AS	Australian Standard
ASU	Air Separation Unit
BIP	Botany Industrial Park
BLEVE	Boiling Liquid Expanding Vapour Explosion
BOM	Bureau of Meteorology
C2s	Aliphatic hydrocarbons with 2 carbon atoms (at Olefines these are mainly ethane, ethylene (ethene) and acetylene (ethyne))
C3s	Aliphatic hydrocarbons with 3 carbon atoms (at Olefines these are mainly propane and propylene)
C4s	Aliphatic hydrocarbons with 4 carbon atoms (at Olefines these are mainly butane, butene and 1,3 butadiene)
CAP	ChlorAlkali Plant
Cl_2	Chlorine
ClO_2	Chlorine Dioxide
DA	Development Application
DCS	Distributed Control System
DG	Dangerous Goods
DMDS	Dimethyl disulphide, (Olefines cracking furnace additive)
DPE	(NSW) Department of Planning and Environment
ECS	Emergency Chlorine Scrubber
EIS	Environmental Impact Statement
EIV	Emergency Isolation Valve
EM	Ethyl mercaptan (ethanethiol), odorising agent for LPG
EO	Ethylene Oxide
ERP	Emergency Response Plan
ERPG	(US EPA) Emergency Response Planning Guideline
ESD	Emergency Shutdown
$FeCl_3$	Ferric Chloride
GTP	Groundwater Treatment Plant
H2	Hydrogen
HAZID	Hazard Identification
HCB	Hexachlorobenzene
HCl	Hydrogen chloride
HDPE	High Density Polyethylene
HIPAP	(NSW DPE) Hazardous Industry Planning Advisory Paper
HSE	(UK) Health & Safety Executive

Hypo	Sodium Hypochlorite
IBL	Olefines: Inside Battery Limits (inside the ethylene production and processing area)
IDLH	Immediately Dangerous to Life and Health
LEL	Lower Explosive Limit
LLDPE	Linear Low Density Polyethylene
LOC	Loss Of Containment
LPG	Liquefied Petroleum Gas (mainly odorised propane)
MHF	Major Hazards Facility
MPP	Multi Purpose Plant
MSDS	Material Safety Data Sheet
N_2	Nitrogen
NIS	Non Ionic Surfactants
NRV	Non-return valve
NSW	New South Wales
NSWFB	New South Wales Fire Brigade
OBL	Olefines: Outside Battery Limits - outside the ethylene plant production and processing area but within the overall Olefines plant area of control. Olefines OBL includes the hydrocarbon storages and the C3 splitter.
Offsite	Outside the boundaries of the land owned by BIP or its constituent companies.
OHS	Occupational Health & Safety
ORP	Oxidation Reduction Potential
P&ID	Piping and Instrumentation Drawing
Pasquill stability	A method of classification of weather stability (used in dispersion modelling) developed by Pasquill
PFD	Process Flow Diagram
PFD_{avg}	Probability of Failure on Demand (for protective device)
PG	Packaging Group
PGP	Polymer Grade Propylene (high purity propylene suitable for manufacture of polypropylene)
PHA	Preliminary Hazard Analysis
PID	Piping and Instrumentation Diagram
PLC	Programmable Logic Controller
Pmpy	Per million per year
PO	Propylene oxide
Ppb	Parts per billion (usually vol/vol for gases)
PPE	Personnel Protective Equipment
Ppm	Parts per million (usually vol/vol for gases)
PSV	Pressure Safety Valve
QRA	Quantitative Risk Assessment
Ref	Reference
RGP	Refinery Grade Propylene (mixture of mainly propylene with some propane)
SA	Statistical Area (from ABS Census)

SDV	Shutdown Valve
SFARP	So Far As Reasonably Practicable
SH&E	Safety Health and Environment
SIL	Safety Integrity Level
SIS	Safety Instrumented System
SMS	Safety Management System
SPC	Special Purpose Company
SRV	Safety Relief Valve
TfNSW	Transport for NSW
Tpa	Tonnes per annum
Tpd	Tonnes per day
TZ	Travel Zone
UEL	Upper Explosive Limit
VCE	Vapour Cloud Explosion
w/w	weight per weight
XSFV	Excess Flow Valve
WHS	Work Health and Safety

1. SUMMARY

1.1. Background

The Botany Industrial Park (BIP) is a large integrated petrochemical and chemical manufacturing complex located at Matraville, NSW. Multiple companies own and operate plants at the site. Facilities include a Chloralkali plant and downstream products plants operated by Ixom, an Olefines plant and plastics manufacturing plants operated by Qenos and a Surfactants Facility operated by Huntsman.

These facilities are licensed Major Hazards Facilities (MHF) under NSW Workplace Health and Safety (WHS) Regulations. Utilities and other services support these plants. There are also a number of remediation processes occurring at the site.

The BIP has a residential area immediately to the east along Denison St, and in all other directions adjoins industrial or commercial land uses.

The NSW Department of Planning and Environment (DPE) approval for the BIP Subdivision required that the BIP cumulative Quantitative Risk Assessment (QRA) be periodically updated and provided to the DPE. The most recent update to the BIP QRA was prepared by Sherpa Consulting Pty Ltd (Sherpa) and issued to the DPE in 2012 (Ref 1). The BIP retained Sherpa to complete a further periodic update of the QRA.

This report contains the results of the 2018 update to the BIP QRA and has been prepared for submission to DPE in accordance with the relevant condition of consent.

1.2. Objectives

The main objective of the study is to provide an updated estimate of the cumulative offsite risk (i.e. risk outside the BIP site boundaries) associated with the BIP operations.

The QRA is primarily intended to determine if there have been any material changes to risk levels from the BIP, either due to changes in the facilities or due to changes in surrounding land uses.

1.3. Scope

The focus of the QRA is on events which may cause an impact offsite, with ‘offsite’ defined as outside the BIP boundary. ‘Impact’ means potential to cause fatality or other risk effects (injury, irritation, property damage) as defined by the risk criteria used in the study.

Broadly, the BIP QRA covers the following process facilities, as well as tanker loading / unloading operations and storages associated with each facility:

- Qenos Botany Manufacturing Facilities which comprises:
    - Olefines plant Inside Battery Limits (IBL). This is the production and processing facility where ethylene is produced from an ethane feed.
    - Olefines plant Outside Battery Limits (OBL). This is the hydrocarbon storages and the Nant St tank farm.

  - Alkathene plant which produces low density polyethylene plastics from ethylene feed.
  - Alkatuff plant which produces linear low density and high density polyethylene plastics from ethylene feed.
- Huntsman Surfactants Plant which comprises
  - Three 'continuous plants', i.e. the Ethylene Oxide (EO), Glycols and Glycol Ethers Plants
  - Batch plants, comprising three non-ionic surfactants plants (NIS A, B, C), the Multi-Purpose Plant (MPP), and the Specialties plant.
  - Associated storages (primarily flammable raw materials such as alcohols and propylene oxide (PO), and the EO product bulk storage).
- Ixom ChlorAlkali Facility which comprises
  - the ChlorAlkali Plant (CAP) where chlorine gas is produced
  - the Products Plants where all manufactured chlorine is used (Hydrochloric Acid, Ferric Chloride and Sodium Hypochlorite plants)
  - in-transit chlorine road tanker
  - in-transit chlorine drum and cylinder storage area.
- Orica Groundwater Treatment Plant (GTP) which treats contaminated groundwater using an air stripping and thermal oxidation process. The GTP is operated by Ixom.
- Major pipelines carrying toxic/flammable materials within the BIP.

Other facilities on the BIP do not present significant risks outside their boundaries hence are not included in the QRA.

Transport of DGs via vehicles or pipeline outside the BIP boundary is not within the scope of the QRA.

1.4. Methodology

The QRA has been updated and reported in accordance with the NSW DPE *Hazardous Industry Planning Advisory Paper 6 (2011), Guidelines for Hazard Analysis (HIPAP 6)* (Ref 2). The steps were:

1. Review of the hazardous incidents included in the QRA based on the most recent individual facility QRAs. The hazardous materials, inventories and operating conditions are similar to the 2012 QRA.
2. Updating meteorological and population data (provided in APPENDIX 7 and APPENDIX 8).
3. Compiling a new QRA model in the most recent software TNO Riskcurves version 10. There are many changes compared to the version (v2.7) of the software used in

the previous QRAs. It was not possible to continue to use the older version of the software as it was no longer compatible with current Windows operating systems.

4. Individual risk contours (fatality, escalation, injury and irritation) and a societal risk (FN curve) were generated from the risk model and compared against the risk criteria in *Hazardous Industry Planning Advisory Paper 4 Risk Criteria for Land Use Safety Planning (HIPAP 4)* (Ref.3).
5. Preparation of the summary QRA report for submission to the NSW DPE and for publishing in the public domain.

The Qenos, Huntsman and Ixom facilities are separate licensed Major Hazard Facilities (MHF) under NSW WHS Regulations. A brief description of risk control measures in place at each facility is included in the BIP QRA report. However the QRA report does not include detailed adequacy assessments of control measures or details of assurance of their integrity via the relevant facility operator’s safety management system. This is covered in detail in the individual operator MHF Safety Cases which have been submitted to the regulator SafeWork NSW in order to obtain an MHF licence.

1.5. Results

1.5.1. Changes since 2012 QRA

The high level QRA methodology and approach are similar to the 2012 QRA. Specific assumptions have been changed only to reflect updated plant operations information or for consistency with MHF Safety Cases. Improved modelling technique such as most recent versions of software have also been used.

A summary of changes made since the previous QRA together with their potential effect on results is included in APPENDIX 1. In summary:

- There have been relatively few changes to the operations (hazardous materials, operating conditions) on the BIP since 2012 that have a significant effect on the QRA results.
- There has been considerable change in the risk software and modelling approach which means that the risk results are not the same as the 2012 QRA even if all inputs could be held constant.
- There has been significant increase in development and population around the BIP which affects the societal risk. Two population cases have been included in the QRA, a ‘current case’ based on 2016 Census data and an ‘approved development’ case which represents Census 2016 populations plus developments that have been approved around the BIP but are not yet occupied.

1.5.2. Results

The fatality risk contours and societal risk results from the QRA are shown in Figure 1.1. All other contours are shown in Section 9 of the QRA report. These supersede the 2012

QRA results. Table 1.1 provides a comparison of the 2018 results against HIPAP 4 risk criteria together with a comparison against the 2012 QRA results.

In summary the QRA found that:

- Individual fatality risk levels comply with all relevant HIPAP 4 fatality risk criteria. Risk levels are similar to those assessed in the 2012 QRA revision, with slightly lower risk levels along the southern end on Denison St such that residential risk contour no longer extends to the housing (compared to a small encroachment reported in the 2012 QRA).
- The heat radiation injury risk contour and escalation risk contours comply with criteria.
- The toxic injury, irritation contours extend to residential areas along Denison St as per the previous QRA however they have reduced in size slightly. This is largely due to change in modelling techniques, not changes in the input scenarios.
- There is a small encroachment of the overpressure injury risk contours into residential areas to the east along Denison St and of the overpressure escalation contours into potentially hazardous land uses to the north. This is similar to the previous QRA results.
- The societal risk remains in the ALARP region, however has increased since the 2012 QRA and increases further for the 'approved development case'. This is largely due to increased population in the areas around the BIP as well as some changes in modelling approach within Riskcurves.

Overall, when considering the individual risk results, these are reasonably low and similar to the previous 2012 QRA.

Societal risk results are also in the ALARP region which indicate the risk is not unacceptable but that it is not negligible.

Any further increases in population outside the land uses included in the risk model would continue to increase the societal risk.

1.6. Recommendations

The risk level generated from the BIP facilities remains very similar to previous years, and as demonstrated in the operator MHF Safety Cases for each facility, control measures are in place that reduce the risk So Far As Reasonably Practicable (SFARP).

Therefore no recommendations have been made as a result of the QRA update.

TABLE 1.1: COMPARISON OF RESULTS WITH RISK CRITERIA

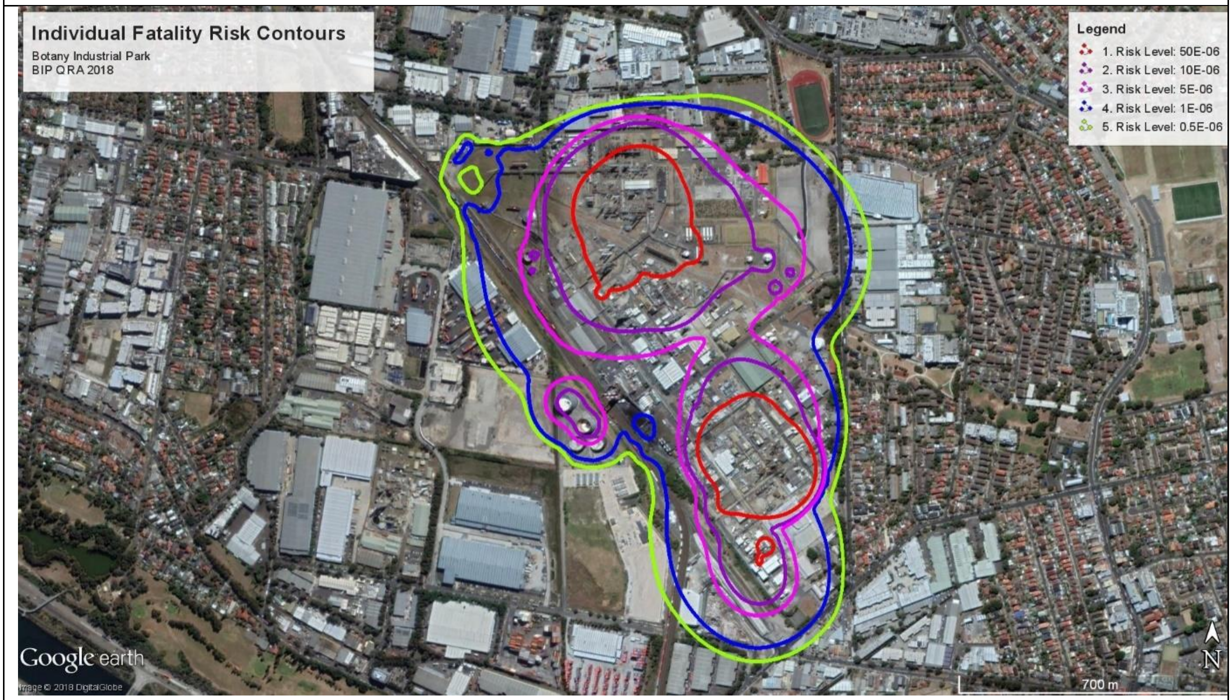
Description	Risk Criterion (per year)	Risk Criteria Met 2018 QRA?	Comments	Comparison with 2012 QRA
Individual Fatality Risk				
Sensitive uses, including hospitals, schools, aged care	0.5×10^{-6}	Yes	Contour extends by a small amount across BIP boundaries but is not near any sensitive uses (Matraville Botany Public School (Beauchamp Rd around 400m away). Complies with criteria.	Similar to 2012 contours.
Residential areas and hotels	1×10^{-6}	Yes	The 1x 10^{-6} per yr contour extends across west and south BIP boundary but does not encroach on any residential uses Complies with criteria.	Similar to 2012 contours. Slightly smaller, no longer encroaches into housing in southern part of Denison St.
Commercial areas, including offices, retail centres, warehouses	5×10^{-6}	Yes	Does not reach the nearest commercial developments (Various commercial businesses in Denison St to the east). Complies with criteria.	Similar to 2012 contours.
Sporting complexes and active open spaces	10×10^{-6}	Yes	Does not reach any open space uses. Complies with criteria.	Similar to 2012 contours.
Contained within the boundary of an industrial site	50×10^{-6}	Yes	Does not extend outside BIP or Nant St site boundaries. Complies with criteria.	Similar to 2012 contours for main BIP site. Smaller contours for Nant St. Contours in 2012 extended outside Nant St boundary.

Description	Risk Criterion (per year)	Risk Criteria Met 2018 QRA?	Comments	Comparison with 2012 QRA
Fire / Explosion Injury Risk				
Heat radiation exceeding 4.7 kW/m^2 (residential and sensitive areas only)	50 x 10^{-6}	Yes	Within BIP boundary Complies with criteria	Smaller than 2012 results. Largely due to a change in ignition probabilities assumed which have reduced for smaller / medium releases.
Overpressure exceeding 7 kPa (residential and sensitive areas only)	50 x10^{-6}	No	Small encroachment into residential area along southern part of Denison St.	Similar to 2012 results.
Fire/Explosion Escalation Risk				
Heat radiation exceeding 23 kW/m^2 (neighbouring hazardous facilities)	50 x 10^{-6}	Yes	Within BIP boundary Complies with criteria	Smaller than 2012 results Largely due to a change in ignition probabilities assumed which have reduced for smaller / medium releases.
Overpressure exceeding14 kPa (neighbouring hazardous facilities)	50 x10^{-6}	No	Small encroachment outside Olefines on northern BIP boundary into neighbouring hazardous facility	Similar to 2012 results.
Toxic Injury/Irritation Risk				
Injury (residential areas only)	10 x 10^{-6}	No	Extends from the BIP into residential areas to the east.	Contour is slightly smaller due to change in approach to assessing frequency of exceeding AEGL3 (10 min) equivalent dose rather than ERPG3 concentration

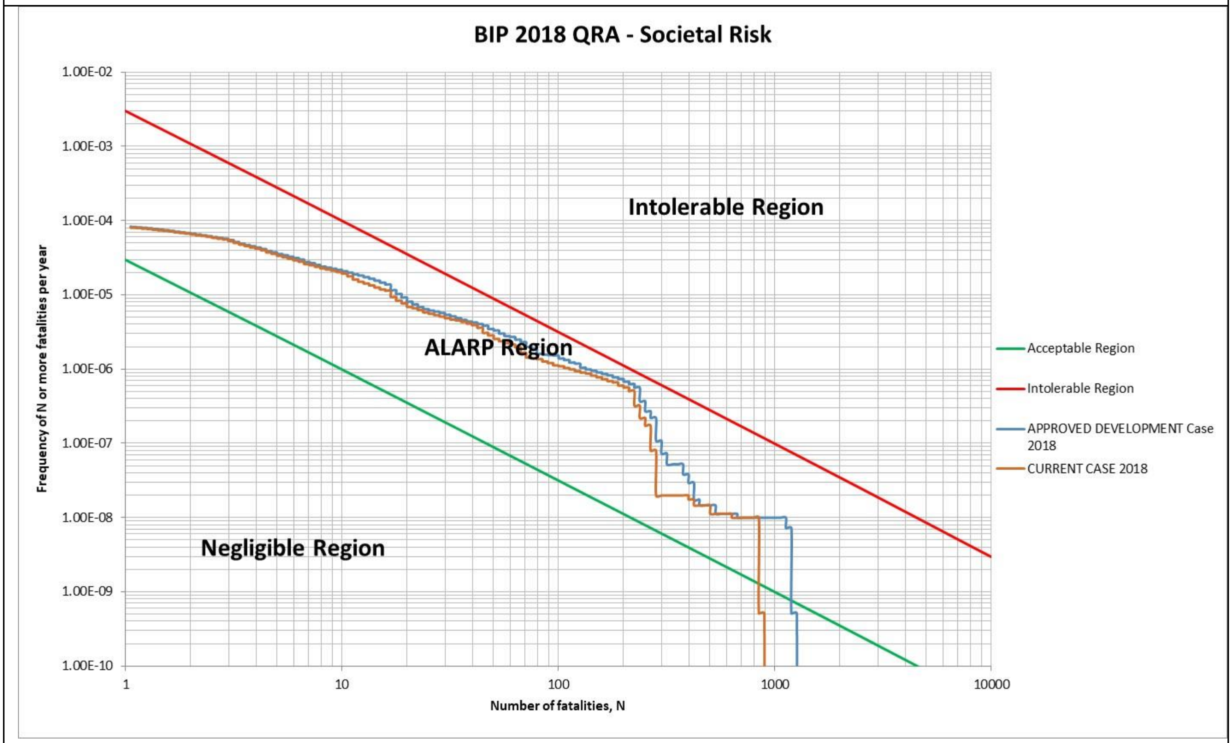
Description	Risk Criterion (per year)	Risk Criteria Met 2018 QRA?	Comments	Comparison with 2012 QRA
Irritation (residential areas only)	50 $\times 10^{-6}$	No	Extends from the BIP into residential areas to the east.	Contour is significantly smaller due to due to change in approach to assessing frequency of exceeding AEGL2(10 min) equivalent dose rather than ERPG2 concentration
Societal Risk				
Populations external to BIP	HIPAP 4 (2011) indicative societal risk criteria	Not intolerable	Results are within ALARP area for all N. For the 'approved development' population case, the maximum number of people 'N' affected exceeds the HIPAP 4 limit that is a maximum N < 1000.	Societal risk is higher. This is largely due to increase in populations but is also due to change in Riskcurves modelling which have the effect of increasing effect distance of some worst case low frequency events.

FIGURE 1.1: RISK RESULTS

Individual Fatality Risk Contours



Societal Risk



2. INTRODUCTION

2.1. Background

The Botany Industrial Park (BIP) is a large integrated petrochemical and chemical manufacturing complex located to the west of Denison St, Matraville, NSW. The site was operated as a single site under the ownership of Orica Australia Pty Ltd (formerly ICI Australia) until late 1998. The site was subdivided in 1999 to form the Botany Industrial Park (BIP) and some of the operating plants were divested to new owners/operators.

In 2015, Orica separated their chemicals business into a new independent entity (Ixom Pty Ltd). Ixom is now the owner and operator of the BIP Chloralkali Facility (which was the last remaining Orica manufacturing process).

In 2018, there are six main industrial manufacturing complexes on the site, which are operated by three different companies, Ixom, Huntsman and Qenos (which is owned by China National Chemical Corporation). Orica retains ownership of some BIP land and is also responsible for various remediation processes. There are also some areas on the BIP owned by or leased to non-manufacturing companies. The overall role of managing the BIP (BIP Operations Manager) is rotated between the main operating companies.

2.2. Requirement for study

One of the Conditions of Consent set by the NSW Department of Planning and Environment (DPE) for the BIP subdivision required that a cumulative site quantitative risk assessment (QRA) be prepared and maintained (Schedule 3, Condition 4, DA 30/98 as modified in DA30/98 MOD 2, 6 Aug 2015) as follows:

9. in Schedule 3, replacing Condition 4 with the following:

3. Site Cumulative Risk Assessment
   (a) The SPC shall maintain an updated Quantitative Risk Assessment for the BIP. This Risk Assessment shall be updated:
      i. if there is a change at the BIP, which will significantly change the results of the Risk Assessment; or
      ii. if required by the Secretary; or
      iii. in accordance with the provisions of the *Work Health and Safety Regulation 2011*; or
      iv. at least every 5 years.
   (b) Each quantitative risk assessment (or update to such an assessment) shall include individual, fatality, injury and irritation risks and societal risks using the most recently available population and meteorological data. Each quantitative risk assessment (or update to such an assessment) shall be in accordance with *Hazardous Industry Planning Advisory Paper No. 6 – Guidelines for Hazard Analysis* (DoP, 2011).
   (c) Each member of SPC shall provide the relevant information and resources to the SPC to ensure that each quantitative risk assessment (or update to such an assessment) is reviewed and updated as necessary.
   (d) Each quantitative risk assessment (or update to such an assessment) shall be submitted to the Secretary for approval.

The most recent update to the BIP QRA was prepared by Sherpa Consulting Pty Ltd (Sherpa) and issued to the DPE in 2012 (Ref 1).

There have been no developments on the BIP since 2012 where a Preliminary Hazard Analysis (PHA) was submitted that required an update to the BIP QRA. Therefore cumulative QRA results have not been provided to the DPE since the 2012 BIP QRA report.

2.3. Responsibility

Separate QRA studies exist for each manufacturing facility and are the responsibility of each operator. The individual facility QRA studies are not available in the public domain.

The BIP coordinates the preparation and integration of the cumulative BIP site QRA. The individual QRAs have been integrated to form the cumulative BIP site QRA. The compiled QRA results are reported in a summary report document. The summary document is provided periodically to DPE in accordance with the condition of consent and is made publicly available via the DPE's website.

Sherpa has been retained on behalf of the BIP to prepare the compiled BIP QRA and the associated summary report using results drawn from the individual facility QRAs.

2.4. Scope

The focus of the QRA is on events which may cause an impact offsite, with 'offsite' defined as outside the BIP boundary. 'Impact' means potential to cause fatality or other risk effects (injury, irritation, property damage) as defined by the risk criteria used in the study (refer to Section 2.7 for risk criteria details).

Broadly, the BIP QRA covers the following process facilities, as well as tanker loading/unloading operations and storages associated with each facility:

- Qenos Botany Manufacturing Facilities which comprises:
    - Olefines plant Inside Battery Limits (IBL). This is the production and processing facility where ethylene is produced from an ethane feed.
    - Olefines plant Outside Battery Limits (OBL). This is outside the ethylene plant production and processing area but within the overall Olefines plant area of control. Olefines OBL includes hydrocarbon storages and the C3 splitter as well as the Nant St tank farm.
    - Alkathene plant which produces low density polyethylene plastics from ethylene feed.
    - Alkatuff plant which produces linear low density and high density polyethylene plastics from ethylene feed.
- Huntsman Surfactants Plant which comprises
    - Three 'continuous plants', i.e. the Ethylene Oxide (EO), Glycols and Glycol Ethers Plants

- Batch plants, comprising three non-ionic surfactants plants (NIS A, B, C), the Multi-Purpose Plant (MPP), and the Specialties plant.
- Associated storages (primarily flammable raw materials such as alcohols and propylene oxide (PO), and the EO product bulk storage).

- Ixom ChlorAlkali Facility which comprises
  - the ChlorAlkali Plant (CAP) where chlorine gas is produced
  - the Products Plants where all manufactured chlorine is used (Hydrochloric Acid, Ferric Chloride and Sodium Hypochlorite plants)
  - in-transit chlorine road tanker
  - in-transit chlorine drum and cylinder storage area.
- Orica Groundwater Treatment Plant (GTP) which treats contaminated groundwater using an air stripping and thermal oxidation process. The GTP is operated by Ixom.
- Major pipelines carrying toxic/flammable materials within the BIP.

Other facilities on the BIP do not present significant risks outside their boundaries hence are not included in the QRA.

Table 4.1 summarises the scope of facilities where risk is quantified within the BIP QRA, as well as identifying the facilities where the risk has not been quantified as there are no identified impacts outside the BIP boundaries.

There have been no changes in overall scope since the 2012 QRA.

2.5. Objectives

The BIP QRA is intended to comply with the relevant Condition of Consent and is used to ensure that changes in the facilities themselves or changes in surrounding land uses are formally assessed. It is intended as a periodic indication of risk status, ie provides an update of the cumulative offsite risk (outside the BIP boundaries) associated with the BIP operations, to monitor risk levels over time.

At a lower level, the objectives of the QRA study are to:

- Review the hazardous incidents associated with the BIP manufacturing facilities that have the potential to have an impact outside the BIP site boundary and identify any significant changes since the previous QRA.
- Quantitatively evaluate the cumulative level of risk from the BIP to surrounding land uses taking into account changes in facilities and surrounding land uses.
- Compare the calculated risk levels with the risk criteria give in NSW DPE's *Hazardous Industry Planning Advisory Paper 4 Risk Criteria for Land Use Safety Planning (HIPAP 4)* (Ref.4).
- Prepare a QRA report that can be submitted to NSW DPE as required under the BIP development consent condition.

The QRA report does not cover detailed adequacy assessments of control measures or the need for additional risk reduction measures as this is addressed by the facility operators via the MHF Safety Case process under NSW Work Health and Safety Regulations (WHS Regs).

2.6. Study Methodology

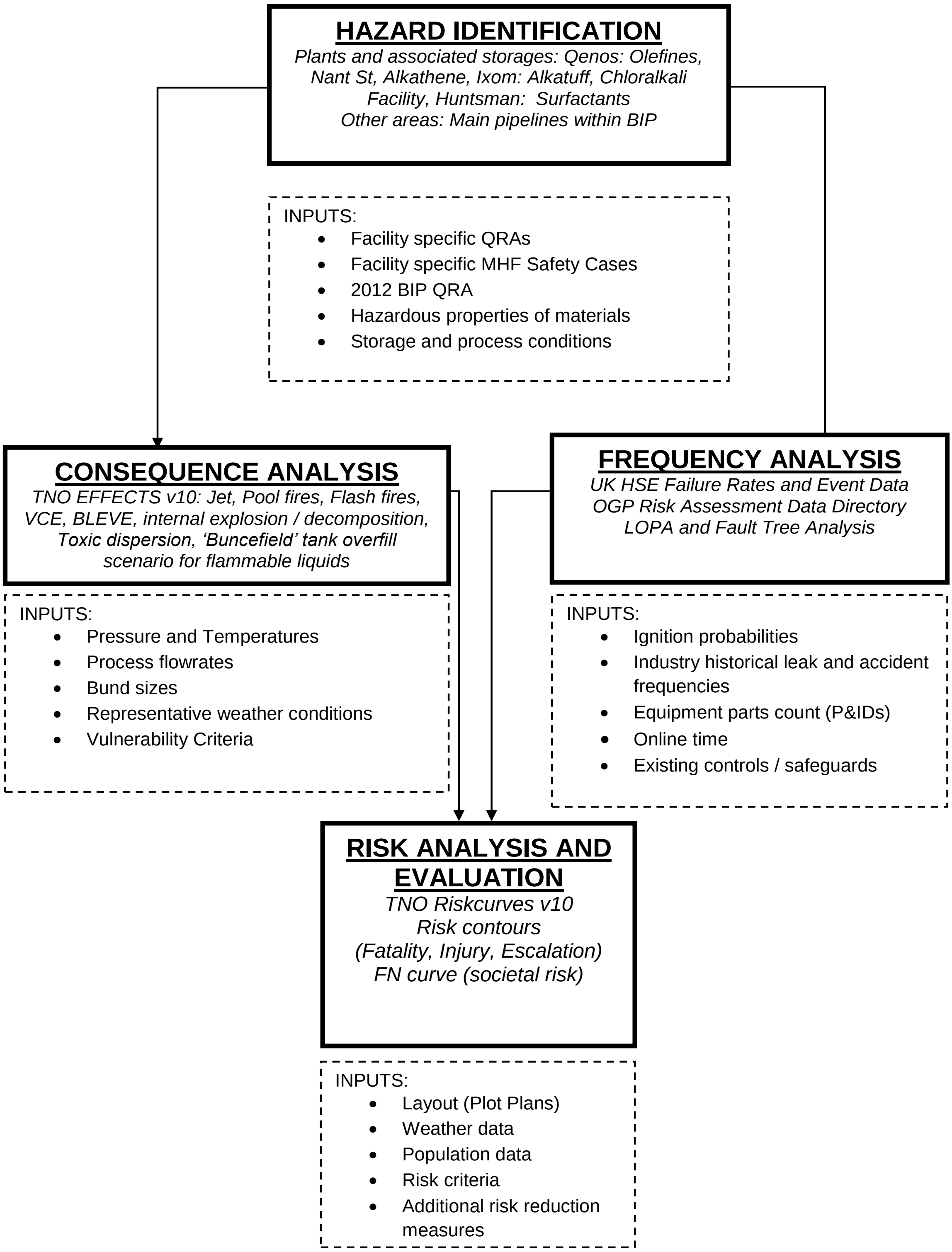
As for previous QRAs, the study was carried out in accordance with *Hazardous Industry Planning Advisory Paper No. 6 - Guidelines for Hazard Analysis* (HIPAP No. 6, Ref 2) and included the following main steps:

- Hazard identification and development of potential incident scenarios. This was compiled from the most recent individual facility QRAs (see APPENDIX 4).
- Consequence assessment. This was carried out quantitatively using a commercially available software package TNO Effects v10 (Ref 5), supplemented by some spreadsheet models and was compiled from the individual facility QRAs (see APPENDIX 5).
- Frequency assessment. Event frequencies were generally estimated from industry statistical databases, supplemented by fault tree, event trees, bowtie analysis or data from the MHF safety cases as per the individual facility QRAs (see APPENDIX 9).
- Risk assessment. The risk assessment approach was a Quantitative Risk Analysis, i.e. a 'Level 3 Assessment', as described in *Multi-level Risk Assessment* (Ref.6). As for previous QRAs, guidance contained in the TNO "Purple Book" was used to define assumptions made to undertake the QRA (Ref 7).
- Quantitative risk results were generated by TNO Riskcurves v10 and are presented as individual fatality risk contours, injury, property damage and irritation risk contours, as well as societal risk FN curves (see Section 9 for results) .

Figure 2.1 provides an overview of the QRA process.

Note that evaluation of additional controls or safeguards is not covered in this report as this is addressed in detail under the MHF regulatory process as explained Section 2.8.1.

FIGURE 2.1: OVERVIEW OF QRA PROCESS



2.7. Risk Criteria

Individual fatality risk injury, escalation/property damage risk, toxic irritation risk and societal risk have been assessed against risk criteria in NSW DPE *HIPAP 4 (2011), Risk Criteria for Land Use Safety Planning* (Ref 3).

HIPAP 4 defines specific risk criteria for new plants and also for existing plants. HIPAP 4 states:

> *"…… while existing industry should ideally meet the same residential and sensitive land use criteria as new proposals, it is recognised that this may not be possible in practice"*.

It goes on to state:

> *"In the case of existing industry, compliance with a risk criterion is part of an overall strategy to mitigate existing risk levels by reducing both the risks and the number of people exposed to those risks".*

As for previous QRAs, new plant risk criteria are adopted in the BIP 2018 update. The HIPAP 4 criteria have not changed since the 2012 QRA.

2.7.1. Individual Risk

Individual risk represents the probability of some specified level of harm (usually fatality or injury) to a theoretical individual located permanently at a particular location, assuming no mitigating action such as escape can be taken, hence is considered to cover sensitive or vulnerable individuals such as the very young, sick or elderly.

The NSW DPE quantitative individual risk criteria for new plants are summarised in Table 2.1. The criteria are expressed in terms of individual fatality risk or likelihood of exposure to threshold values of heat radiation, explosion overpressure or toxicity.

All criteria are relevant to the cumulative risk assessment, although not to each of the facilities individually.

For example, toxicity is the main hazard associated with the Ixom facility and flammability with the Qenos facilities.

TABLE 2.1: HIPAP 4 RISK CRITERIA

Description	Risk Criteria (per year)	Applicable
Individual Fatality Risk		
Fatality risk to sensitive uses, including hospitals, schools, aged care	0.5×10^{-6}	Yes
Fatality risk to residential and hotels	1×10^{-6}	Yes
Fatality risk to commercial areas, including offices, retail centres, warehouses	5×10^{-6}	Yes
Fatality risk to sporting complexes and active open spaces	10×10^{-6}	Yes
Fatality risk to contained within the boundary of an industrial site	50×10^{-6}	Yes

Description	Risk Criteria (per year)	Applicable
Injury / Irritation		
Fire / Explosion Injury risk – incident heat flux radiation at residential areas should not exceed 4.7 kW/m^2 at frequencies of more than 50 chances in a million per year or incident explosion overpressure at residential areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year	50×10^{-6}	Yes *Flammable inventories only
Toxic Injury - Toxic concentrations in residential areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure at a maximum frequency of 10 in a million per year	10×10^{-6}	Yes *toxic inventories only
Toxic Irritation - Toxic concentrations in residential areas should not cause irritation to eyes, or throat, coughing or other acute physiological responses in sensitive members of the community over a maximum frequency of 50 in a million per year	50×10^{-6}	Yes *toxic inventories only
Escalation		
Incident heat flux radiation at neighbouring potentially hazardous installations or land zoned to accommodate such use should not exceed a risk of 50 per million per year for the 23 kW/m^2 heat flux contour	50×10^{-6}	Yes *Flammable inventories only
Overpressure at neighbouring potentially hazardous installations or the nearest public building should not exceed a risk of 50 per million per year for the 14kPa overpressure contour	50×10^{-6}	Yes *Flammable inventories only

2.7.2. Societal Risk

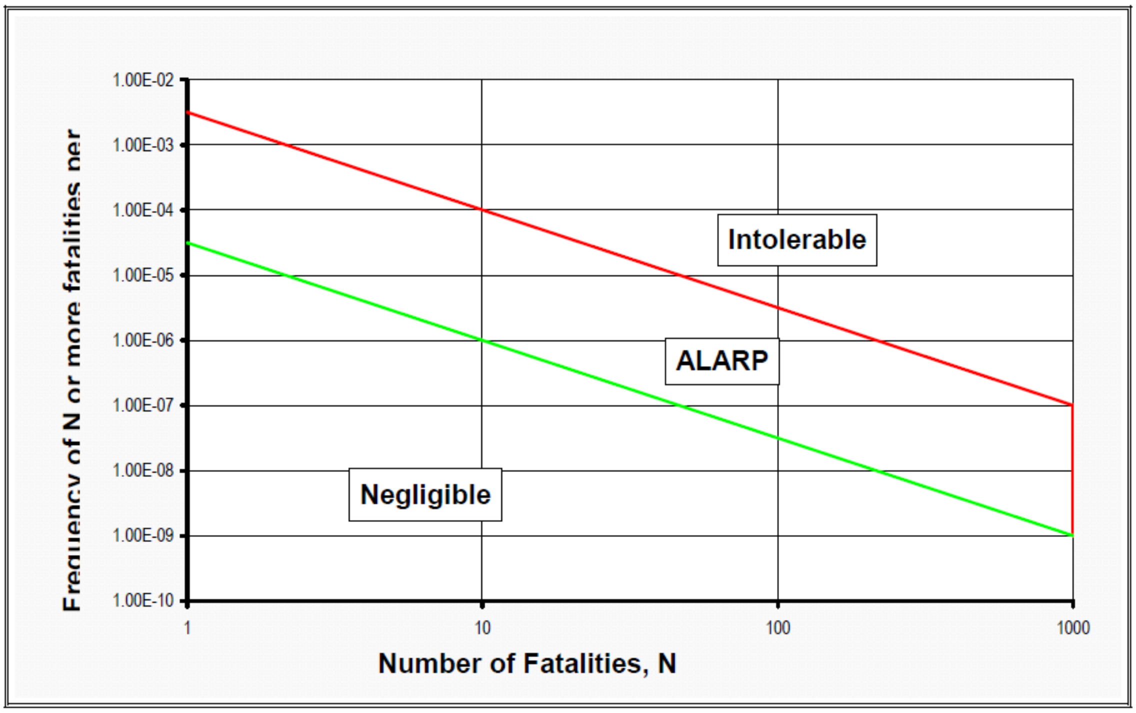
Societal risk is a measure of the probability of incidents affecting an actual population (rather than a theoretical individual as in individual risk). It is usually presented in the form of an “FN” curve which is a graph of the cumulative frequency of fatality (F) of a number (N) or more people.

Generally societal risk is considered in three regions (Ref 3):

- “Intolerable region” represented by an upper criterion line above which an activity is considered undesirable, even if individual risk criteria are met.
- “Negligible” represented by a lower criterion line below which, provided other individual criteria are met, societal risk is not considered significant.
- “ALARP” or “as low as reasonably practicable” region in between the ‘’negligible’’ and ‘’intolerable’’ where the emphasis is on reducing risks as far as possible towards the negligible line. Provided other criteria of HIPAP 4 are met, the risks from the activity would be considered tolerable in the ALARP region.

HIPAP 4 provides indicative societal risk criteria as shown in Figure 2.2. This includes a limit of N<1000 in the graph as shown by the vertical red line on the right side of the graph. However this limit is not referred to or explained in the supporting text in HIPAP 4.

FIGURE 2.2: SOCIETAL RISK CRITERIA FROM FIGURE 3, HIPAP 4 (2011)



2.8. Links to Other Studies

2.8.1. MHF Safety Cases

The Qenos, Huntsman and Ixom facilities are each separate licensed Major Hazard Facilities (MHF) under NSW WHS Regulations. Each operator has submitted an MHF Safety Case report to the regulator SafeWork NSW in order to achieve an MHF licence.

The overall objective of an MHF Safety Case is to demonstrate that the risks associated with an MHF have been eliminated, or if this is not achievable, adequate controls must be implemented to reduce the risk “So Far As Reasonably Practicable” (SFARP). A Safety Management System (SMS) must be in place at the MHF that ensures the effectiveness and reliability of the controls. This demonstration must be made in the Safety Case to obtain an MHF licence.

A brief summary of relevant risk control measures at each of the BIP facilities is included in the QRA in APPENDIX 2, together with the effect of control measures quantified in the QRA in APPENDIX 9. However the QRA report does not include detailed adequacy assessments of control measures or details of assurance of their integrity via the relevant facility operator’s safety management system. Details are covered in the individual operator MHF Safety Case reports.

2.8.2. Denison St DG Transport study

A Dangerous Goods (DG) Transport QRA, Denison St, Hillsdale (Scott Lister, 12th February, 2015) and associated Addendum (May 2015) were released in 2015 in relation to the Bunnings development on Denison St.

The BIP QRA does not cover offsite DG transport and there is no link to the DG transport QRAs.

2.9. Limitations and Exclusions

The QRA focussed on the effects of potential accident scenarios. It did not cover long-term or continuous emissions, or occupational, health and safety issues that may arise from routine plant operations. These are addressed via other mechanisms such as EPA licences and safety management systems.

The exclusions and limitations of this study are summarised in Table 2.2. These are similar to the 2012 QRA approach.

Table 2.2: Study Exclusions and Limitations

Item	Exclusions & Limitations	Remarks
1.	<u>Scope</u> Offsite risk assessment only	The QRA focuses on the hazardous events with the potential to cause offsite impacts (ie outside the BIP boundary). Onsite risk to employees, contractors or any other personnel within the BIP is not assessed in the QRA.
2.	<u>Scope</u> Areas included for assessment	Only sections of the process plant and/or storage which contain significant inventory of hazardous materials were included in the QRA. Excluded facilities / materials are summarised in Table 4.1.
3.	<u>DG Transport Risk Assessment</u>	Transport operations of hazardous materials within the BIP, or to and from the BIP site are generally not covered in the QRA. The exception is that transport of Cl_2 drums within the BIP from BIP Gate 3 to the Chloralkali is included in the QRA for consistency with the Ixom MHF Safety Case and Ixom facility specific QRA.
4.	<u>Risk Criteria</u>	HIPAP4 criteria have been adopted with comparison made at the BIP site boundary. The BIP was formerly a single site owned by ICI and was subsequently sub-divided amongst various operators and for historical reasons the BIP boundary is regarded as the ‘offsite’ boundary for land use planning purposes. Unlike neighbours outside the BIP boundary, the BIP has an integrated management team with representatives of all operators onsite and this includes factors such as interaction between sites for emergency response purposes.

Item	Exclusions & Limitations	Remarks
5	Environmental risk	The main concern relating to environmental risk from accident events is generally with effects on whole systems or populations. Whereas any adverse effect on the environment is obviously undesirable, there are no materials now handled at the chlorine and product plants with significant persistent toxicity or bioaccumulation issues. Environmental risk is excluded from the scope of the QRA.
6	MHF considerations (including: SFARP demonstration, control measure adequacy)	A brief description of relevant risk control measures at the facilities is included in the QRA APPENDIX 2. However the QRA does not include detailed adequacy assessments of control measures or details of assurance of their integrity via the relevant facility operator's safety management system, as this is covered in the MHF Safety Cases.
7	Safety Management Systems (SMS)	All operators have a Safety Management system (SMS) that covers the elements of DPE's HIPAP 9 Safety Management Systems and has been reviewed as part of the MHF Safety Case and by various internal and external audits. The QRA does not attempt to quantitatively account for the quality of the SMS. This is because data used to estimate event frequencies in a QRA is based on historical information from a variety of plants and processes with different standards and designs. It is assumed that these generic failure frequencies apply to installations which have safety management systems corresponding to 'industry practice'. This assumption is believed to be conservative in that it will overstate the risk from modern, well-managed installations.

3. DOCUMENT STRUCTURE

3.1. Contents

The QRA report is structured as follows:

- Summary (Section 1): This is a 'plain English' summary of the QRA process and main results and can be used for discussion with third parties.
- Main Report (Sections 2 to 10): Details of the approach and structure of the QRA and the overall results compared against the risk criteria.
- Informative Appendices: These contain additional details of methodology and main input assumptions (for example a summary of the types of hazardous materials included and hazardous incident scenarios covered in the QRA, meteorological data, population data), and a summary of the main changes since the 2012 QRA.

Note that there is no security sensitive or confidential commercial information included in the QRA report.

3.2. Revision History

This report is the compiled BIP QRA summary document for 2018. It is the final revision (Rev 0) incorporating comments on the draft from DPE, and approved by the BIP operators for release to DPE.

3.3. Confidentiality

Note that some QRA basis information used to prepare the QRA is regarded as security sensitive, for example inventories of hazardous material and locations of these inventories.

As the QRA report will be publicly released, security sensitive information is not provided in this report in accordance with section 14 of the Government Information (Private Access) Act 2009.

4. BIP DESCRIPTION

4.1. Location

The main BIP site occupies approximately 73 hectares, bounded by an industrial area to the north by Corish Circle, to the east by Denison St, to the south by Beauchamp Rd and to the west by the Botany Goods railway line easement. In addition, Qenos owns land to the west of the railway line near Nant St which contains a tank farm.

Note that where the term “site boundary” is used in this report, it refers to the boundary of the overall BIP site.

4.2. Surrounding Land Use

The BIP site is bounded to the north by a general industrial area (as the land adjoining Corish Circle has now been sold as per Figure 4.2), the east by Denison St, the south by Beauchamp Rd and to the west by the Botany Goods railway line easement. The land around most of the BIP site perimeter is zoned commercial and industrial.

The exception is land adjacent to part of the eastern boundary of the BIP site which is zoned residential, with significant residential areas along Denison Street directly opposite the BIP and beyond.

The nearest known sensitive land use is Matraville Public School, approximately 400m to the east of the Denison St BIP boundary.

On the western side, there are residential areas extending west from Stephen Rd. Banksmeadow Public School is located near Stephen Rd, about 650 m southwest of the nearest BIP boundary.

The area around Corish Circle at the northeast corner of the BIP is zoned recreational (Hensley Athletic Field), and beyond this to the north is the large commercial Eastgardens shopping complex. A significant high density residential development is occurring immediately north of Eastgardens on the former British Tobacco site.

A map of the area showing the location of the BIP in the context of its surroundings is presented in Figure 4.1.

4.3. Security and Access

The BIP site is a secure site with extensive security measures to prevent unauthorised access. All vehicle entry controlled through the gatehouse at Gate 3, which is manned 24 hours per day. Additional measures are provided within the individual facilities.

The BIP site is fully fenced and non-operating gates are locked.

There are patrols by security guards and cameras installed around the BIP. Security personnel are site inducted, have a checklist of areas to inspect and report on unusual incidents. In addition, all the plants on the BIP have lighting throughout the night to aid observation.

Personnel gain access to the BIP via Gate 3 or by swipe pass at other gates. Access for visitors must be prearranged.

Visitors to any process areas must be accompanied by an inducted person and report to the relevant control room prior to visiting the plant area.

4.4. Facility Description

There are two main facilities on the BIP producing feedstock for downstream plants:

1. At the northern end of the BIP, the Qenos Olefines plant manufactures ethylene, propylene and co-products by cracking ethane feed supplied to the BIP by pipeline. The ethylene is reticulated around the BIP and used by the Qenos Alkathene and Alkatuff Plants, and the Huntsman Surfactants Plant to produce other materials.
2. At the southern end of the BIP is the Ixom ChlorAlkali Facility. The ChlorAlkali Plant (CAP) uses salt, water and electricity to manufacture gaseous chlorine, caustic soda and hydrogen using electrolysis in a membrane cell plant. All produced chlorine is consumed in the Products Plants, comprising the sodium hypochlorite (Hypo) plant, the hydrochloric acid (HCl) plant and the ferric chloride ($FeCl_3$) plant.

A brief summary of each facility is provided in Table 4.1 and additional details of the processes are provided in APPENDIX 2.

Figure 4.2 shows the approximate operational areas for each main facility.

TABLE 4.1: BIP SITE FACILITIES

Operator	Plant	Description	Included in 2018 BIP QRA?	Included in 2012 QRA?
Qenos	Olefines	Manufactures ethylene from ethane feedstock for use in downstream plants The Olefines facility comprises two main areas - the ethylene production process (referred to as Inside Battery Limits or IBL) where ethane is cracked using steam, and various separation processes recover ethylene and other hydrocarbons - Outside Battery Limits (OBL) which is primarily large hydrocarbon storages	Yes	Yes
	Nant St	Storage of flammable hydrocarbon liquids in bulk atmospheric tanks. Tanks filled by pipeline from Caltex Banksmeadow for Olefines plant start up or receive by products from Olefines.	Yes	Yes
	Alkathene	Manufactures low density polyethylene plastics using a high pressure / low volume continuous reaction process with ethylene as the feedstock. The reaction is catalysed by organic peroxides.	Yes	Yes
	Alkatuff	Manufactures linear low density and high density polyethylene plastics. UNIPOL low pressure" process characterised by relatively small inventories of gaseous hydrocarbons and very low inventories of liquid hydrocarbons. The polymerisation reaction takes place in a fluidised bed reactor into which the ethylene supplied by pipeline from Olefines, hexene, hydrogen, isohexane (ICA), activator and catalyst are injected.	Yes	Yes
	Site Utilities	Supplies electricity, steam, nitrogen etc. to the various plants at the site. (No significant offsite effects)	No	No
Huntsman	Surfactants	Manufactures ethylene oxide from ethylene supplied by Qenos and oxygen from ALA These react in a catalysed reactor to form ethylene oxide for use in downstream Glycols, Glycol Ethers and NIS plants to make a range of materials such as detergents, glycols, surfactants.	Yes	Yes
Ixom	ChlorAlkali Facility	Manufactures chlorine from salt and electricity. All chlorine is used directly in the downstream hydrochloric acid, caustic soda, ferric chloride, and sodium hypochlorite plants.	Yes	Yes

Operator	Plant	Description	Included in 2018 BIP QRA?	Included in 2012 QRA?
	Groundwater Treatment plant (GTP)	Some of the groundwater at and around the BIP is contaminated with chlorinated hydrocarbons (CHCs). The GTP plant treats the contaminated groundwater using a pump and treat (thermal oxidation and air stripping) process.	Yes	Yes
Orica	HCB Repackaging	Repacking of HCB drummed material in closed shed. Occasional use only. (No significant offsite effects)	No	No
Air Liquide (ALA)	Air Separation Plants (ASU)	Air separation units (x 2) manufacturing oxygen and nitrogen. Hydrogen (H_2) trailer storage CO_2 dry ice manufacture using CO_2 from Huntsman. (No significant offsite effects)	No	No
BOC Gases	CO_2 Facility	CO_2 dry ice manufacture (No significant offsite effects)	No	No

FIGURE 4.1: BIP LOCATION (SHOWING AREA ALONG DENISON ST AND CORISH CIRCLE THAT HAS BEEN SOLD)

FIGURE 4.2: BIP OPERATIONAL AREAS

Note: Areas shown are approximate only

5. QRA BASIS

5.1. Overview

Many simplifying assumptions need to be made to prepare a QRA and the results are dependent on the assumptions made in defining the input scenarios.

The BIP QRA has been compiled from the most recent individual facility QRAs as summarised in Table 5.1.

TABLE 5.1: QRA SOURCES

Operator	Plant	Main Source	Comments re requirement for QRA
Qenos	Olefines Nant St Alkathene Alkatuff	Doc ref: *21136-RP-001, 2017* Sherpa Consulting Pty Ltd Quantitative Risk *Assessment for Input To BIP QRA 2017, Botany Manufacturing Facility (Olefines, Alkathene And Alkatuff)*	Updated QRA model 2017. This was prepared specifically for input to the 2018 BIP QRA. Report internal to Qenos.
Huntsman	Surfactants (all plants)	Doc ref: *20934-RP-002, Dec 2015* Sherpa Consulting Pty Ltd *Quantitative Risk Assessment, 2015 Operations, Botany Surfactants Facility*	QRA prepared for MHF licence conditions. Report provided to Safework NSW. Some updates to process specific event frequencies have been made since the 2015 QRA report as part of MHF update work. These updates are included in the BIP QRA. 2015 report has not been updated at time of BIP QRA
Ixom	ChlorAlkali Facility	Doc ref: *21103-RP-001, Oct 2017* Sherpa Consulting Pty Ltd *Quantitative Risk Assessment Report, Chloralkali Facility, Botany Industrial Park Ixom Australia Pty Ltd*	Periodic QRA update required as CA facility condition of consent Report provided to NSW DPE by Ixom.
	Groundwater Treatment plant (GTP)	Doc ref: *Ixom GTP FHA Report Rev F.doc, Dec 2015* Pinnacle Risk Management Pty Ltd *Final Hazard Analysis Groundwater Treatment Plant Ixom Australia Pty Ltd Botany Industrial Park, NSW*	General update after 10 years operation. Report internal to Ixom.

5.2. Summary of Changes since 2012 QRA

The general methodology and approach are similar to the 2012 QRA. Assumptions have been changed only to reflect updated plant operations information or for consistency with MHF Safety Cases. Improved modelling technique such as new versions of software have also been used.

A summary of changes made since the previous QRA together with their potential effect on results is included in APPENDIX 1. Changes are described briefly below.

5.2.1. General Assumptions

Each facility specific QRA has been developed using a similar approach as follows:

- Maximum working capacity for bulk storages was generally assumed (ie DG licence notification quantity for storages). Average inventories will be lower.
- Maximum DG licence quantity for packaged storages (eg chlorine drums) assumed. Average inventories will be lower.
- "Normal" process vessel/isolatable inventory based on normal operating conditions was assumed for in-process inventories.
- Isolatable section inventory is determined as limited by remotely operable (if gas or fire detection in place to provide operator with alarm) or automatically activated shutdown valves.
- Name-plate plant production capacities were assumed (though average production rates may be lower).
- Equipment on-line times were adjusted as relevant to reflect production for batch/campaign-based or seasonal plants. Continuous plants (CAP, Olefines, EO Plant) were assumed to be operational 100% of the time which is a sight overestimate due to periodic major plant shutdowns for planned maintenance.
- Materials handled in minor quantities or with low potential offsite acute impact (e.g. environmentally hazardous materials such as Class 9 materials, Class 8 corrosives, combustible materials at ambient temperature, minor storages of Class 3 materials, isolated gas cylinders etc) are not included in the QRA.

5.2.2. Changes to QRA inputs

Required updates to scenarios included in the QRA compared to 2012 were identified with input from each operator by:

- Review of most recent version of individual facility QRAs.
- Review of any development applications made for facilities within the BIP to determine if there were new hazardous materials or a PHA that identified potential changes to risks.
- Review of MHF safety cases.

There have been relatively few changes to the facility hazardous materials, operating conditions, inventories or equipment since 2012.

Confirmation and update of meteorological data and population data was also undertaken.

5.2.3. Changes to QRA methodology

The initial cumulative BIP QRA model was compiled in 2006 using commercially available software TNO Riskcurves 2.7. This software version was also used to generate results in the form of individual fatality risk, injury and irritation risk, property damage risks and societal risks for the 2012 QRA update. However Riskcurves 2.7 can no longer be run on current Windows operating systems and is no longer supported by the software supplier.

Therefore the current software version, TNO Riskcurves v10 / EFFECTS v10 has been used instead of TNO Riskcurves v2.7/ EFFECTS v5.5 to undertake the consequence and risk modelling. There have been numerous changes and improvements to the consequence models and the risk software, therefore even if no input data changes are made, risk model results will not be identical to previous results.

Significant changes in approach to modelling which have a noticeable effect on consequence or risk results are noted in APPENDIX 1.

5.2.4. Changes to risk criteria and assessment thresholds

The HIPAP 4 risk criteria continue to be used and are unchanged since the 2012 QRA as per Section 2.7.

There have been no changes to the approach for assessing fatality risk since the 2012 QRA.

The approach for assessing toxic injury and irritation risk has been updated to provide a comparison with US EPA Acute Emergency Guideline Levels (AEGLs) (Ref 8) rather than Emergency Response Guideline Levels (ERPGs, Ref 9).

This change has been made as:

- AEGLs are defined for a range of exposure periods from 10 minutes to 8 hours whereas ERPGs are defined for 60 mins only. AEGL (10 mins) more closely reflects the HIPAP 4 toxic injury/irritation assessment criteria of "*a relatively short period of exposure"* compared to ERPGs (60 mins).
- AEGLs as toxic assessment criteria are consistent with the facility MHF safety cases hence provide a more consistent basis for assessing the cumulative toxic injury risk as part of the BIP QRA.
- Riskcurves v10 now allows frequency of exceedance of a toxic dose (non-fatal) to be assessed (which was not possible in Riskcurves 2.7). This means that the duration of exposure (hence dose) can now also be accounted for in the toxic injury/irritation assessment by using an equivalent dose rather than concentration

exceedance only. The previous QRA approach assessed frequency of exceeding a concentration, which is not meaningful when the exposure duration is below the duration defined for the threshold concentration. The equivalent dose approach is regarded as a more realistic methodology.

5.2.5. Changes to surroundings

There has been significant development in the industrial and residential areas surrounding the BIP which is reflected in the population data used in the societal risk calculations.

Orica has subdivided a section of the BIP along Corish Circle and Denison St and sold this land to a third party as shown in Figure 4.1, so the overall BIP boundary in the north east of the site has contracted, with the new boundary shown in Figure 4.2.

5.3. Report restructure

Some of the information used to prepare the QRA is regarded as security sensitive in accordance with section 14 of the *Government Information (Private Access) Act* 2009.

Compared to the previously issued 2012 QRA report, this QRA report document has been restructured to remove any potentially sensitive information.

6. HAZARD IDENTIFICATION

6.1. Hazardous Material Properties

The hazardous materials handled at each plant that are flammable, toxic or both have the potential to result in an offsite risk, hence are considered in the compiled BIP QRA. A brief description of the hazards and relevant physical properties of each material is included in APPENDIX 3.

These flammable materials include ethylene, C3s, C4s, ethylene oxide, propylene oxide, hydrogen and various flammable liquids. As per APPENDIX 1, there have been no new flammable materials introduced. The main acutely toxic materials are chlorine and hydrogen chloride, with smaller quantities of DMDS and mercaptan. Butadiene, EO and PO are both flammable and toxic.

Since 2012, changes in toxic materials are that anhydrous ammonia is no longer used at Olefines (hence is not included in the updated QRA) and chlorine dioxide has been introduced at the GTP so has been included in the updated QRA.

6.2. Hazardous Incident Identification

Potentially hazardous incidents associated with each facility have been identified as part of the individual facility risk assessments. A summary of the incidents included in the QRA for each facility is given in APPENDIX 4. These cover fires, explosions, toxic releases as well as escalated events such as BLEVEs of C3 and C4 storages, and EO decompositions.

6.3. Summary of QRA scenarios

Representative scenarios have been defined for each incident type for inclusion in the QRA. In summary:

- The majority of fire, explosion and escalation (generally BLEVE) scenarios are associated with the Olefines and Huntsman facilities since these plants have the largest flammable inventories on the BIP site.
- A smaller number of fire, explosion and BLEVE scenarios are included for Alkatuff and Alkathene which have relatively small flammable inventories.
- The majority of toxic release scenarios are associated with the ChlorAlkali facility, with a small number (with no offsite fatality potential) also defined for the Qenos Olefines Plant, the Ixom GTP and the Huntsman Surfactants Plant for inclusion in the toxic injury and irritation risk model.

Each type of scenario has a large number of individual quantitative release cases associated with it covering the isolatable plant inventories. There are over 1000 scenarios in total in the QRA model. These are not provided in the BIP QRA report. Assumptions made to define the individual release cases and to perform the quantitative assessment are described in Sections 7 and 8 of this report.

7. CONSEQUENCE ASSESSMENT

7.1. Scenarios

Consequence analysis involves qualitative and/or quantitative review of the identified hazardous incidents to estimate the potential to cause injury or fatalities, damage to property or damage to the environment.

The consequences of the following types of events were evaluated to determine the extent of impact of the identified hazardous scenarios in the BIP facilities:

- Jet fires
- Pool fires
- Flash Fires
- Vapour Cloud Explosion (VCE)
- EO Decomposition
- Internal Explosion (in reactor vessels)
- Boiling Liquid Expanding Vapour Explosion (BLEVE)
- Dispersion of toxic releases

The possible outcomes following loss of containment are described in the event tree shown in Figure 8.1.

7.2. Software

Consequence calculation was carried out using commercially available risk and consequence assessment software, TNO's Riskcurves v10 and Effects v10. The consequence models used within Effects and Riskcurves are documented in the TNO Yellow Book (Ref 10) and supplementary technical manuals for the software.

For flammable liquid tank overfill scenarios, the extent of the flammable cloud envelope and associated overpressure was modelled following the UK HSE Vapour Cloud Assessment (VCA) method, Ref (11). The UK VCA method is an empirical model that can be set up in a spreadsheet and was developed after significant research as part of the incident investigation into the Buncefield incident in 2005. The model provides a means of predicting the distance to the LFL of the cloud and the distance to specified overpressure levels.

7.3. Assumptions for Consequence Models Source Terms

The main assumptions are briefly described in the following sections and a summary table of the approach is provided in APPENDIX 5.

7.3.1. Release Sources

Releases from equipment mechanical leaks was modelled for the hole sizes of 3 mm, 13 mm, 25mm, 50mm and rupture.

Release rates were calculated by Effects from standard flow rate correlations based on the material state, the operating temperature and pressure and hole size defined.

For scenarios where the calculated release rate exceeded a limiting process flow rate, the consequences were modelled using the limiting flow rate (eg maximum production rate, maximum flow through a restriction orifice or control valve).

For releases downstream of a pump, flow rates were restricted to 1.5 x the maximum design flow of the pump.

7.3.2. Flash and Evaporation Rate

In the case of a spill of a pressurised liquefied gas, part of the material will initially flash off and evaporate, with any remaining liquid evaporating at a lower rate due to the cooling down of the liquid spill.

Flash and evaporation rate calculations were performed by Riskcurves with a concrete surface assumed, as all areas are hardstand. In some cases, a maximum pool spreading area was defined based on the plant layout (kerbing or bunding in place).

7.3.3. Maximum Release Inventory

Inventories available for release were generally taken as the maximum vessel capacity for storage vessels, or the normal working inventory within an isolatable section for process systems such as pipelines. Assumptions are summarised in Table 7.1.

TABLE 7.1: INVENTORY LIMITATIONS

Type of System / Scenario	Maximum Inventory Assumption	Comments
Storage vessel, road tanker etc.	Generally maximum working capacity for storage tanks, unless routinely tank managed to a lower level, in which case average volumes used Filled volume for tankers	DG licence notification quantity for storages. Average inventories will be lower
Process system / vessel – isolation / plant shutdown occurs very quickly.	Normal working volume of isolatable section.	Volume converted to mass using normal operating temperature and pressure, (and an average or typical density for multi-component systems).
Process system / vessel – isolation fails.	Inventory calculated from defined release duration (e.g. time to manual isolation) or maximum inventory in un-isolated system (whichever is lower).	Isolatable section inventory is determined as limited by remotely operable (if gas or fire detection in place to provide operator with alarm) or automatically activated shutdown valves
Package stores	Maximum DG licence quantity of packaged material	Packaged storages include chlorine drums and cylinders. Average inventories will be lower

Type of System / Scenario	Maximum Inventory Assumption	Comments
BLEVE	Two thirds of normal working volume of vessel	Allows for partial vaporisation of contents through relief valve which almost always precedes a BLEVE

7.3.4. Release Duration

The release duration is the lesser of the time taken to exhaust the inventory as calculated by Effects, or else the time taken to isolate the inventory from the release location.

For the case where isolation valves operate as required, the maximum inventory available for release is still that within the isolatable section. For a failure case, i.e. if the isolation fails to occur, the amount is limited by the time taken to stop and control a release by some alternative means. For items where isolation is possible, durations of 3 to 60 minutes to isolate a leak from a plant have been assumed. The maximum duration of any scenario is set to 60 minutes.

7.4. Model inputs

7.4.1. Meteorological Data

The 2012 QRA used meteorological data based on the wind and weather data for Sydney Airport (located about 2 km from the BIP) over the period of 1999 –2004. This was not updated for the 2012 QRA.

This meteorological data has now been updated to include hourly observation data from January 2006 to January 2017. An updated representative meteorological data set was consolidated from the overall data for use in the QRA model, as per Table 7.2. Wind direction data and a wind rose is included APPENDIX 7.

TABLE 7.2: METEOROLOGICAL DATA SUMMARY

Pasquill Stability Class	Wind Speed (M/S)	Description
B	2.2	Daytime, moderate wind speed
C	4.5	Daytime, moderate wind speed
D	5.6	Moderate wind speed, split between day and night
D	9.2	High wind speed, split between day and night
E	3.4	Night time and moderate wind
F	1.7	Night time/early morning, low wind speed

7.4.2. Environmental Conditions

The following environmental conditions were used for consequence modelling:

- Ambient air temperature: 20°C
- Relative humidity: 70%.

7.4.3. Topography

Ground roughness affects turbulent flow properties of wind, hence dispersion of a released material. Terrain effects are taken into account to some degree in dispersion modelling by use of a parameter known as surface roughness length.

A surface roughness factor of 1m was used, corresponding to an area with densely located low buildings or an industrial area with low structures such as the BIP. This surface roughness factor is also appropriate for suburban areas adjacent to the BIP.

7.5. Vulnerability

As per the HIPAP 4 criteria in Section 2.7, risk is expressed as either a probability of fatality due to exposure to toxic material, heat radiation or overpressure, or of exceeding a threshold value.

Vulnerability relationships are used to estimate the probability of fatality. Probit equations are used in this QRA together with the threshold levels defined in HIPAP 4 for injury and escalation risk. The vulnerability levels used in the QRA for fires, explosions and toxic releases are summarised in APPENDIX 6.

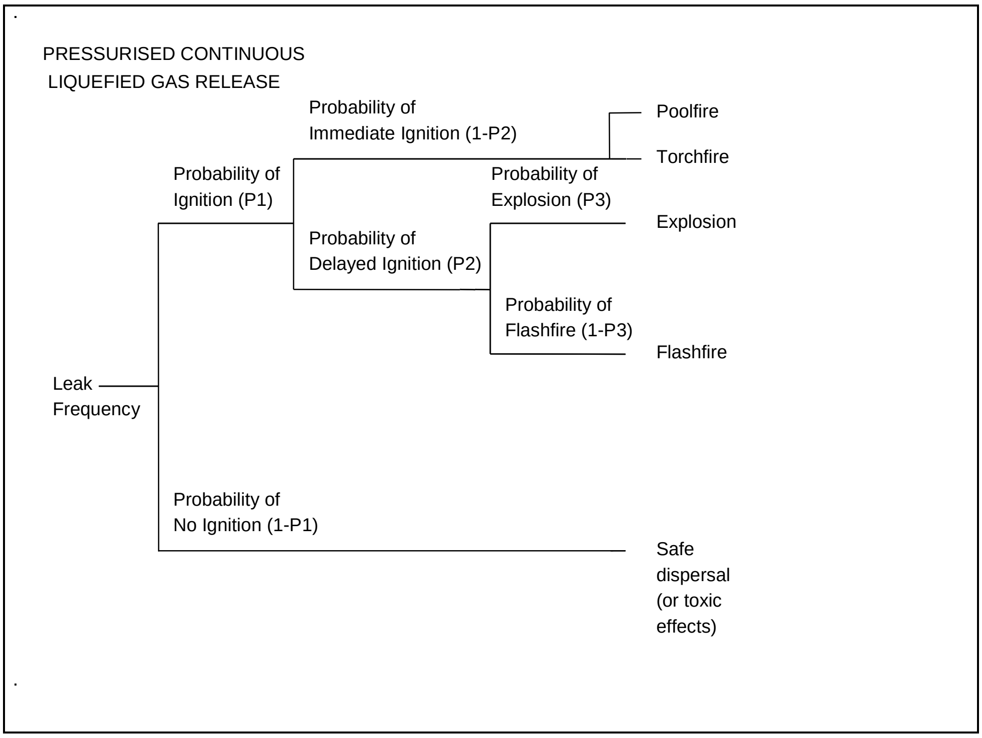
8. FREQUENCY ASSESSMENT

8.1. Overview

The frequency of an event is defined as the number of occurrences of the event over a specified time period; with the period in risk analysis generally taken as one year.

Frequency analysis involves estimating the likelihood of occurrence of each of the identified hazardous scenarios considered in this study and populating event trees developed to characterise the accident pathways and outcomes as per the example below.

FIGURE 8.1: EVENT TREE



8.2. Frequency Input Data

Two main approaches have been used to estimate the frequencies of hazardous events:

1. The likelihood of loss of containment was estimated by counting equipment items ('parts count' from P&IDs) and combining with historical leak frequency data for each equipment type. The main sources of historical leak frequencies used in this study include:
    - UK HSE Failure Rate and Event Data (Ref. 19)
    - OGP's Risk Assessment Data Directory Process release frequencies (Ref.12).
    - Where equipment specific data is available (eg for failures of Cl_2 drums) this is used instead of generic equipment failure data.

2. Frequencies for process specific scenarios were either calculated using event trees or fault tree analysis, or estimated using event specific frequencies from the MHF Safety Case LOPA or bowties.

APPENDIX 9 includes the following input information:

- Historical equipment leak frequencies
- Parts count
- Operational error frequencies
- Ignition probability
- Effect of safeguards
- Online time

Note that minor updates to frequency data inputs have been made compared to 2012 QRA to use consistent statistical data and reflect any operational changes as per APPENDIX 1.

8.3. External Events

There are a number of external events that could cause a leak or explosion at the BIP facilities. These include earthquakes, plane crashes, floods etc. The UK HSE failure rate data for catastrophic vessel ruptures already includes a factor for external events.

Even allowing for the airport a few kilometres away, these are very low frequency events in the Botany area. Therefore, the effect of external events is not quantified in this QRA.

9. RISK ASSESSMENT

9.1. Risk Quantification

Having established the consequence and frequency for each event of interest, risk quantification requires the following calculation for individual incidents which are then summed for all potential recognised incidents.

Risk = Frequency x Consequence

A separate summation is carried out using Riskcurves v10 for each consequence of interest, e.g. injury or individual fatality.

9.2. Risk Presentation

For this QRA, the results of the risk calculations are presented in the following forms:

- **Individual Fatality Risk:** the likelihood of fatality to notional individuals at locations around the site, as a result of the defined fire/explosion and toxic gas release scenarios. This is shown as contours on a map of the area. The units for individual risk are probability (of fatality) per million per year. By convention it is assumed that people are located outdoors, are always present and take no evasive action if an incident occurs. The results are presented cumulatively for all fire/explosion and toxic impacts.
- **Injury and Irritation Risk:** is the likelihood of injury or irritation to individuals at locations around the site as a result of the same scenarios used to calculate individual fatality risk. As for individual risk, evasive action is not allowed for. Results are presented as contours and are shown separately for fire and explosion injury, and toxic injury and irritation impacts, as there are different criteria for flammable and toxic exposures.
- **Escalation/Property Damage:** is the likelihood of property damage occurring to surrounding facilities as a result of exceeding threshold levels of heat radiation or overpressure. Results are presented as risk contours.
- **Societal Risk:** takes into account the number of people exposed to risk. Whereas individual risk is concerned with the risk of fatality to a (notional) person at a particular location (person 'most at risk'), societal risk considers the likelihood of actual fatalities among people exposed to the hazard and allows mitigating effects such as probability of presence, whether they are located inside or outside etc, to be accounted for, hence requires population data as an input.

9.3. Individual Risk Results

9.3.1. Individual Fatality Risk

Figure 9.1 shows the cumulative individual fatality risk contours for the BIP.

Overall, the QRA shows that the cumulative risk from the BIP satisfies all HIPAP 4 quantitative criteria for individual fatality risk as follows:

- The 0.5 x 10^{-6} per year contour extends outside the BIP boundary but does not encroach into any sensitive land uses. (The nearest sensitive land use is Matraville Public School around 400m from the east Denison St boundary. The risk level at the school is well below 1x10^{-8} per year, i.e. more than 50 times lower than the applicable fatality risk criterion.)
- The 1 x 10^{-6} per year risk contour, applicable for residential areas, extends outside the site boundary but does not encroach into residential areas across the eastern site boundary along Denison St.
- The 5 x 10^{-6} per year risk contour, applicable for commercial areas, extends slightly outside the BIP site boundaries in some directions but does not encroach into commercial areas (the nearest is a Bunnings across the eastern BIP site boundary along the northern part of Denison St).
- The 10 x 10^{-6} per year risk contour, applicable for recreational areas, extends slightly outside the BIP site boundaries in some directions but does not encroach into recreational areas (the nearest is the oval at Corish Circle).
- The 50 x 10^{-6} per year contours are entirely within the BIP, satisfying the criterion that this contour be contained within the site boundary for industrial land uses.

9.3.2. Toxic Injury and Irritation Risk

The injury and irritation contours show the likelihood of a threshold concentration being exceeded at a particular location.

Figure 9.4 shows the 10 x 10^{-6} per year cumulative toxic injury risk contour. This contour represents frequency of exceedance of a toxic dose corresponding to the AEGL3 (10 mins) and extends into the residential area to the east of Denison St.

Figure 9.5 shows the cumulative toxic irritation risk contour for the BIP. This contour represents frequency of exceedance of a toxic dose corresponding to the AEGL2 (10 mins). It also extends into the residential area.

9.3.3. Injury due to heat radiation or overpressure

Figure 9.2 and Figure 9.3 show the injury risk contours for heat radiation and overpressure respectively, i.e. potential to exceed 4.7kW/m^2 or 7kPa in residential areas (assuming no mitigating action such as moving away or sheltering from a heat source).

It can be seen that the 50 x 10^{-6} per year contour for the heat radiation is well within the BIP boundaries and does not extend into residential areas. However there is a small encroachment (approximately 30 m) across the eastern BIP boundary into residential areas along Denison St for the overpressure (7kPa) injury risk contour.

9.4. Property Damage - Fire and Explosion

Figure 9.6 and Figure 9.7 show the escalation/property damage risk contours for heat radiation and overpressure, i.e. potential to exceed 23kW/m^2 or 14kPa in neighbouring facilities. These assume no mitigating action to protect any property (e.g. application of cooling water, emergency response etc).

9.4.1. Within BIP

There is no interaction between the escalation risk contours for the Huntsman and Qenos Olefines facilities, for either overpressure or heat radiation impacts, hence the risk of escalation between the major flammable inventories within the BIP is low.

The contours also do not extend to the Chloralkali Facility so the probability of an explosion event resulting in domino event of a toxic gas release is regarded as low and is not quantified.

9.4.2. Outside BIP boundaries

Figure 9.7 showing the escalation/ property damage risk contour for overpressure, (i.e. potential to exceed 14kPa in neighbouring facilities) indicates that the BIP facilities comply with the HIPAP 4 explosion overpressure propagation damage risk criterion, except for a very small encroachment into the south-eastern corner of the ALA site (to the north west of Olefines). The ALA site is a potentially hazardous adjacent industrial installation, where flammable gases such as hydrogen and other Dangerous Goods such as liquid oxygen are handled.

The heat radiation risk property damage contour (23kW/m^2) does not extend to neighbouring hazardous facilities.

9.5. Societal Risk

Societal risk is a measure of the probability of incidents affecting an actual human population (rather than a theoretical individual as in individual risk).

Mitigation, for example the probability of people being inside or outside during a release is therefore taken into account in the risk estimation.

Societal risk results are presented as F-N curves, which take into account the number of people affected by each incident. The curves show the cumulative frequency (F) of fatality to N or more people.

9.5.1. Population Data

Population data has been completely updated since the 2012 QRA (which was based on 2006 Census data). For the 2018 update, data from the 2016 Census was obtained from the Australian Bureau of Statistics (ABS) and used as the basis for defining the population data around the BIP site. Two population cases were assessed:

1. ‘Current case’ based on 2016 Census data.
2. ‘Approved development’ case which represents Census 2016 populations plus population estimates for developments that have been approved around the BIP but are not yet occupied or were likely to be occupied only after the collection date of the 2016 Census. This includes the BIP subdivision on Denison St and Corish Circle,

Bunnings on Denison St opposite the BIP, and the Meriton redevelopment of the former tobacco sites adjacent to Eastgardens. The populations assumed for these developments are thought to be conservative estimates, ie likely to overestimate the populations once occupancy commences.

As per previous QRAs for the BIP site, the following assumptions have been applied to populations:

- 10% of the population during the day outdoors (with daytime being between the hours of 7 am to 7 pm)
- 5% of the population outdoors at night.
- By convention for societal risk calculations, the population on the site that is the source of risk is not included in the total population. For calculation of societal risk, the population on the BIP site is not included in the population. This convention was agreed between Orica and DPE during discussions at the time of the initial BIP site subdivision and is consistent with all previous QRAs.

Refer to APPENDIX 8 for further details of the population data used.

9.5.2. Mitigation taken into account

Mitigation factors are accounted for in societal risk calculations as follows:

- population probability of presence as per factors in APPENDIX 8.
- protection factors for indoor populations from radiant heat and toxic exposures as per APPENDIX 6 Section A.6.4.

9.5.3. Societal Risk Results

Figure 9.8 shows the societal risk results compared against the indicative HIPAP 4 societal risk criteria.

- The societal risk is in the ALARP zone. It does not extend into the “intolerable” area.
- There is an approximately proportional reduction in frequency as the number of fatalities increases, i.e. the frequency of 10 fatalities is around one order of magnitude (i.e. a factor of 10) lower than the frequency of 1 fatality, and the frequency of 100 fatalities is around one order of magnitude lower than the frequency of 10 fatalities.
- For the ‘approved development’ case the limit of N<1000 in the HIPAP 4 indicative criteria graph is exceeded at the boundary of the ALARP/negligible region (N is approximately 1180). Whereas for the ‘current case’ the maximum N is approximately 850 (ie below 1000) at the boundary of the ALARP/ negligible region as shown by the dotted line on the graph.

9.6. Comparison with 2012 QRA

Table 9.1 shows a summary of all categories of risk compared with the relevant criteria. It can be seen that the cumulative risk levels from the BIP comply with all individual fatality risk criteria.

The individual fatality risk results are very similar to the results of the previous QRA as noted in the last column of Table 9.1. Comparative contours to the 2012 QRA results are shown in APPENDIX 10.

There are some differences in the toxic injury/irritation risk contours, ie a reduction in size in the 2018 results. The main reason is that the assessment methodology now represents frequency of exceeding a toxic dose (ie accounts for exposure duration) rather than frequency of exceeding a concentration (the previous QRA approach, which includes affected areas even if exposure duration is below the 10 minute duration defined for the selected AEGL endpoint).

The societal risk is higher than the 2012 QRA due to two main factors:

1. Increased populations around the BIP.
2. Change in modelling approach for some low frequency worst case events such as BLEVEs and catastrophic ruptures and associated dispersion modelling. This is not noticeable in the individual fatality risk result as the frequencies of these events are low (ie well below the HIPAP 4 individual fatality risk criteria values).

FIGURE 9.1: CUMULATIVE INDIVIDUAL FATALITY RISK, BIP

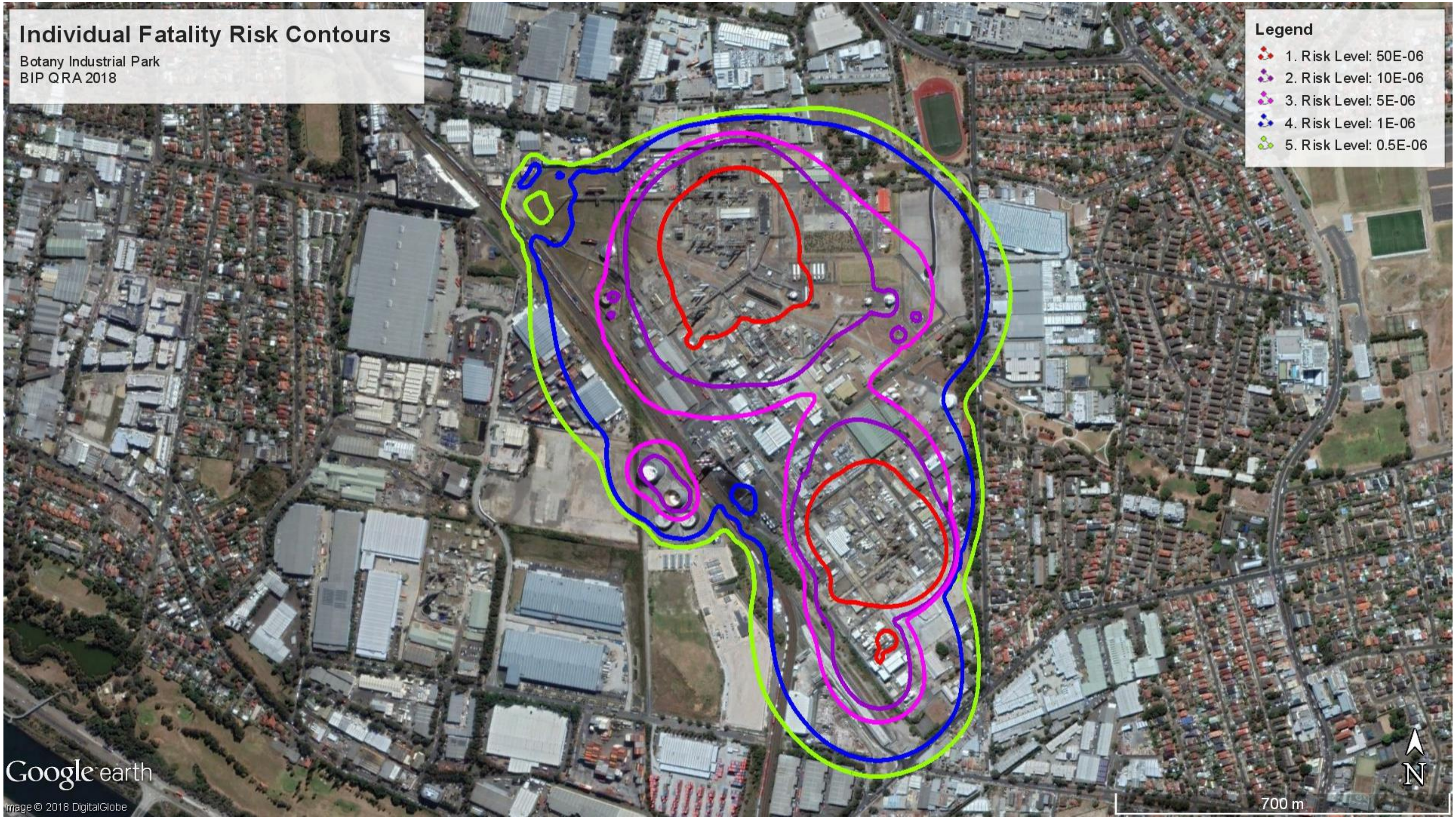


FIGURE 9.2: CUMULATIVE INJURY RISK, HEAT RADIATION EXCEEDING 4.7 KW/M[2] BIP

FIGURE 9.3: CUMULATIVE INJURY RISK, OVERPRESSURE EXCEEDING 7 KPA, BIP

FIGURE 9.4: CUMULATIVE TOXIC INJURY RISK, BIP

FIGURE 9.5: CUMULATIVE TOXIC IRRITATION RISK, BIP

FIGURE 9.6: CUMULATIVE ESCALATION RISK, HEAT RADIATION EXCEEDING 23 KW/M[2] BIP

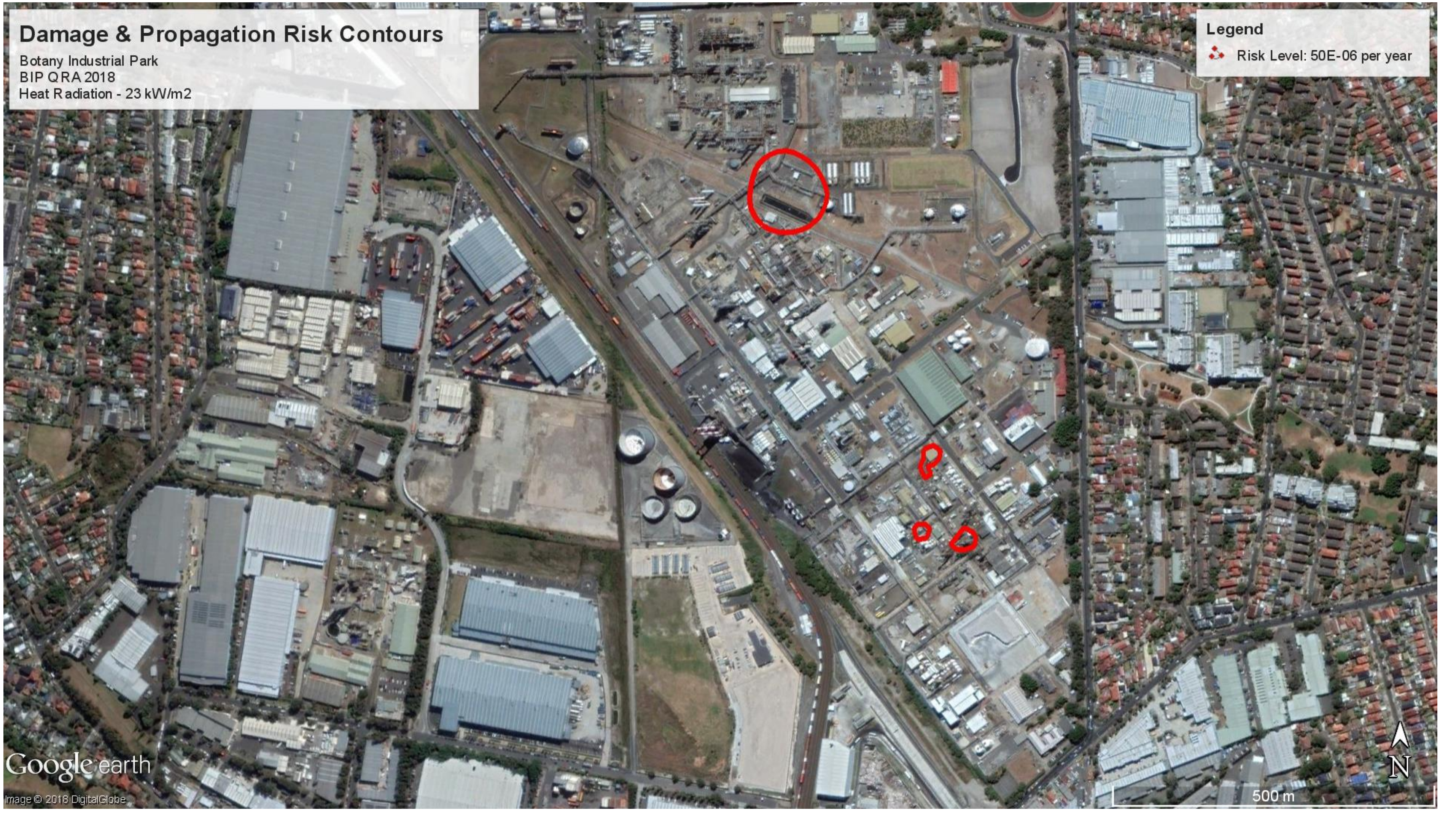


FIGURE 9.7: CUMULATIVE ESCALATION RISK, OVERPRESSURE EXCEEDING 14 KPA, BIP

FIGURE 9.8: CUMULATIVE SOCIETAL RISK, BIP

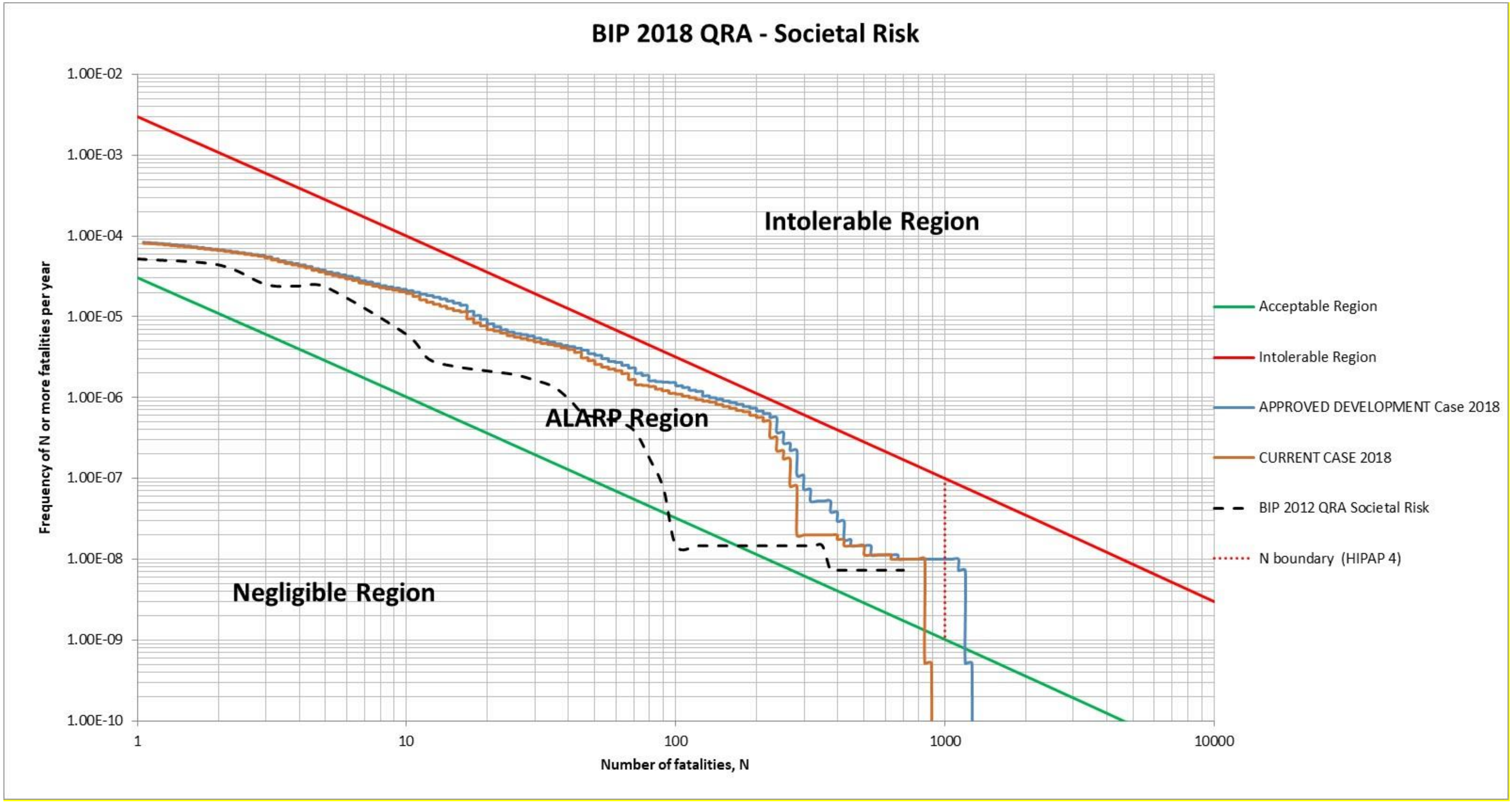


TABLE 9.1: COMPARISON OF RESULTS WITH RISK CRITERIA

Description	Risk Criterion (per year)	Risk Criteria Met	Comments	Comparison with 2012 QRA
Individual Fatality Risk				
Sensitive uses, including hospitals, schools, aged care	0.5 x 10^{-6}	Yes	Contour extends by a small amount across BIP boundaries but is not near any sensitive uses (Matraville Botany Public School (Beauchamp Rd around 400m away). Complies with criteria.	Similar to previous contours.
Residential areas and hotels	1 x 10^{-6}	Yes	The 1x 10^{-6}/yr contour extends across west and south BIP boundary but does not encroach on any residential uses Complies with criteria.	Similar to previous contours. No longer encroaches into housing in southern part of Denison St.
Commercial areas, including offices, retail centres, warehouses	5 x 10^{-6}	Yes	Does not reach the nearest commercial developments (Various commercial businesses in Denison St to the east). Complies with criteria.	Similar to previous contours.
Sporting complexes and active open spaces	10 x 10^{-6}	Yes	Does not reach any open space uses. Complies with criteria.	Similar to previous contours.
Contained within the boundary of an industrial site	50 x 10^{-6}	Yes	Does not extend outside BIP or Nant St site boundaries. Complies with criteria.	Similar to previous contours. Previously extended outside Nant St boundary.
Fire / Explosion Injury Risk				
Heat radiation exceeding 4.7 kW/m^2 (residential and sensitive areas only)	50 x 10^{-6}	Yes	Within BIP boundaries Complies with criteria	Smaller than previous results. Largely due to a change in ignition probabilities assumed which have reduced for smaller / medium releases.

Description	Risk Criterion (per year)	Risk Criteria Met	Comments	Comparison with 2012 QRA
Overpressure exceeding 7 kPa (residential and sensitive areas only)	50×10^{-6}	No	Small encroachment into residential area along southern part of Denison St.	Similar to previous results.
Fire / Explosion Escalation Risk				
Heat radiation exceeding 23 kW/m^2 (neighbouring hazardous facilities)	50×10^{-6}	Yes	Within BIP boundaries Complies with criteria	Smaller than previous results Largely due to a change in ignition probabilities assumed which have reduced for smaller / medium releases.
Overpressure exceeding14 kPa (neighbouring hazardous facilities)	50×10^{-6}	No	Small encroachment outside Olefines on northern BIP boundary into neighbouring hazardous facility	Similar to previous results.
Toxic Injury / Irritation Risk				
Injury (residential areas only)	10×10^{-6}	No	Extends from the BIP into residential areas to the east.	Contour is slightly smaller due to change in approach to assessing frequency of exceeding AEGL3 (10 min) equivalent dose rather than ERPG3 concentration
Irritation (residential areas only)	50×10^{-6}	No	Extends from the BIP into residential areas to the east.	Contour is significantly smaller due to due to change in approach to assessing frequency of exceeding AEGL2(10 min) equivalent dose rather than ERPG2 concentration
Societal Risk				
Populations external to BIP	HIPAP 4 (2011) indicative societal risk criteria	Not intolerable	Results curve within ALARP area for all N for both 'approved development' case and 'current case'.	Societal risk is higher. This is largely due to increase in populations but is also due to change in Riskcurves modelling which have the effect of increasing effect distance of some worst case low frequency events.

10. CONCLUSIONS

10.1. Overview

An updated cumulative QRA has been prepared for the BIP site. This supersedes the 2012 QRA results. The study covered:

- Review of the hazardous incidents included in the QRA based on the most recent individual facility risk assessments. The hazardous materials, inventories and operating conditions are similar to the 2012 QRA. A summary of main changes and a brief description of likely significance to risk results has been provided in APPENDIX 1.
- Updating the meteorological and population data.
- Building a new QRA model in the most recent software TNO Riskcurves version 10. There are many changes in this version compared to the version (v2.7) of the software used in the previous 2006 and 2012 QRAs. It was not possible to continue to use the older version of the software as it was no longer compatible with current Windows operating systems.

10.2. Results

The QRA found that

- Individual fatality risk levels comply with all relevant HIPAP 4 fatality risk criteria. Risk levels are similar to those assessed in the 2012 QRA revision, with slightly lower risk levels along the southern end on Denison St such that residential risk contour no longer extends to the housing (compared to a small encroachment in the 2012 QRA).
- The heat radiation injury risk contour and escalation risk contours comply with criteria.
- The toxic injury and irritation contours extend to residential areas along Denison St as per the 2012 QRA however they have reduced in size slightly. This is largely due to change in modelling techniques, not changes in the input scenarios.
- There is a small encroachment of the overpressure injury risk contours into residential areas along Denison St and of the overpressure escalation contours into potentially hazardous land uses. This is similar to the previous QRA results.
- The societal risk remains in the ALARP region, however has increased. This is largely due to increased population in the area as well as some changes in modelling approach within Riskcurves.

Overall, when considering the individual risk results, these are reasonably low and similar to the 2012 QRA. Societal risk results are also in the ALARP region which indicate the risk is not unacceptable but that it is not negligible. Any further increases in population outside the land uses included in the model would continue to increase the societal risk.

10.3. Recommendations

The risk level generated from the BIP facilities remains very similar to previous years, and as demonstrated in the operator MHF Safety Cases for each facility, control measures are in place that reduce the risk So Far As Reasonably Practicable (SFARP).

Therefore there are no recommendations made in relation to additional control measures as part of the QRA update.

APPENDIX 1. CHANGES COMPARED TO 2012 QRA

This section summarises the main changes compared to the 2012 QRA and potential effect on QRA results.

- Section A.1.1 covers changes to facility specific inputs such as addition/deletion of hazardous materials or significant change to definition of incident scenarios. Minor changes eg to process conditions are not noted as they have minimal effect.
- Section A.1.2 covers general changes in approach on overall QRA model input data. There have been many changes so it is not possible to quantitively isolate the effect on each change in method individually so qualititave comments only are provided.

The net effect is that individual fatality risk results are very similar to the previous 2012 QRA however the societal risk has increased noticeably. This is due to two main effects:

- an increase in population in all areas surrounding the BIP
- an increase in effects distance for some low probability but high consequence events such as vessel rupture and BLEVE due to some model changes within Effects / Riskcurves.

A.1.1. Changes to QRA Basis specific facility inputs

Operator	Plant	Hazardous Materials	Operations	Incident Scenarios	Comments
Qenos	Olefines	Anhydrous ammonia (for water treatment) no longer used	DMDS now handled in IBCs not drums	Ammonia leaks deleted DMDS change has significantly reduced handling compared with drums so error / leak frequency reduced	Reduced toxic injury / irritation risk around Olefines
	Nant St	No changes	No changes	Buncefield scenario for tank overfill and vapour cloud (naphtha / gasoline) added using UK HSE VCA method (Ref 13).	This scenario wasn't included in 2012 model. Change in risk contour in west of BIP site
	Alkathene	No changes	1 reactor decommissioned	Minor change to incident frequencies	No effect on offsite risk
	Alkatuff	No changes	Hydrogen trailer storage added in 2013 (replaced H_2 piped supply from ALA)	Added H_2 fire / explosion scenarios	No effect on offsite risk
Huntsman	Surfactants (all plants)	No changes	Several NIS A reactors decommissioned	Minor change to incident frequencies	No effect on offsite risk
Ixom	ChlorAlkali Facility	No changes	No changes	No significant changes	No effect on offsite risk
	Groundwater Treatment plant (GTP)	Chlorine dioxide added for control of biofouling in air strippers	No changes	Added ClO_2 leak scenarios	No effect on offsite risk
Other	Pipelines within BIP	Ethylene Ethane Propane (for C3s) Flammable liquid	No changes	Added pipeline leak / fire / explosion scenarios.	These weren't included in 2012 model. Change in risk contour in west of BIP site

A.1.2. Changes to methodology or overall inputs

Item	Description	2012	2018	Effect on Risk
External	BIP Boundary change	Along Denison St and Corish Circle	Now to west of Orica subdivision See Figure 4.1	Boundary is now closer to Qenos especially OBL area covering large flammable inventories ethylene and C3/C4 storage area. Population in this area increases societal risk (was previously set to zero as land was part of BIP).
	Populations	2006 Census 2010 projections used	2016 Census Plus known new developments such as Bunnings, BIP subdivision See APPENDIX 8	Generally higher populations in all areas around the BIP so cumulative societal risk is higher.
	Met data	2002 – 2008 B3.0, C4.1, D3.6, D7.7, E3.7 and F2.	Jan 2006 to Jan 2017 B2.2, C4.5, D5.6, D9.2, E3.4 and F1.7. See APPENDIX 7	Minor changes to directional averages and average windspeeds. Slightly changes shape of contours for low endpoint toxic injury / irritation risk Not significant.

Item	Description	2012	2018	Effect on Risk
Software	Version	Riskcurves 2.7, some external conseq modelling from ALOHA for toxics (This version had been retained for consistency with the 1999 CAP FHA up until the 2012 QRA, but can no longer be used with current Windows operating systems)	Latest version Riskcurves 10.0.6 (incorporates Effects 10)	A lot of model changes: eg Dynamic BLEVE, different view factor calculations, DIPPR material database instead of YAWS, updates to SLAB dispersion model. General effect is: - slight increases in consequence distances in far field for most explosion and BLEVE models, tends to also increase the societal risk as low frequency / high consequence effect distances (eg for BLEVEs) are larger. - slight decrease in far field for low end points for toxics (affects the irritation/injury rather than fatality levels) - slight increase in heat radiation effects for some types of fire (due to change in view factor)
Release scenarios	Size of release	25mm,50mm, RUPTURE	Added 3mm hole size for consistency across all QRAs	No effect on BIP boundary risk
Consequence	BLEVE modelling	Static BLEVE Model	Dynamic BLEVE model - accounts for changing view factor as fireball rises - predicts slightly greater effect distances than static model	Small increase in consequence, very minor increase in risk contours size at $1x10^{-6}$ per year level (if everything else stayed the same) Tends to also increase the societal risk as low frequency / high consequence effect distances (eg for BLEVEs) are larger
	Toxic Dose	Numerical integration of toxic dose	Numerical integration of toxic dose (smaller step sizes) more accurately accounting for exposure duration	Reduces toxic dose for short duration releases Overall reduces the fatality effect distances for toxics (relevant mainly to Choralkali facility).

Item	Description	2012	2018	Effect on Risk
Vulnerability	Toxic Injury / Irritation thresholds	Based on HIPAP 4 and TNO Purple Book probits for Fire/explosion and all fatality ERPGs and AEGLs (60 min) for toxic injury / irritation	No change to fatality approach r fire / explosion injury / damage Toxic injury/ irritation thresholds have been changed to AEGL3/AEGL2 equivalent dose rather than ERPG3/2 concentration.	AEGL more closely aligned with "short exposure duration" definition for toxic injury in HIPAP4. AEGLs generally higher values so reduced toxic injury / irritation contours Accounting for duration has the most effect on short duration scenarios and low endpoints (essentially reduces irritation risk effect distance the most).
	Indoor Toxic Dose	Modified probit to account for reduced dose experienced indoors (Fielding Ref 14)	Method for estimating toxic dose is now based on ventilation rate as this is available within the software. The ventilation rate method accounts for exposure duration more accurately, the modified probit tends to overestimate the dose for shorter exposure / shorter release durations.	Reduced exposure to toxic dose for indoor populations (applicable mainly to Choralkali facility scenarios). No noticeable effect on overall cumulative societal risk as this is dominated by fire / explosion scenarios.
Frequency	Generic equipment leaks	A mixture of sources	UK HSE largely	Consolidated to UK HSE for parts count, supplemented by OGP data.
	Process specific events	As per fault trees	Generally revised as per MHF Safety Case bowties and LOPAs	Generally, these events have changed in frequency but in a relatively minor way (ie generally down or approximately the same although for a small number of event there has been a reduction of an order of magnitude)

Item	Description	2012	2018	Effect on Risk
	BLEVE frequency	0.7 of all Ruptures frequencies were added as BLEVE	Scenarios that can impact a target (based on conseq to 23kW/m^2 reaching the target). The un-isolated frequency adjusted by a directional factor (divided by 6) is a potential initiated for a BLEVE	No specific pattern some inventories higher some lower. Still in similar escalated event range of 10^{-7} to 10^{-9} per year per inventory.
	Ignition	Various from DNV Safeti, Purple Book, Cox	Consolidated to Cox Lees and Ang, plus going to ignition probability of 1 for massive releases such as F349 rupture	Cox Lees and Ang is generally a bit lower than Purple Book, small reduction in frequencies of ignited events for continuous leak ignited events, increase in frequency for worst case rupture type events. Generally reduces radiant heat risks.
	Parts count	As per PIDs and online times	As per PIDs and online times (as revised) If equipment has been decommissioned, parts count reduced accordingly New equipment (very few items as per previous table) included as needed	Relatively minor

APPENDIX 2. FACILITY DESCRIPTIONS

This appendix provides a brief description of each main facility on the BIP.

A.2.1. Qenos Olefines Process

The Olefines facility comprises two main areas, the ethylene production process (referred to as Inside Battery Limits or IBL) and other areas, referred to as Outside Battery Limits (OBL).

A 2.1.1. Ethylene Process (Inside Battery Limits)

The following major equipment items are within the IBL process area:

- Cracking furnaces manufacturing ethylene and other hydrocarbons, normally using ethane feedstock, and associated quenching towers.
- Gas compressors and associated heat exchangers and vessels.
- Gas separation area (consisting of a number of distillation columns and ancillary equipment) which separates the different products of the cracking furnaces.
- Dimethyl disulphide storage and pumping for cracking furnace dosing.

In the ethylene manufacturing process, ethane feedstock is diluted with steam and thermally cracked in tubular pyrolysis furnaces to yield a mixture of ethylene, ethane, propylene, butadiene, gasoline, fuel gas and fuel oil. Residual ethane is recycled and recracked; other materials leave as products[1]. The gases leaving the furnaces are rapidly cooled and quenched with circulating oil and then with water to condense the heavier products. The furnace effluent gas after quenching is washed with caustic to remove acid gases and then condensed prior to cryogenic distillation which separates the various components of the cracked gas.

Ethylene, recovered at a purity of greater than 99.9%, is mainly used in the Qenos polyethylene plants (Alkatuff and Alkathene Plants) and Huntsman Surfactants plant on the BIP. Some ethylene gas is distributed to offsite customers via pipeline. It is also possible to import or export liquid ethylene via Port Botany.

A 2.1.2. Olefines Outside Battery Limits

The following major equipment items are outside the main ethylene manufacturing process, and are referred to collectively as OBL (Outside Battery Limits):

- C3 splitter area which purifies refinery grade propylene (RGP) from the IBL gas separation area and imported feed into polymer grade propylene (PGP) and propane.

[1] All the furnaces can crack LPG so this can be used if ethane feedstock is unavailable. Propane and C4 product may also be re-cracked if required.

- Emergency gas disposal (comprising a ground furnace and elevated flare).
- Storages including refrigerated ethylene, propane, polymer grade propylene and C4 hydrocarbons.
- Ethyl mercaptan storage and odorising facility for dosing propane while it is being loaded into LPG tankers.
- Loading bay for loading tankers with LPG (odorised propane), polymer grade propylene and other hydrocarbons.
- Nant St storage tanks, two tanks of which are currently leased to Mobil.
- Olefines pipelines on the BIP, including pipelines conveying:
  - ethane to Olefines
  - refrigerated liquid ethylene to and from the ethylene sphere
  - ethylene gas from the ethylene sphere
  - ethylene gas to offsite customers
  - RGP to the Olefines C3 splitter.

RGP is imported by road tanker. Together with smaller quantities of byproduct propylene from the Olefines operations, this is purified in the plant area known as the "C3 splitter". The main product is Polymer Grade Propylene (PGP) which is loaded into LPG tankers for export by road to external customers. Byproduct propane and other hydrocarbons from this operation and from the Olefines Plant are also exported by road tanker and sold as LPG.

A 2.1.3. Other

The following pipelines external to the BIP boundary connect the Olefines plant with Port Botany. The sections external to the BIP are not included in the QRA.

- ethylene gas line for import or export of ethylene
- a propane/butane pipeline for backup feedstock transfers (used occasionally).

A 2.1.4. Olefines Design Safety

Technical safety measures used to limit potential hazards associated with the chemicals are summarised as follows:

- Critical duty piping (potential flashing hydrocarbon release exceeding 15 te) were identified in the ethylene plant design and robustly designed; they are routinely monitored to ensure integrity. In the QRA, generic pipework frequencies of failure for these sections of critical piping were reduced by a factor of 10.
- The number of flanges (joints) has been kept to a practical minimum in flammable fluid pipelines, reducing the potential leak sources as far as practicable. For this QRA, the pipeline and joint failure frequencies used are based on the length of piping and number of joints as per the P&IDs and layouts.

- Critical instruments and loop components for selected high-risk plant areas have been graded using industry-standard guidelines. Where protective systems have been accounted for in the QRA (e.g. a trip / shutdown function), the current specified maintenance frequency has been used to assess the reliability of the system.
- There is a dedicated high integrity safety instrumented system (SIS) which automatically shuts down critical sections of the plant if an unsafe condition is detected. Where the SIS has been included in an assessment of protective systems, it is assumed that a SIL 3 reliability is achieved.
- There are two large furnaces or flares (the ground flare and the elevated flare) which are designed to safely combust excess hydrocarbons from relief systems and emergency valve operations, so that inventories of hydrocarbons can quickly be emptied from the plant vessels in an emergency shutdown. This has not been specifically accounted for in the QRA.
- Remotely or automatically operated emergency isolation valves are installed on selected vessels, pump suction lines and pipelines to limit the quantity released should a leak occur. In the QRA these have been assumed to operate at a reliability assessed using the current specified maintenance frequency and generic EIV failure data.
- High integrity double mechanical seals are installed on many pumps handling flashing hydrocarbon fluids (accounted for in QRA by choice of seal leak frequencies).
- Non-return valves are fitted on the discharges of all pumps handling flashing hydrocarbon fluids to minimise backflow from the destination vessel in the event of a serious pump LOC. Where NRVs were fitted, the inventory used in the QRA for pump failures was the supply vessel to the pump, not the destination vessel.
- Plant storages where hazardous liquid spills can occur are bunded. In the QRA, for liquid spills into a bund, the available surface area of the bund was the maximum available surface area for a fire or for evaporation.
- Mechanical excess flow valves (XSFV) are installed on the main discharge line from the C4 sphere F178, the filling hose lines at the LPG tanker loading bay, and the LPG tanker. These are designed to shut immediately if there is unexpectedly high flow through the valve such as would be caused by a serious line failure. In the QRA these have been assumed to operate for leak scenarios with a flow greater than the XSFV setting, at a reliability assessed using generic XSFV failure data.
- Gas detectors are located throughout the site which would initiate an alarm and alert personnel in case of a flammable hydrocarbon release (used in setting release durations).
- Fire sensors near many vessels will stop the discharge pumps and shut vessel discharge valves to the pump suction automatically in the event of fire. This is not

specifically accounted for in the QRA except to set leak durations for the case where EIVs operate as designed.

- The ethylene sphere is protected by passive fire protection, a firewater deluge system and a steam curtain to aid dispersion of ethylene gas following a leak, (steam curtain is not accounted for in QRA).
- Major storages of flashing hydrocarbons and the associated pumps are protected by automatic fire deluge systems, (not specifically accounted for in QRA, except in BLEVE likelihood calculations).
- Firewater monitors are placed at strategic points for firefighting, (not specifically accounted for in QRA).
- A steam curtain can be generated to prevent escaping hydrocarbons in eth Olefines process areas reaching the cracking furnaces and igniting, (not specifically accounted for in QRA).

A.2.2. Qenos Alkathene Facility

A 2.2.1. Alkathene Process

The Alkathene plant produces polyethylene using a high pressure continuous reaction process with ethylene as the feedstock. The reaction is catalysed by organic peroxides. The plant consists of four parallel production trains. Units 1 and 2 were built in 1957, Unit 3 in the early 1960s, and Unit 4 in 1984. Reactor drench systems designed to prevent aerial decompositions were installed in the early 1980s.

One reactor has been decommissioned since 2012.

In each unit, ethylene is compressed in two stages, firstly up to 25 Mpa, and then to the reactor operating pressures of approximately 120 MPa to 160 MPa. The reaction takes place continuously in a stirred cylindrical vessel of approximately 500 L capacity at an average temperature of 250^{0}C. Catalysts (initiators) are injected into the reactor vessel by catalyst dosing pumps.

The polymerisation of ethylene is exothermic. Decomposition reactions are a known process hazard. The heat of reaction is carried away with the gas/polyethylene mixture leaving the vessel. On average, about 18% of the ethylene is converted to polythene. The remaining gas is recirculated.

The mixture of gas and polyethylene from the reaction vessel passes through a product cooler and into the separator, from where much of the gas returns to the 25 MPa system to be cooled and re-compressed, and recycled to the reactor.

The polyethylene is let-down to a low pressure hopper at approximately 100kPag, where nearly all the remaining gas is separated.

Product is removed from the hoppers gear pump or screw extruder which extrude the polyethylene through a die-face cutter which produces small granules. The granules are stored in silos. They are then despatched in bulk containers.

A 2.2.2. Alkathene Design Safety

The Alkathene plant is designed in a modular fashion to reduce the flammable inventory in each reaction train.

- Each reaction train has a separate compressor bay and a separate high pressure reaction bay (each containing a reactor, separator and cooler). The ethylene inventory for each reaction train is approximately 1400kg. Each reactor bay is shielded by concrete blast walls to minimise the extent of damage if an explosion does occur.
- Each reaction unit is provided with an Emergency Shutdown system (ESD system). For the QRA, this is assumed to always operate to limit the maximum release inventory to 1400kg.
- High pressure / high temperature process equipment is also separated from bulk storages, utilities and polyethylene product handling areas.
- A water drench system is provided for each reactor to prevent ignition of the hydrocarbon gas released to atmosphere from the reactor if the burst disc ruptures (i.e. prevent an aerial decomposition by quenching the hot carbon particles produced in a decomposition in the reactor). This system has been proven in practice to considerably reduce the chances of an aerial decomposition following a reactor burst disc release.
- There are 6 ethylene gas detectors in each high pressure reaction bay, and 6 in each compressor bay. These raise an alarm in the control room but do not automatically initiate any emergency measures. There are also gas detectors in the propane storage area. (Not specifically accounted for in QRA).

A.2.3. Qenos Alkatuff Facility

A 2.3.1. Alkatuff Process

The Alkatuff plant manufactures polyethylene products known as Linear Low Density polyethylene (LLDPE) and High Density polyethylene (HDPE), using a fluidised bed reaction system. The process (UNIPOL™) is licensed from Univation (formerly known as Union Carbide Corporation (UCC)). The UNIPOL™ process, compared to conventional polyethylene plants, is a "low pressure" process characterised by relatively small inventories of gaseous hydrocarbons and very low inventories of liquid hydrocarbons.

The polymerisation reaction takes place in a fluidised bed reactor into which the ethylene supplied by pipeline from Olefines, hexene, hydrogen, isohexane (ICA), activator and catalyst are injected. The reaction takes place at a moderate temperature (around

100°C) and pressure (up to 2400kPag). A recycle gas flow is used to cool the reactor and is maintained by a single stage centrifugal recycle gas compressor, provided with an elaborate labyrinth seal to protect against recycle gas leakage. The overall reaction and cycle gas system pressure is modulated by the control of the incoming ethylene feed rate. The reaction rate is controlled by catalyst addition rate.

Polyethylene resin is produced. This is purged with nitrogen to remove residual hydrocarbons, extruded and cut up to form granules which are stored and loaded into road tankers for bulk delivery to customers.

A 2.3.2. Alkatuff Design Safety

The main means of achieving process safety is tied to choice of technology. The process is continuous, fluidised bed and gas phase.

- The largest hydrocarbon inventory in the process is in the reactor/cycle gas process (4.2te hydrocarbon, about 6.3te in total including inerts), with the ethylene and hexene purification systems containing a total of about 2.8te hydrocarbon.
- Emergency isolation valves (EIVs) are provided at the main ethylene feed, at each feed into to the reactor/cycle gas system and at each pump, i.e. the hexene and isohexane (ICA) charge pumps and the tanker unloading bay.
- Various process trips (including high pressure and high temperature in the reactor or feed purification system) initiate shutdown and isolation of the reactor, and automatic blowdown to the emergency flare. To stop the reaction on emergency shutdown a catalyst poison is injected into the reactor.
- The plant is provided with a dual purpose flare system which functions as a continuous ground flare during normal operations and as an emergency flare under pressure relief conditions. During a major plant upset (i.e. reactor/cycle gas PSV relief or ESD initiation) pressurised areas of the plant are relieved to the emergency flare. The pressure relief system is sized to remove the largest hydrocarbon inventory in 5 minutes. Pressure vessels are provided with appropriately sized relief valves which relieve to flare.
- Gas detection is provided at specific potential leak points in areas including the cycle gas / reactor system at the compressor seal and expansion joints area and at various levels of the reactor structure (grade and catalyst injection platform), hexene purification area and hexene reactor charge pump, isohexane reactor charge pump, unloading bay and storage areas, and the polyethylene product bins vapour space. Generally, there is no automatic shutdown on gas detection (with the exception of tripping the electric drier regeneration heater).

A.2.4. Huntsman Surfactants Facility

Ethylene oxide (EO) is produced in the EO plant and is then used in the following derivatives plants:

- The Glycols Plant
- The Glycol Ethers Plant
- The Condensates Plants (NIS A, B and C).

Some of the derivatives produced by the plants listed above are then used as feed to the Multi-Purpose Plant (MPP) and Specialties Plant.

A 2.4.1. Ethylene Oxide Plant

In the presence of a silver catalyst, ethylene and oxygen react to form ethylene oxide. Carbon dioxide and water are also formed in a parallel reaction along with trace quantities of acetaldehyde.

The reaction takes place by passing a combined make-up/recycle gas stream containing ethylene, oxygen and inert gases through a shell and tube reactor. The pressure at the reactor inlet is approximately 2000kPag and the gas temperature at the reactor outlet ranges from approximately 245ºC with new catalyst to 280ºC with old, less active catalyst. The heat of reaction is removed by a recirculating heat transfer oil.

The conversion of ethylene in each pass is not complete, so the exit gas is recycled following removal of firstly ethylene oxide and then carbon dioxide by dissolution in water and potassium carbonate liquor, respectively. The ethylene oxide is purified by a series distillation processes with two product grades: low aldehyde (LA) ethylene oxide and normal grade ethylene oxide. Both product grades are stored in dedicated, purpose-built bullets.

The reactor gas system is primarily comprised of nitrogen, ethylene and oxygen. The composition is tightly controlled to avoid ethylene and oxygen ratios which can lead to runaway reactions and ultimately an explosion in the reactor system.

A 2.4.2. Glycols Plant

The Glycols Plant and Glycol Ethers Plant operate continuously to produce a range of glycols and ethers. The technology and chemistry of the plants are very similar.

In the glycols plant, water, ethylene oxide and recycled glycol are reacted at 118-220ºC and 2270kPag to produce glycol in a tubular plug flow reactor. The reaction, which is exothermic, occurs between ethylene oxide and water. Recycle glycol is used to control product distribution.

The reaction converts all of the ethylene oxide to glycol and the reaction products are then dried (water removed, leaving liquid glycol mixture) and separated into mono-, di-, tri- and heavy glycols in a series of vacuum distillations.

A 2.4.3. Glycol Ethers Plant

In the Glycol Ethers plant, reaction is carried out in a similar fashion to the glycols plant. Ethylene oxide is reacted with various alcohols to produce a wide range of ethers. Again all ethylene oxide is reacted out in the plug flow reactor. Temperatures and pressures are generally higher than in the glycol process, with 160-230ºC and 3030kPag being typical. A similar refining process to the glycols plant is used to purify the ethers, with the first step being the removal of excess alcohol.

Propylene oxide feed campaigns are also run at the glycol ethers plant.

A 2.4.4. NIS Plants

The three NIS plants operate in the same fashion. Surfactants are produced by batch processes which react ethylene oxide (or propylene oxide for some campaigns) and a variety of raw materials to produce a wide range of end products. More than three hundred products are produced by the three plants.

The NIS A Plant consists of six independent CSTR reactors, four of 8 tonne capacity and two of 6 tonne capacity. Each reactor has separate feeds for ethylene oxide and other raw materials. Internal coils connect to water and steam utilities to provide cooling and heating at different stages of the batch. Two reactors may also be fed with propylene oxide. An ejector system provides a vacuum if required, or the reactor can be padded or pressurised with nitrogen. A stirrer within the vessel provides circulation throughout the batch. Reaction temperatures vary from 120ºC to 165ºC, and pressures from partial vacuum to 250kPag.

The NIS B and C Plant reactors use an external circulation loop to provide heating and cooling but otherwise operate in a similar fashion to NIS A. Each reactor is supplied with ethylene oxide and propylene oxide. The NIS B Plant reactor has a 30 tonne capacity, while the C Plant has two reactors of 20 tonne and 5 tonne capacity.

A 2.4.5. Multi-Purpose Plant

The Multi Purpose Plant (MPP) contains a single 16 tonne batch reactor and two blending vessels. The plant is used to produce batches of specialty chemicals which cannot be produced in the NIS plants. The major products produced on this plant are brake fluid intermediates, biodegradable surfactants derived from glucose and Amine Oxides. It is a very flexible plant which uses raw materials from the NIS Plants and external sources. The MPP does not use ethylene oxide or propylene oxide as a feedstock.

A 2.4.6. Specialties Plant

The Specialties Plant produces formulated coolants and brake fluids and a range of further derivatised non ionic surfactants and blends. The plant has a single reaction vessel (CSTR) in which surfactants are sulphated or phosphated using sulphamic acid, phophorus pentoxide or polyphosphoric acid. The reactions are mildly exothermic and are controlled manually.

A 2.4.7. Bulk Storages

EO Bulk Storage

EO is stored under nitrogen pressure in two bullets of 50 tonne and 80 tonne maximum capacity. A refrigeration system maintains the temperature in the bullets to below the atmospheric boiling point of EO (less than 10°C). A tanker export bay is also provided.

Water deluges protect both the bullets and the loading bay; gas detectors are located around the bullets at bund level.

PO Bulk Storage

Bulk propylene oxide is stored in a bunded, horizontal bullet located near Gate 3 in clear view of the Gate 3 Communications Centre. The bullet stores 120 tonne maximum capacity of propylene oxide at ambient temperature, under a pressurised nitrogen atmosphere.

Propylene oxide is transported to the site in isotankers from the rail freight yard. Unloading operations are carried out in a dedicated unloading bay with spill containment, located approximately 40 m to the west of the storage bullet.

Water deluges (heat initiated or manually activated) protect both the bullet and the unloading bay; gas detectors are located around the bullet at bund level.

Within Plant Bulk Storages

Beside the process plant areas, there are four main tank farms and several areas where drummed product or raw materials are stored within the plant area. The bulk of materials stored are class C1, C2 (combustibles) or non-classified liquids.

The Glycol Ethers tank farm provides Class 3 (flammable liquid) storage of alcohols and intermediates for Glycol Ethers plant. These materials are generally methanol or butanol used for the production of glycol ether products, glycol ether intermediates or glycol ether products. Foam bund and tank fire fighting capability with an alcohol compatible foam (ie Aqueous Film Forming Foam (AFFF)) is provided.

A 2.4.8. Huntsman Plant Design Safety

Technical safety measures of particular interest which are used to control the hazardous nature of the chemicals are summarised as follows:

- Critical duty piping and vessels have been identified and robustly designed and are routinely monitored to ensure integrity (not specifically accounted for in QRA).
- The number of flanges in the pipelines has been kept to a practical minimum in the flammable gas systems, reducing the potential leak sources as far as practicable within the constraints of providing maintenance access to valves and fittings. For this QRA, the pipeline and joint failure frequencies used correspond as closely as possible to the actual length of piping and number of flanges installed.
- High integrity independent trips are provided via a SIS at the EO plant, bulk storages, NIS and Glycols and Glycol Ethers Plants.

- Emergency isolation valves are installed on selected pipelines to limit the amount released should a leak occur (accounted for in maximum inventory defined in QRA).
- Higher integrity double mechanical seals are installed on all pumps handling the more hazardous fluids (accounted for in QRA by choice of seal leak frequencies).
- Magnetic drive pumps are used at selected locations (seal leaks prevented).
- Excess flow valves are installed (e.g. on the EO and PO lines exit the storage tanks) to limit the amount released if a pipe broke etc. These are not specifically accounted for in the QRA.
- Ethylene oxide is stored at refrigerated conditions (minimising the consequences of a loss of containment compared to a pressurised release).
- Back flow prevention systems have been installed to help prevent reverse flow of contaminated ethylene oxide to the bulk storage tanks (prevents the catastrophic failure of the bulk tanks due to uncontrolled, exothermic reactions), this is accounted for in the choice of frequencies in the QRA.
- Fire water is available for use as a water curtain to aid dispersion of a gas leak. (Not specifically accounted for in the QRA).
- A number of gas detectors are located throughout the site which would initiate an alarm and alert personnel in case of a flammable gas release, (not specifically accounted for in QRA).

A.2.5. Ixom Chloralkali Plant

The CAP is divided into a number of principal process areas:

Brine plant: Raw salt, delivered to site by truck is dissolved in heated water and in brine returning from the cells. Impurities present in the salt, particularly calcium, magnesium and sulphate, are detrimental to the membrane process and are removed by chemical precipitation and filtration, followed by ion exchange and nanofiltration.

Electrolysis/Cells: Using purified brine and electricity, banks of membrane cells produce wet chlorine at the anodes and wet hydrogen gas and caustic soda (33% w/w NaOH) at the cathodes.

Brine Dechlorination: Saturated brine ex the membrane cells is acidified and treated with sodium sulfite to remove chlorine, then recycled to the brine dissolution area. The chlorine from the dechlorination process is used in the Hypo plant.

Purification, drying and compression: Chlorine gas is cooled then dried using sulfuric acid so that it can be handled in carbon steel equipment. It is then compressed to around 200kPag. Compressed chlorine is used in the existing HCl, $FeCl_3$ and Hypo plants.

Hydrogen: Hydrogen produced in the cells is cooled and compressed then piped for use in the existing HCl plant. Any excess is vented to atmosphere via an elevated vent pipe.

Caustic soda: Caustic soda produced in the cells is concentrated from 33% w/w to 50% w/w using a steam vaporiser to evaporate some of the water content, then stored in tanks and loaded into tankers for delivery to customers.

Emergency Chlorine Scrubber (ECS): Emergency scrubbing capacity is provided by the emergency chlorine scrubber. During a plant upset, chlorine from the plant is directed to the ECS and is removed from the gas stream before venting to atmosphere by reacting with caustic soda, forming a stable solution of sodium hypochlorite. A small flow of chlorine is always directed to the ECS to control the pressure in the chlorine header.

The ECS consists of a packed tower, pump tank, two pumps, cooler, emergency caustic dump tank, two suction fans and an emergency chlorine ejector (inert gas powered).

A 2.5.1. Sodium Hypochlorite Plant

The Hypo Plant was replaced in 2010. It consists of a packed tower, a caustic tank, a circulation pump and duty/standby fans. It operates in continuous mode and produces sodium hypochlorite from chlorine and caustic soda. This is stored and supplied to customers by road tanker. Excess gas from the make tower is passed through the backing tower (a caustic scrubber) which removes any chlorine before the gas is vented to atmosphere.

A 2.5.2. HCl Plant

Synthesis of hydrochloric acid is a two stage process. Chlorine and hydrogen are supplied to the burner at moderate pressure and reacted together to produce hydrogen chloride gas, which is then absorbed into water forming the acid solution. The product acid concentration is 33% w/w HCl in water (33% w/w HCl aq). The reaction and absorption stages are integrated into a single physical unit (i.e. the "burner"). The synthesis units operate at a slight positive pressure. The product acid flows by gravity to bulk storage tanks. From here the acid is loaded into road tankers for distribution to customers.

A 2.5.3. Ferric Chloride Plant

Ferric chloride is produced in a continuously operated plant by reaction between chlorine and iron, and the addition of pickle liquor (ferrous chloride) and/or water. The iron feed is comprised of fine gauge off-cuts in the form of pellets.

The product is pumped to storage tanks and is loaded into road tankers for distribution to customers.

Excess chlorine from the reaction is vented through the Hypo Plant backing tower (a caustic scrubber).

A 2.5.4. Process control and shutdown systems

The chlorine and products plant area is controlled by an integrated DCS.

Critical trips at the chlorine plant are provided via a separate hardwired relay based system and displayed separately in the control room in the critical controls cabinet.

The critical trips at the products plants are executed via high integrity safety instrumented systems (SIS).

A 2.5.5. Chloralkali Plant Design Safety

The significant technical safety features and means of inclusion in the QRA are briefly discussed below.

Inventory Minimisation

The chlorine plant is a gas plant, designed to operate at very low pressures and ambient temperatures with minimal inventory of chlorine. There is no storage of gaseous or bulk liquid chlorine. The inventory at any given time is limited to what can be trapped in the process equipment.

Chlorine production is stopped by tripping the cells (i.e. isolating power which immediately stops production).

Containment and Leak Minimisation

The chlorine side of the chlorine plant operates under a slight vacuum up to the suction of the chlorine compressor. For small leaks, provided that the compressor or ECS fans are running, air will be sucked into the system rather than chlorine leaking out. The frequency of leaks out of this system from holes 13mm diameter or less is mitigated based on the probability of the fans (i.e. suction) failing.

The length of chlorine pipelines has been minimised and the number of flanges on chlorine pipelines reduced to a minimum, reducing potential leak sources as far as practicable within the constraints of providing maintenance access to valves and fittings. Piping and flange failure frequencies used in the risk assessment have been updated in this QRA to correspond closely to the actual length of piping and number of flanges installed.

Emergency Caustic Scrubber

The compressed chlorine supply pipework to the downstream product plants can be vented to the emergency caustic scrubbing system (ECS). This includes all process vents, pressure seals and relief valve discharges. There are no vents direct to atmosphere.

The ECS is permanently online, however it is only required to absorb a small flow of chlorine during normal plant operation (i.e. any excess chlorine that is not used by the products plants). In the event of a plant upset, the chlorine produced by the cells is diverted to the ECS.

The ECS is designed to absorb the full chlorine production rate (at 1 kg/s) for 10 minutes, with a maximum chlorine level of less than 3 ppm in the exhaust. In the event of a chlorine plant trip, the chlorine in the equipment and derivatives plant supply pipework is vented to the ECS.

Drum and Cylinder Storage

A number of gas detectors are located at the site boundary, which initiate an alarm and alert personnel in case of a chlorine release.

No flammable or combustible material is stored in the vicinity of this storage area. No hot work is undertaken on any chlorine containers. Hence the likelihood of a fire scenario involving a chlorine drum or cylinder is therefore considered negligible and is not assessed quantitatively.

Emergency capping equipment for holes and leaks from drums and cylinders is available which may limit the duration of a leak. Fire water is available for use as a water curtain to aid dispersion of a chlorine leak.

However emergency response actions such as these are not specifically accounted for in the QRA. As is conventional in QRAs, emergency response action has not been taken into account in the risk assessment of the chlorine containers; in particular no mitigation of a chlorine leak due to emergency response actions has been included in the consequence calculations.

Parked Tanker

The empty chlorine tanker is parked in a dedicated area, close to the drum storage area, away from the main thoroughfare (minimising the probability of impact with a moving vehicle). An in-transit full tanker could also be parked in this area if required. Tankers are not filled or unloaded on site.

The prime mover is disconnected from the tanker so a vehicle fire is not credible while the tanker vessel is in transit. There are no storages of combustible or flammable material in the parked tanker transit area.

A tanker emergency response vehicle is available in the event of a leak from the in-transit tanker. However as is conventional in QRAs, emergency response action has not been taken into account in the risk assessment of the chlorine tanker, in particular no mitigation of a chlorine leak from the use of the emergency response vehicle has been included in the consequence calculations.

HCl Plant

The HCl plant relies heavily on an instrumented protective system. The instrumented protective system and the control of the plant were substantially upgraded when an Emerson Delta V SIS (Safety Instrumented System) was implemented.

Hypo Plant

The hypo make tower circulation pumps and fans (both duty/standby) are backed up by emergency power to ensure high reliability. Excess chlorine from the make tower is removed in the backing tower and residual gas vented to atmosphere. The backing tower is a caustic scrubber designed to reduce chlorine levels to below 1ppm during plant upset conditions.

Ferric Plant

Excess chlorine from the process is vented via the backing tower at the Hypo Plant. The likelihood of a process upset resulting in chlorine release via the backing tower stack has been assessed using fault trees.

Gas Detection and Emergency Response

Atmospheric chlorine detectors are located along the site boundary and throughout the Chlorine and Products Plant areas. Hydrogen chloride detectors are located around the hydrochloric acid loading bay. An audible gas detection alarm alerts plant operators if gas detectors are activated.

An emergency procedure exists and is periodically tested via simulated emergencies. There are a number of desktop tests and simulations conducted every year to ensure all shift personnel participate.

Initial response may include isolating the source of the leak, setting up water sprays to disperse chlorine or capping holes in drums or cylinders with emergency capping equipment.

Wind speed and direction is monitored adjacent to the Control Room building, and a continuous readout available in the control room. Windsocks provide external visual indication.

A.2.6. GTP

Groundwater (contaminated with chlorinated hydrocarbons, primarily ethylene dichloride, EDC) is pumped from various extraction wells to a nitrogen padded groundwater feed tank. It is dosed with hydrochloric acid then pumped to air strippers. Air is passed countercurrently up through a falling column of water, transferring almost all the volatile chlorinated hydrocarbons from the water to the air. Heavier contaminants remain in the water.

Since 2012, chlorine dioxide dosing has been implemented to control biofouling in the air strippers. Chlorine dioxide is produced on site by reacting sodium chlorite with HCl and is handled as an aqueous solution in small volumes.

The contaminated air from the air strippers is drawn into a thermal oxidation unit where it is heated to a high temperature in the presence of air to break down the contaminants to form carbon dioxide, water vapour, hydrochloric acid and chlorine.

The gas stream leaving the thermal oxidation unit is cooled, quenched with a weak hydrochloric acid (HCl) solution (5 wt%) then passes through the acid absorber where the remaining hydrogen chloride is recovered. The air stream then continues to the caustic scrubber to remove other acid gases and chlorine to meet emission specifications. The air stream is then mixed with hot air before exiting the plant via a 34m high stack at over 100°C, the plume is invisible under almost all atmospheric conditions.

The stripped water from the air strippers is pumped to activated carbon adsorber beds which remove the remaining hydrocarbons.

A.2.7. Qenos Site Utilities

The Site Utilities plant comprises 3 medium pressure boilers, two are coal-fired and the other gas fired. These boilers are used to supply the BIP with 6.2MPa steam, some of which is letdown to supply 2.8MPa, 1.1MPa, & 0.5MPa steam via seven conversion stations. The average site steam load is approx 110te/hr with larger amounts required during plant disruptions or start-ups.

To service the coal-fired boilers a stockpile of coal is maintained with an average inventory of 3000 tonnes. Natural gas is supplied to the remaining boiler via a main underground pipeline managed by Olefines Plant.

In addition to steam, Site Utilities also supplies cooling water, instrument air, demineralised water, de-aerated water and manages electricity, firewater, towns water and nitrogen distribution. Site Utilities is also responsible for the site effluent treatment and discharges to Malabar Sewage Treatment Plant.

A.2.8. Other Operators Outside BIP

A 2.8.1. Air Liquide

Air Liquide Australia (ALA) operates two sites in Baker St on the north perimeter of the BIP.

Dry Ice Manufacture

The northern site produces Dry Ice from carbon dioxide (CO_2) which is a byproduct from the Huntsman EO plant. Gaseous CO_2 is first pressurised and refrigerated to form liquid CO_2, which is allowed to expand in an atmospheric chamber. When CO_2 converts from liquid to gas, there is an extreme drop in temperature. This causes some of the gas to freeze, yielding both snow-like CO_2 and vapor CO_2. The “snow” is then hydraulically pressed into dry ice blocks and pellets. The CO_2 vapor produced during the production of dry ice is captured and recycled using a recovery system to maximise the yield of dry ice.

The dry ice is packed into boxes and removed from site by truck.

Air Separation Plant (ASU)

The ASU plant is located on Baker St on the north boundary of the BIP close to the Olefines cooling towers. There are 2 ASUs which manufacture oxygen and nitrogen for use at the BIP. Air is compressed, impurities removed, dried, cooled to cryogenic conditions and then separated into its component gases in a cryogenic distillation process, producing liquid nitrogen and liquid oxygen. These gases are then vapourised and distributed by pipeline.

Gaseous oxygen is compressed and piped from ALA to the Huntsman EO plant. Gaseous nitrogen is piped to Site Utilities for distribution around the BIP.

This site also stores a number of hydrogen trailers.

A 2.8.2. BOC Gases

BOC Gases is located on Anderson St on the north boundary of the BIP. BOC produces dry ice from a CO_2 feed stream from ALA using a similar process to ALA.

Hydrogen filling operations at BOC were decommissioned after the CAP became operational in 2001 as there was no longer excess hydrogen.

APPENDIX 3. HAZARDOUS MATERIALS

This appendix summarises the toxic and flammable hazardous materials covered in the BIP QRA.

The table does not include the following potentially hazardous materials that are handled at the BIP but do not result in significant offsite risk:

- Combustible liquids (eg diesel, fuel oil, various raw materials and products of Surfactants.
- Class 2.2 (nitrogen, oxygen, CO_2)
- Class 8 (unless there is a toxicity or reaction with incompatible material hazard)
- Class 9
- Wastes and effluent

A.3.1. Hazardous Material Summary

KEY:

Y	relevant hazard / material
-	not present or hazard not applicable
Note 1…...n	see Notes at end of table

Flammable or Toxic Materials	**Description of Properties**	**Plants**								**Events**							
		Olefines	Alkatuff	Alkathene	Huntsman	Chloralkali	GTP	Nant St	Other - Pipelines within BIP	Jet Fire	Pool Fire	Flashfire	Explosion - VCE	BLEVE	Toxic exposure	Toxic reaction product (Note 1)	Other
1,3 Butadiene	Toxic, probable human carcinogen, central nervous system depressant Flammable, boiling point -4°C, flash point -76°C, autoignition temp 420°C LEL / UEL is 2 - 11.5 vol%	Y	-	-	-	-	-	-	-	Y	Y	Y	Y	-	Y	-	-
C3s (Propylene / Propane)	C3s are highly flammable heavier than air gases and can be liquefied at ambient temperatures under their own vapour pressure. The normal boiling point is approximately -44°C. LEL in air is approximately 2% (by volume) and UEL is approximately 10%. Flashpoint is around -104°C. The autoignition temp is around 460°C	Y	Y	-	-	-	-	-	Y	Y	Y (refrig only) (Note 2)	Y	Y	Y	-	-	-
C4s (butane, butene)	Aliphatic hydrocarbons with 4 carbon atoms. C4s are flammable heavier than air gases and can be easily liquefied at ambient temperatures under their own vapour pressure (boiling point close to ambient temps). The normal boiling point is approximately 0.5oC. LEL in air is approximately 2% (by volume) and UEL is approximately 8%. Flashpoint is around -60oC. The autoignition temp is around 430oC	Y	-	-	-	-	-	-	-	Y	Y	Y	Y	Y	-	-	-
Chlorine	Chlorine is a greenish-yellow highly reactive halogen gas with a pungent odour. It is heavier than air (specific gravity is 2.4 relative to air). It is a highly irritating and corrosive gas that reacts directly with moist surfaces in the eyes and respiratory tract producing hydrochloric and hypochlorous acids. It is easily detected by odour by most people at low levels (around 0.3ppm).	-	-	-	-	Y	-	-	-	-	-	-	-	-	Y	-	-
Chlorine dioxide	Chlorine dioxide is not flammable in the usual sense of combining with oxygen, however, concentrations greater than 10% may decompose at temperatures above 130°C (Ref 7). Chlorine dioxide is highly toxic and acts as a respiratory and eye irritant in a similar manner to chlorine. Levels above 5 ppm cause severe irritation, levels exceeding 19 ppm for unspecified periods have caused death	-	-	-	-	-	Y	-	-	-	-	-	-	-	Y	-	Y Note 3
Dimethyl disulphide (contains 1% methyl mercaptan)	Toxic at high concentrations, strong foul odour at very low concentrations Flammable liquid, boiling point 109°C, flash point 16°C, autoignition temp n/a LEL / UEL approx 1- 16 vol%	Y	-	-	-	-	-	-	-	-	Y	-	-	-	Y	Y	-
Ethane	Ethane is a highly flammable gas and can be liquefied at low temperatures. The normal boiling point is -88°C. LEL in air is 3% (by volume) and UEL is 12% Flashpoint is -135°C. The auto-ignition temperature in air is 472°C.	Y	-	-	-	-	-	-	Y	Y	Y (refrig only) (Note 2)	Y	Y	-	-	-	-
Ethyl mercaptan	Toxic, objectionable odour at very low concentrations Flammable liquid, boiling point 35°C, flash point -48°C, autoignition temp 299°C LEL / UEL approx 3- 18 vol%	Y	-	-	-	-	-	-	-	-	Y	Y	Y	-	Y	-	-

Flammable or Toxic Materials	Description of Properties	Plants								Events							
		Olefines	Alkatuff	Alkathene	Huntsman	Chloralkali	GTP	Nant St	Other - Pipelines within BIP	Jet Fire	Pool Fire	Flashfire	Explosion - VCE	BLEVE	Toxic exposure	Toxic reaction product (Note 1)	Other
Ethylene	Ethylene is a highly flammable gas and can be liquefied at cryogenic temperatures. The normal boiling point is -104 ºC. LEL in air is 2% (by volume) and UEL is 28% Flashpoint is -136ºC. The auto-ignition temperature in air is 490ºC.	Y	Y	Y	Y	-	-	-	Y	Y	Y (refrig only)	Y	Y	Y	-	-	-
Ethylene Oxide	Ethylene oxide is a toxic, highly flammable and explosively unstable material. The normal boiling point is 10.5ºC, i.e. EO has a high vapour pressure and at ambient temperature is often above its atmospheric boiling point (i.e. can be a gas or liquid). LEL in air is 3% (by volume). There is no upper flammability limit as at the high concentrations up to pure ethylene oxide, combustion is replaced by explosive decomposition. The flash point (open cup) is -17.8ºC. The auto-ignition temperature in air is 429ºC.	-	-	-	Y	-	-	-	-	Y	Y	Y	Y	Y	Y Note 12	-	Y Note 3
Gasoline	Gasoline is a flammable liquid. The normal boiling point is from 40-70ºC depending on grade. LEL in air is 2% (by volume) and UEL is 37%. The flash point (open cup) is -40ºC. LEL in air is approx 1% (by volume) and UEL is 8% The auto-ignition temperature in air is 280oC Some components of gasoline are toxic; however this is a secondary concern compared to flammability	Y	-	-	-	-	-	Y	Y	-	Y	Y	Y	-	Note 10	-	Y Note 13
Hexene	Hexene is similar to petrol and is classified as Class 3 Dangerous Goods (Flammable Liquid, PG II). It has a boiling point of around 63°C and a flash point of -22°C. The LEL and UEL of hexene are 1.2% and 6.9% respectively.	-	Y	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
Hydrochloric acid	A corrosive liquid that emits fumes of hydrogen chloride if spilt.	-	-	-	-	Y	Y	-	-	-	-	-	-	-	Y	Y Note 4	-
Hydrogen	Hydrogen is a colourless, odourless flammable gas. The gas diffuses readily through small holes Very low density. Hydrogen is very easy to ignite, and flammable over a wide range of concentrations (4-75 vol%). The flames produced have low heat radiation, about one-tenth that of propane, and are only hazardous on contact with, or immediately adjacent to the flame. However, the low luminosity of the flame makes it very difficult to see, and thus avoid.	-	Y	-	-	Y	-	-	-	Y	-	-	Y	-	-	-	-
Hydrogen	Hydrogen is a highly flammable much lighter than air gas that disperses very easily if unconfined. LEL in air is 4% (by volume) and UEL is 75% The auto-ignition temperature in air is 400ºC and its ignition energy I very low.	Y	Y	-	-	Y	-	-	-	Y	-	Y	Y	-	-	-	-
Hydrogen chloride	Hydrogen chloride is an irritating gas with a pungent odour. It is a highly irritating and corrosive gas that reacts directly with moist surfaces in the eyes and respiratory tract producing hydrochloric acid. It is detected by odour by most people at low levels (around 0.3ppm).	-	-	-	-	Y	Y	-	-	-	-	-	-	-	Y	Y	-
Isohexane	Isohexane has similar physical properties to hexene with a boiling point around 60°C and a flash point of -7°C. The LEL and UEL of isohexane are 1.2% and 14% respectively.	-	Y	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
Metal alkyls (catalyst activators)	The activator is a pyrophoric class 4.2, i.e. spontaneously combustible in air, dangerous good. (It also reacts violently with water, i.e. sub risk 4.3).	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	Note 7,8

Flammable or Toxic Materials	Description of Properties	Plants								Events							
		Olefines	Alkatuff	Alkathene	Huntsman	Chloralkali	GTP	Nant St	Other - Pipelines within BIP	Jet Fire	Pool Fire	Flashfire	Explosion - VCE	BLEVE	Toxic exposure	Toxic reaction product (Note 1)	Other
Methane (natural gas has very similar properties)	Methane is a highly flammable lighter than air gas and can be liquefied at cryogenic temperatures. The normal boiling point is -88ºC. LEL in air is 3% (by volume) and UEL is 12%. Flashpoint is -222ºC. The auto-ignition temperature in air is 472ºC.	Y		-	-	-	-	-	-	Y	Y (refrig only) (Note 2)	Y	Y	-	-	-	-
Methanol	Methanol is a toxic, highly flammable liquid. The normal boiling point is 65ºC. LEL in air is 2% (by volume) and UEL is 37%. The flash point (open cup) is -37ºC.	-	-	-	Y	-	-	-	-	-	Y	-	-	-	Note 10	-	-
Organic peroxides (catalysts)	Organic peroxides are highly reactive liquids, combustible and thermally unstable.	-	-	Y	-	-	-	-	-	-	Note 8	-	Note 8	-	-	-	Note 9
Organo-metal halides (catalysts)	Pyrophoric class 4.3, i.e. water reactive flammable material, (sub risk 4.1) dangerous good. The flash point is 21oC (for the reaction products from reaction with water). Dust is flammable and poses a significant dust explosion hazard. Flammable mixtures are easily ignited, even by static. .	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	Note 5, 6	Note 5, 6, 7,8, 11
Propylene Oxide	Propylene oxide is a toxic, highly flammable material. The normal boiling point is 34ºC. LEL in air is 2% (by volume) and UEL is 30%. The flash point (open cup) is -30ºC. The auto-ignition temperature in air is 465ºC.	-	-	-	Y	-	-	-	-	Y	Y	Y	Y	Y	Y Note 12	-	-
Sodium chlorite	A corrosive liquid. Reacts with acids to form ClO2.	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	Y Note 4	-
Sodium hypochlorite	A corrosive liquid. Reacts with acids to form Cl2.	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	Y Note 4	-
Various EO derivatives	Flammable or combustible liquids	-	-	-	Y	-	-	-	-	-	Y	-	-	-	-	-	-

NOTES:

1. All hydrocarbons can form toxic products of incomplete combustion such as Carbon Monoxide (CO) during a fire. This is a secondary hazard and is not considered separately.
2. None of these materials is handled at low temperatures in significant quantities so pool fires are not considered in the BIP QRA.
3. EO can decompose explosively in the absence of air. ClO2 can decompose in the presence of impurities or at elevated temperatures
4. Hypo reacts with acid to form Cl2. Sodium chlorite forms ClO2 when acidified
5. Organo metal halides - Reaction with incompatible materials (e.g. water, oxidising agents, air) will result in rapid temperature increase and produce flammable and irritation vapours.
6. Organo- metal halides - Temperatures above 140oC may result in self accelerating exothermic decomposition (SADT), producing flammable and toxic vapours and rapid pressure rise inside closed containers
7. Pyrophoric
8. Organo metal halides - The decomposition products from fires are oxides of aluminium, carbon dioxide and water, and do not pose toxic risk effects.
9. Organic peroxides undergo strongly exothermic runaway decomposition reactions caused by heat, mechanical shock/friction or contamination.
   This usually results in a violent pressure rise, which bursts storage containers and releases hot flammable vapours which self ignite.
10. Gasoline and methanol are not acutely toxic for short exposure durations, though they do have potentially chronic adverse health effects. Offsite toxicity impacts not included in QRA
11. Dust explosion hazard
12. EO and PO are toxic although as they are highly flammable, extended duration unignited events are unlikely. Unignited events are included in irritation / injury risk but not for fatality as fatality dose approaches LEL.
13. Buncefield scenario - large flammable vapour cloud during extended overfill

APPENDIX 4. HAZARDOUS INCIDENT SUMMARY

The hazardous incident scenarios have been summarised from the individual facility QRAs.

At each QRA revision these are reviewed to determine if any changes are required. Minor updates have generally been made as required. The comments column notes any significant changes to inputs or type of scenario.

A.4.1. Hazardous Incident Summary

KEY:

Yes scenario included in quantification
No not quantified for reasons given in Comments columns
- not present or hazard not applicable

No major changes' means no significant changes in inputs such as inventory, process conditions etc since previous QRA

ID	Incident Description	Comments		Included in QRA (i.e. consequence and frequencies quantified)					Comments re changes in 2018 QRA
		Offsite fatality / Injury potential	Escalation potential	Fatality risk	Injury Risk		Irritation Risk	Escalation Risk	
				Individual / Societal	Fire / Explosion	Toxics	Toxics	Fire / Explosion	
Plant	**Olefines**								
	Leaks of pressurised liquefied gas (ethane, ethylene, propane, propylene, 1,3 butadiene) from vessels resulting in fires / explosions	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Leaks of flammable liquid (petrol, EM, DMDS) from vessels (containing more than 250 kg of flammable liquid or 100 litres of toxic liquid)	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Leaks of pressurised liquefied gas (ethane, ethylene, propane, propylene, 1,3 butadiene, RGP) from piping resulting in fires / explosions	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Leaks of flammable liquid (petrol, EM, DMDS) from piping	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Leaks of gas from piping (ethylene, natural gas) resulting in fires / explosions	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	leaks of pressurised liquefied gas (ethane, ethylene, propane, propylene, 1,3 butadiene) from pumps (centrifugal)	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Leaks from diaphragm pumps (DMDS)	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	BLEVEs of storage vessels and process vessels with significant inventories	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Unignited leaks of ethyl mercaptan during storage and drum handling	Toxicity issues only for this group of scenarios. Consequence modelling facility risk assessment shows fatality due to toxicity not credible, however can contribute to injury and irritation risk	None	-	-	Yes	Yes	-	Seldom used, reduced frequency
	Unignited leaks of 1,3 butadiene from storage and pumps	Toxicity issues only for this group of scenarios. Consequence modelling facility risk assessment shows fatality due to toxicity not credible, however can contribute to injury and irritation risk	None	-	-	Yes	Yes	-	No major changes

ID	Incident Description	Comments		Included in QRA (i.e. consequence and frequencies quantified)					Comments re changes in 2018 QRA
		Offsite fatality / Injury potential	Escalation potential	Fatality risk	Injury Risk		Irritation Risk	Escalation Risk	
				Individual / Societal	Fire / Explosion	Toxics	Toxics	Fire / Explosion	
	Unignited leaks of DMDS from storage, package handling and pumps	Toxicity issues only for this group of scenarios. Consequence modelling facility risk assessment shows fatality and injury due to toxicity not credible, Irritation also not credible (ERPG2 basis)	None	-	-	Yes	Yes	-	Now handled in IBCs rather than drums. Reduced leak frequency
	Leaks from ammonia drums and piping (water treatment chemicals)	Toxicity issues only for this group of scenarios.	None	-	-	-	-	-	Ammonia deleted from QRA. No longer used at Olefines
Plant	**Nant St**								
	Tank top fires	Flammable	Flammable	Yes			-		No major changes
	Leaks of flammable liquid (petrol) from pumps and tanks	Flammable	Flammable	Yes			-		No major changes
	Gasoline tank overfill	Flammable	Flammable	Yes			-		Buncefield scenario - new scenario added
Plant	**Huntsman Surfactants**								
	Methanol fires due to leaks from D-1301A/B/C (Ethers Reactor)	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Fires / explosions due to EO leaks from process vessels in EO plant	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	EO cycle gas explosion	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	O2 supply line fire	Oxidising	Yes - to cycle gas - included as cause in cycle gas explosion	No	No	-	-	Yes	No major changes
	Hot oil fire in EO reactor hot oil system	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	EO fire / explosions in EO storage area (bulk storages, break tank QF-20)	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	EO fire / explosions in EO tanker loading bay	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	EO fire / explosions in EO break tank F-1304 (ethers plant)	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Fires / explosions due to EO leaks from NIS B reactor	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Fires / explosions due to EO leaks from NIS C reactor	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Fires / explosions due to leaks from ethylene piping	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Fires / explosions due to leaks from natural gas piping	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Fires / explosions due to leaks from EO piping from EO plant to glycols and storage	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Fire / explosions in PO storage area (bulk storage, tanker unloading)	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Fire / explosions in PO break tank (O1/F2)	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Flammable liquid fires in Glycol Ethers Tank Farm	Flammable	Flammable	Yes	Yes	-	-	No	No major changes
	BLEVEs of storage vessels and process vessels with significant inventories	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	Reactor internal explosion - NIS A, B, C	Flammable	Flammable	Yes	Yes	-	-	Yes	No major changes
	EO decomposition in EO storages, break tanks or purification section of plant	Flammable	This is the escalated event	Yes	Yes	-	-	Yes	No major changes
	MPP plant flammable liquid pool fires	Localised impact only	Localised impact only	No	No	-	-	No	No major changes

ID	Incident Description	Comments		Included in QRA (i.e. consequence and frequencies quantified)					Comments re changes in 2018 QRA
		Offsite fatality / Injury potential	**Escalation potential**	**Fatality risk**	**Injury Risk**		**Irritation Risk**	**Escalation Risk**	
				Individual / Societal	**Fire / Explosion**	**Toxics**	**Toxics**	**Fire / Explosion**	
	Unignited EO releases from EO plant backend	Toxic (i.e. unignited cases only)	n/a	Yes	-	Yes	Yes	-	No major changes
	Unignited EO liquid spills from EO storages, tankers and break tanks	Toxic (i.e. unignited cases only)	n/a	Yes	-	Yes	Yes	-	No major changes
	Unignited PO releases, bulk storage and tanker unloading	Toxic (i.e. unignited cases only)	n/a	No	-	Yes	Yes	-	No major changes
Plant	**Chloralkali**								
	Gaseous chlorine release from mechanical failures resulting in leaks from piping or vessels.	Toxicity only. Not flammable	None - toxic materials do not have the capability of causing a knock on event	Yes	-	Yes	Yes	-	No major changes
	Liquid or gaseous chlorine leak from static drum, cylinder or parked tanker.	Toxicity only. Not flammable	None - toxic materials do not have the capability of causing a knock on event	Yes	-	Yes	Yes	-	No major changes
	Liquid or gaseous chlorine leak due to damage to drums during handling.	Toxicity only. Not flammable	None - toxic materials do not have the capability of causing a knock on event	Yes	-	Yes	Yes	-	No major changes
	Gaseous chlorine release from process operations or plant upset conditions and simultaneous failure of emergency caustic scrubber (ECS).	Toxicity only. Not flammable	None - toxic materials do not have the capability of causing a knock on event	Yes	-	Yes	Yes	-	No major changes
	Chlorine breakthrough at Hypo or Ferric Plants due to plant upset conditions and simultaneous failure of the backing tower caustic scrubber.	Toxicity only. Not flammable	None - toxic materials do not have the capability of causing a knock on event	Yes	-	Yes	Yes	-	No major changes
	Chlorine or HCl breakthrough at HCl plant and emission from HCl stack due to plant upset conditions and shutdown failure.	Toxicity only. Not flammable	None - toxic materials do not have the capability of causing a knock on event	Yes	-	Yes	Yes	-	No major changes
	Large spills of hydrochloric acid at HCl bulk storage / tanker loading area.	Toxicity only. Not flammable	None - toxic materials do not have the capability of causing a knock on event	Yes	-	Yes	Yes	-	No major changes
		Toxicity only. Not flammable	None - toxic materials do not have the capability of causing a knock on event	Yes	-	Yes	Yes	-	Some new locations added as per MHF Safety Case
	Hydrogen leak, torch fires / explosions	Flammable - Localised impact only Hydrogen is used at low flowrates (maximum production rate is 0.03kg/s). the plant inventory is low, the maximum operating pressure is low (less than 100kPag). Facility risk assessment contains torch fire consequence mode results showing flame lengths of less than 1m and heat radiation levels above 4.7kW/m2 confined to within 1m of the flame. All areas handling hydrogen are well ventilated (there is no hydrogen handled within buildings) so confinement of a leak and subsequent explosion is also very unlikely.	Flammable - Escalation potential is also minimal as hydrogen inventories are very small and there are no external flammable or combustible inventories in the vicinity of the hydrogen piping and compressor	No	No	-	-	No	No major changes
Plant	**Alkatuff**								

ID	Incident Description	Comments		Included in QRA (i.e. consequence and frequencies quantified)					Comments re changes in 2018 QRA
		Offsite fatality / Injury potential	Escalation potential	Fatality risk	Injury Risk		Irritation Risk	Escalation Risk	
				Individual / Societal	Fire / Explosion	Toxics	Toxics	Fire / Explosion	
	Ethylene leak to atmosphere from reactor / purification vessels / cycle gas system resulting in jet fire or formation of a gas cloud and subsequent explosion	Flammable	Yes	Yes	Yes	-	-	Yes	No major changes
	High pressure spray fire - Catastrophic pressure vessel failure in hexene / isohexane (ICA) feed purification system	Flammable	Yes	Yes	Yes	-	-	Yes	No major changes
	Class 3 (hexene, isohexane) pool fire at tanker unloading bay (hose leaks, pump seal etc)	Flammable Localised impact only - distance to 4.7kW/m2 in facility risk assessment is < 30m	None Localised impact only - distance to 23kW/m2 in facility risk assessment is < 10m. No other inventories in this region	No	No	-	-	No	No major changes
	Class 3 (hexene, isohexane) storage tank incidents	Hexene and isohexane (ICA) are stored inside mounded above-ground tanks enclosed in concrete sarcophagi. This virtually eliminates these tanks from being affected by incidents from adjoining plants, or from having an effect on each other.	Hexene and isohexane (ICA) are stored inside mounded above-ground tanks enclosed in concrete sarcophagi. This virtually eliminates these tanks from being affected by incidents from adjoining plants, or from having an effect on each other.	No	No	-	-	No	No major changes
	Hydrogen leak, torch fires / explosions	Localised impact only Hydrogen is used at low flowrates (maximum rate is 1.5kg/hr), with no significant inventory. All areas handling hydrogen are well ventilated (there is no hydrogen handled within buildings) so confinement of a leak and subsequent explosion is also very unlikely.	Escalation potential is minimal as hydrogen inventories are very small and there are no external flammable or combustible inventories in the vicinity of the immediate vicinity of hydrogen piping.	Yes	Yes	-	-	Yes	H_2 trailer storage introduced and new scenarios included
	Metal alkyl catalyst fire	Localised impact only. catalyst has been known to result in small localised fires when inadvertently blown to atmosphere during maintenance operations (e.g. due to incorrect procedures). Stored in small cylinders under low pressure nitrogen in two storage areas. A container of catalyst is connected directly to process pipelines via stainless steel flexible hoses, and the contents displaced by nitrogen into the process. This minimises in-plant hazardous material inventories.	None - storage areas are well separated from the hydrocarbon process area (around 50m separation) and cooling water can be applied to the outside of other containers in storage from hydrants.	No	No	-	-	No	No major changes

ID	Incident Description	Comments		Included in QRA (i.e. consequence and frequencies quantified)					Comments re changes in 2018 QRA
		Offsite fatality / Injury potential	Escalation potential	Fatality risk	Injury Risk		Irritation Risk	Escalation Risk	
				Individual / Societal	Fire / Explosion	Toxics	Toxics	Fire / Explosion	
	Metal alkyl catalyst activator fire - e.g. reaction inside a container, or mechanical failure of a container leading to release and spontaneous ignition, escalating to involve other containers	Localised impact only. Purpose built 1635L cylinders and stored under low pressure nitrogen. A container of activator is connected directly to process pipelines via stainless steel flexible hoses and pumped into the process. A leak during container changeover or due to failure of hoses or pump leaks etc would result in a fire. However the activator inventory is limited to the contents of a single container, located at the south west corner of the storage area well away from hydrocarbon process equipment, limiting the likely duration and impact of a fire.	None - storage area is an outdoor plot, well separated from the reactor area (around 50m separation) and hexene / isohexane (ICA) storage and unloading areas (more than 80m). Cooling water can be applied to the outside of other containers in storage from hydrants. activator cylinder connection area includes fire bays, fixed water fog sprays and bunding which drains to a dedicated fire ground in event of spillage. cylinder changeovers are carried out under detailed procedures. Similarly due to the separation distance, a fire in the flammable liquids unloading area or in the main process area is unlikely to escalate to the catalyst / activator store area.	No	No	-	-	No	No major changes
Plant	**Alkathene**								
	Ethylene leak to atmosphere resulting in fire or formation of a gas cloud and subsequent explosion	Flammable Consequence calculations in facility risk assessment indicated that only catastrophic ruptures could cause a gas cloud large enough to have offsite effects, hence smaller leaks not included in QRA	Yes	Yes	Yes	-	-	Yes	No major changes

ID	Incident Description	Comments		Included in QRA (i.e. consequence and frequencies quantified)					Comments re changes in 2018 QRA
		Offsite fatality / Injury potential	Escalation potential	Fatality risk	Injury Risk		Irritation Risk	Escalation Risk	
				Individual / Societal	Fire / Explosion	Toxics	Toxics	Fire / Explosion	
	Ethylene decomposition in process equipment, relief to atmosphere and subsequent aerial decomposition	Plant impact only (based on operational experience at Qenos and other facilities) In a decomposition reaction, ethylene rapidly decomposes forming solid carbon particles and gaseous H2 and methane. The temperature and pressure in process equipment rise very rapidly, resulting in a release to atmosphere via the burst discs, or possible rupture of equipment if pressure relief is inadequate, and formation of a vapour cloud (hydrogen, methane, carbon dust, residual ethylene). Ignition occurs as the vented material is hot and contains glowing carbon particles, and contains hydrogen which is very easily ignited, e.g. by static, hence a vapour cloud explosion occurs. This is referred to as an aerial decomposition. Experience indicates these events are very damaging to process equipment and the immediate environs, but do not have significant heat radiation or blast effects at distances of hundreds of metres. From a plant perspective, aerial decompositions are considered a severe event, however make minimal contribution to offsite risk	No. Elevated short duration event. Reactor drench system operate - cleanup required no escalation effects.	No	No	-	-	No	No major changes
	Catalyst exothermic decomposition reaction and storage area fire or explosion	Local impact only The operator's experience at Botany and other facilities suggests that catalyst decomposition can be considered a severe, localised fire or explosion event, Quantitative estimates in the facility risk assessment based on a UK HSE methodology support this giving distances to injurious overpressures or heat radiation levels less than 70m	None Short duration fire event (about 4 minutes), distances to 23kW/m2 or 14kPa < 40m. Separation distances to hydrocarbon inventories much greater than this.	No	No	-	-	No	No major changes
	Propane leak to atmosphere resulting in fire or formation of a gas cloud and subsequent explosion	Flammable Consequence calculations in facility risk assessment indicated that only catastrophic storage vessel ruptures could cause a gas cloud large enough to have offsite effects, hence smaller leaks not included in QRA	Yes	Yes	Yes	-	-	Yes	No major changes

ID	Incident Description	Comments		Included in QRA (i.e. consequence and frequencies quantified)					Comments re changes in 2018 QRA
		Offsite fatality / Injury potential	**Escalation potential**	**Fatality risk**	**Injury Risk**		**Irritation Risk**	**Escalation Risk**	
				Individual / Societal	**Fire / Explosion**	**Toxics**	**Toxics**	**Fire / Explosion**	
	Propane storage vessel BLEVE	Yes	Yes (albeit at very low frequency, particularly given that the propane is piped to storage from Olefines rather than delivered by road tanker)	Yes	Yes	-	-	Yes	No major changes
	Pool fire (combustible liquids)	Flammable Localised impact only - distance to 4.7kW/m2 in facility risk assessment is < 30m	None Localised impact only - distance to 23kW/m2 in facility risk assessment is < 10m. No other inventories in this region	No	No	-	-	No	No major changes
Plant	**GTP**								
	HCl leak from pipes or vessels from the air stripper to the plant exhaust vent	FHA shows max distance to ERPG1 is 147m, all other met < 60m. Nearest residential is > 300m away	None	No	-	No	No	No	No major changes
	Recovered waste EDC liquid Isotainer and transfer system including connecting piping and hose	Localised impact only	None. Bunded area, limited heat radiation effects.	No	No	-	-	No	No major changes
	Recovered waste EDC liquid storage systems fires	Localised impact only	None. Bunded area, limited heat radiation effects.	No	No	-	-	No	No major changes
	Natural gas torch fires	Localised impact only	Localised impact only, Isolation at EIVs and at manual isolation limiting duration of fire. No significant hazardous inventories in vicinity of NG piping	No	No	-	-	No	No major changes
	Thermal oxidiser internal explosion	Localised impact only	Localised impact and asset damage only. No significant hazardous inventories in vicinity.	No	No	-	-	No	No major changes
	Caustic scrubber (loss of reflux flow), HCl breakthrough	HCl breakthrough from elevated stack. FHA shows no significant effects at grade in residential areas	None	No		No	No	No	No major changes
	Releases of Chlorine Dioxide – Reactor or Batch Tank Failure	FHA Rev F indicates offsite toxicity effects under some conditions	None	Yes	-	Yes	Yes	-	New scenario for ClO2 system
	Releases of Chlorine Dioxide –Batch Tank Overflow	FHA Rev F indicates offsite toxicity effects under some conditions	None	Yes	-	Yes	Yes	-	New scenario for ClO2 system
	Releases of Chlorine and Chlorine Dioxide – Tank Filled with the incorrect chemical	FHA Rev F indicates offsite toxicity effects under some conditions	None	Yes	-	Yes	Yes	-	New scenario for ClO2 system
Plant	**Site Utilities**								
	Natural gas torch fires	Localised impact only	Localised impact only, Isolation at EIVs and at manual isolation limiting duration of fire. No significant hazardous inventories in vicinity of NG piping	No	No	-	-	No	No major changes
	Boiler explosions	Localised impact only	Secondary dust explosions. Localised impact and asset damage only. No significant hazardous inventories in vicinity of NG piping. Separation to other plants (Alkatuff, CA) well over 150m	No	No	-	-	No	No major changes

ID	Incident Description	Comments		Included in QRA (i.e. consequence and frequencies quantified)					Comments re changes in 2018 QRA
		Offsite fatality / Injury potential	Escalation potential	Fatality risk	Injury Risk		Irritation Risk	Escalation Risk	
				Individual / Societal	Fire / Explosion	Toxics	Toxics	Fire / Explosion	
	Coal dust explosions	Localised impact only	Secondary dust explosions. Localised impact and asset damage only. No significant hazardous inventories in vicinity. Separation to other plants (Alkatuff, CA) well over 150m	No	No	-	-	No	No major changes
	Coal stockpile incidents	Local impact only. Slow to develop, low heat radiation levels	Localised impact. No significant hazardous inventories in vicinity.	No	No	-	-	No	No major changes
Plant	**ASU (Air Liquide)**								
	Explosion in ASU	Yes (worst case explosion event)	Extremely unlikely, potential for HC accumulation in liquid oxygen well understood hazard. Various hydrocarbon detectors in atmosphere and liquid oxygen. ASU would be shut down well before hazardous HC levels could occur. Olefines cooling towers also provide a physical barrier between ASU and Olefines process area. Not included in QRA	No	No	-	-	No	No major changes
	Explosion in Oxygen compressor	Localised impact only. Compressor located within blast enclosure	Extremely unlikely. Compressor located within blast enclosure	No	No	-	-	No	No major changes
	Hydrogen fire / explosion	Localised impact only All areas handling hydrogen are well ventilated (there is no hydrogen handled within buildings) so confinement of a leak and subsequent explosion is very unlikely.	Escalation potential is minimal as hydrogen inventories are separated from each other, no impingement by more likely leak sources such as burst discs, tubing.	No	No	-	-	No	No major changes
Plant	**Dry Ice Manufacture (Air Liquide and BOC Gases)**								
	CO2 release	Localised impact only Asphyxiant in the immediate vicinity of release	None	No	-	-	-	No	No major changes
Plant	**Other**								
	Leaks from BIP ethylene reticulation piping	Jet fires Explosions - very small cloud masses due to high pressures. Minimal confinement		Yes	Yes	-	-	Yes	Pipelines are new inclusions - was not in previous QRA
	Leaks from BIP propylene reticulation piping	Jet fires Explosions - very small cloud masses due to high pressures. Minimal confinement		Yes	Yes	-	-	Yes	Pipelines are new inclusions - was not in previous QRA
	Leaks from BIP flammable liquid piping	Pool and jet fires - localised impact only.		Yes	Yes	-	-	Yes	Pipelines are new inclusions - was not in previous QRA

APPENDIX 5. CONSEQUENCE MODELING

A.5.1. Models used

The TNO Effects models and modelling parameters used for modelling of consequences are shown in Table A5.1 and Table A5.2 respectively.

TABLE A5.1: MODELS USED IN SOFTWARE

CONSEQUENCE	EFFECTS MODELS	COMMENTS
Pool fire	Pool fire model with two zone model	Latest pool fire model for modelling in Effects. Includes a luminous and sooty flame fraction
Jet fire	Jet fire Chamberlain model	Typical jet fire model used for modelling in Effects
Flash fire	Pool Evaporation model or Dense Gas Dispersion: Flammable Cloud model	Typical flash fire model for dense gases used for modelling in Effects
Dispersion of toxic releases	SLAB model for dense gas dispersion Low momentum releases with release fluid density close to air (e.g. ambient temperature vapour from an evaporating pool) a Gaussian dispersion model	Effects internally selects the relevant dispersion model depending on releases and material conditions
Vapour Cloud Explosion (VCE)	TNO Multi Energy method	Curve strength 3 or 7 used depending on congestion level in plant area
Internal Explosion (in reactor vessels)	Vessel burst model	Parameters set within Effects to either flammable mixture and internal explosion, or runaway reaction and burst
Boiling Liquid Expanding Vapour Explosion (BLEVE)	Dynamic BLEVE model	Dynamic BLEVE model - accounts for changing view factor as fireball rises - predicts slightly greater effect distances than static model
EO Decomposition	TNO Multi Energy method	The consequence modelled for 'Decomposition' scenarios is the escalated loss of containment event following the decomposition reaction which results in vessel rupture and release of EO inventory to the atmosphere/plant leading to a VCE, not the decomposition itself

A 5.1.1. Pool Fires

Pool fires are caused by ignition of a flammable liquid pool. The pool size is dependent upon the release rate, spillage containment conditions and drainage.

Since pool fires will expand in all directions, provided there are no impeding obstacles, it is assumed that the resulting fire will be circular. The flame height will vary with the pool diameter and the direction of the flame may be influenced by the wind direction and speed. In case where the pool is contained within a bund, the pool diameter was estimated using the area of the bund. If a person is engulfed within a pool fire, the resultant injury may be serious or fatal.

To calculate the dimensions of the pool fires an equilibrium point is assumed, where the burn rate equals the release rate of material.

A 5.1.2. Jet Fires

Jet fires result from the ignition of a high-pressure release of gas or two-phase liquid from a pipe or vessel. The jet entrains air causing the mixture to burn turbulently, generating high radiant and convective heat. Due to the high pressures involved and the exit velocity, the initial outflow rate of material may be large. However, the pressure will generally fall rapidly due to depressurisation effects, thus reducing the impact of any jet fire.

A 5.1.3. Flash Fires

A flash fire occurs when a cloud of vapour accumulates and spreads until the edge of the cloud reaches a source of ignition. A flame at the edge then passes rapidly through the cloud. If a person is within the cloud when it ignites, the resultant injury may be serious or fatal.

The flammable cloud sizes at lower flammable limit (LFL) concentrations were assessed. Flammable vapour cloud assumed to undergo unrestricted free field dispersion and growth of the cloud does not take into account any adjacent equipment/obstruction that may change the direction and size of cloud.

A 5.1.4. Dispersion

The SLAB model within Effects / Riskcurves is used for dense gas dispersion calculations. Dispersion from a ground level evaporating pool, a horizontal or vertical jet or an instantaneous release can be modelled. The model predicts dispersion behaviour by solving the conservation equations for mass, momentum and energy.

The resulting gas cloud is treated as a steady state plume, a transient "puff" or a combination of the two, depending on the release duration. In the case of a finite duration release, cloud dispersion is initially described using a steady state plume model as long as the source is active. Once the source has been shut off, subsequent dispersion is calculated by the transient puff model. For instantaneous releases the transient puff model is used for the entire calculation.

For dispersion of low momentum releases (e.g. ambient temperature vapour from an evaporating pool) a Gaussian dispersion model is used.

A 5.1.5. VCE

Unignited flammable vapour clouds have potential to result in a vapour cloud explosion (ie delayed ignition case). By definition, a VCE is the deflagration/detonation of a flammable vapour cloud resulting in blast waves with damaging overpressure effects. Partial confinement is regarded as a major cause of blast in vapour cloud deflagrations. Where there is no confinement, a flashfire would occur rather than explosion (ie no overpressure effects).

For this study, the TNO Multi Energy Method was used to estimate the impact of vapour cloud explosions (ie overpressure levels). The method assumes that a strong blast is generated only by that part of the cloud that is subjected to congestion and confinement and the remaining part of the cloud will have no significant contribution to the blast.

If there is no confinement, a flashfire (i.e. no overpressure effects) would occur rather than explosion.

Explosive Mass: This parameter sets the amount of explosive mass used the calculation. The total explosive amount in cloud was obtained from the dispersion calculation.

Degree of confinement: This parameter essentially sets the proportion of the total mass in the cloud that contributes to the explosion calculation. For example, if the total mass and degree of confinement is set to 100 kg and 50% respectively, this is equivalent to 50 kg as the maximum amount that can be included in the explosion calculation.

- 10% for pipelines and isolated storages;
- 25% for open plant areas and most storages;
- 75% for the congested plant areas

Blast strength: The blast strength is represented by a series of curves relating overpressure to distance, where curve 1 means slow deflagration and curve 10 means detonation.

  - curve 7 (strong deflagration) was used for most scenarios in process area.
  - curve 3 (weak deflagration) was used for most scenarios in storage or open areas

Location of Explosion Ignition is assumed to occur at the centre of the gas cloud formed.

A 5.1.6. Internal Explosion

Internal explosion can occur due to the ignition of flammable mixture inside a reactor or other plant system. Internal explosions in reactors were assessed and overpressure effects from vessel burst assessed.

Potential explosion of cycle gas in the EO reactor due to excess of oxygen in the system (ie due to incorrect oxygen ratio control) was also assessed.

A 5.1.7. BLEVE

Flame impingement (typically due to escalation by a jet/pool fire) on a vessel containing liquefied pressurised gas type inventory could result in vessel failure and a BLEVE. A BLEVE is a catastrophic failure of a pressure vessel containing a flammable liquid above its boiling point at atmospheric pressure. Due to the intense heat radiation levels, a BLEVE may result in fatality and/or property damage to the surrounding areas.

For this study, BLEVEs were modelled using the dynamic BLEVE model for inventories or C3s, C4s, liquefied ethylene, EO and PO where escalation due to impingement from a fire from nearby equipment could occur.

A 5.1.8. EO Decomposition

EO decomposition can occur due to contamination or impinging fire (ie EO is heated to a temperature sufficient to initiate decomposition reaction). An EO decomposition reaction primarily produces gaseous carbon monoxide and methane and may also produce ethane, ethylene, hydrogen, carbon and acetaldehyde as well as significant heat energy.

EO contamination incidents can be described as ‘kindling chain’ events. A typical description of such a chain of events is: a small contamination of an EO vessel leads to a reaction of EO in the vessel, which leads to an overpressure and rupture of the vessel, which leads to formation of an EO vapor cloud, which subsequently results in a vapour cloud explosion. In many of the contamination incidents, as well as many of the EO decomposition incidents, most of the damage was due to the subsequent EO vapour cloud explosion.

For this study, the mechanism or extent of a decomposition reaction leading to the vessel rupture was not quantified. The consequence modelled for 'Decomposition’ scenarios is the loss of containment event following the decomposition reaction which results in vessel rupture and release of EO inventory to the atmosphere/plant leading to a VCE. No attempt was made to account for the amount of EO reacted to other flammables in the actual decomposition event. This released inventory was dispersed using the burst dispersion model to estimate the maximum flammable mass in the cloud. Subsequently, the TNO Multi Energy Method was used to estimate the impact of vapour cloud explosions (ie overpressure levels).

Although some of the EO quantity would have been 'used-up' during the initiating decomposition reaction, it is assumed that the whole EO inventory is available for release.

A.5.2. Model parameter summary

TABLE A5.2: MODELLING PARAMETERS

ITEM	VALUE	BASIS
Environment		
Ambient temperature	20 ˚C	Weather data, average annual temperature (assumed for whole year).
Soil temperature	20 ˚C	Assumed equal to ambient temperature.
Relative humidity	70%	Weather data, average relative humidity (assumed for whole year).
Solar radiation	1 kW/m^2 Day 0 kW/m^2 Night	Summer/winter insolation - estimated typical values (0.1 – 1 kW/m^2). Upper end is conservative.
Surface type	Light Concrete	Typical terminal surface parameters appropriate to gravel surface in bund and concrete in terminal area assumed for pool spreading calculation in Effects.
Roughness length	1 m	Ground roughness affects turbulent flow properties of wind, hence dispersion of a released material. Terrain effects are taken into account to some degree in dispersion modelling by use of a parameter known as surface roughness length. A surface roughness length of 1 m used corresponding to corresponding to an area with densely located low buildings or an industrial area with low structures such as the BIP. Also appropriate for suburban areas next to the BIP.
Model parameters		
Averaging time (flammables)	18.75 sec	TNO Yellow Book, Ref (10)
Averaging time (toxics)	600 se	TNO Yellow Book, Ref (10)
Receptor height (jet/pool fires)	1.5 m	1.5 m around upper body/face height
Receptor height (to LFL tank overfill scenario only)	1 m	For dispersion to LFL, based on UK HSE VCA model, Ref (11).
Maximum release duration	3600 sec	Assumed that emergency response would have occurred within this timeframe Note that actual release duration is dependent on inventory and release parameters of scenario
Maximum exposure duration	3600 sec	Assumed that emergency response would have occurred within this timeframe Note that actual exposure duration is dependent on type of scenario as per vulnerability correlations in APPENDIX 6.

APPENDIX 6. VULNERABILITY

A.6.1. Overview

There have been no changes to the fire and explosion vulnerability criteria applied since the 2012 QRA. There have been some changes to toxicity assessment as per Section A.6.3.

Individual fatality risk contours are based on the outdoor fatality vulnerability correlations for all types of effect (ie fire, explosion, toxicity).

Societal risk calculations account for different exposures for indoor and outdoor populations as per Section A.6.4.

A.6.2. Fire and explosion

For fire scenarios, people are vulnerable to fire through:

- engulfment by fire
- thermal radiation from a fire
- inside buildings exposed to fire.

Fixed levels of heat radiation are correlated to probability of fatality or injury. The fatality levels assume exposure duration to heat radiation of 20 seconds, ie exposed people do not or cannot move away or take shelter within this time, as per the TNO Green Book heat radiation probit.

For explosion scenarios, people are vulnerable to:

- impact by debris due to building damage
- overpressure

For explosions, fixed levels of overpressure are correlated to a probability of fatality. Fatality probabilities for people located both within buildings and outdoors are applied as per the default values in the Riskcurves software. Outdoor fatality probability due to overpressure is less than the fatality probability for people inside a building exposed to the same overpressure level as the building collapse risk is lower outside.

Fire and explosion vulnerability correlations are shown in Table A6.1.

TABLE A6.1: VULNERABILITY CRITERIA – FIRE / EXPLOSION

Event	Level	Probability of fatality assumed in QRA	Other effects
Jet fire Pool fire (Heat Radiation) 20 sec exposure TNO Green Book Probit Pr = -36.38 + 2.56 ln ($tQ^{1.33}$)	4.7 kW/m^2	-	Injury only as per HIPAP 4
	10 kW/m^2	1%	
	14 kW/m^2	10%	
	20 kW/m^2	50%	
	23 kW/m^2	70%	Escalation due to heat radiation as per HIPAP 4
	35 kW/m^2	100%	Often this will be within the flame envelope
	Within flame envelope	100%	Escalation (direct impingement)
Flash fire (Lower Explosive Limit (LEL))	Flame engulfment within LEL	100 %	Escalation (engulfment, but very short duration)
Explosion Additional explosion fatality effects outside the LEL are taken into account by assuming an average 2.5% fatality between the LEL and until the overpressure drops to 10 kPa or less as per Riskcurves default parameters.	7 kPa	-	Injury only as per HIPAP 4
	10 -30 kPa	(Inside building) 2.5% (Outside) 0%	
	14 kPa	as for 10-30 kPa	Escalation as per HIPAP 4
	≥ 30 kPa	(Inside building) 100% (Outside) 100%	
	Within LEL (flash fire envelope)	within LEL 100% fatality (inside building) and (outside).	
BLEVE	Diameter of BLEVE	100% fatality within the diameter of the fireball projected onto the ground. Heat radiation outside the diameter of the fireball is calculated as per the probit equation for fires, but using the estimated BLEVE duration calculated by Riskcurves (usually of the order of 8 – 12 seconds) rather than 20 seconds	NOTE: As for explosions, overpressure effects can cause an additional 2.5% fatality up to the 10 kPa overpressure radius. For BLEVEs the peak overpressure is normally within the fireball radius so overpressure effects do not contribute to the fatality calculations.
NOTE: Pr probit corresponding to probability of death (-) Q heat radiation level (W/m2) T exposure time (s)			

A.6.3. Toxicity

As required by HIPAP 4, the risk of a range of acute toxic effects including irritation, serious injury or fatality due to a toxic gas release is considered in the QRA. Table A6.2 summarises the toxic fatality, injury and irritation effects and corresponding probability criteria used in the QRA. The text following the table provides some additional explanation of the selection basis.

Some changes have been made to the approach to reflect improved modelling techniques as summarised in Section A 6.3.4.

A 6.3.1. Fatality

Probability of fatality is estimated from a toxic dose using probit equations of the form

$$Pr = A + b \ln(c^n t)$$

c concentration (ppm)

t time (min)

These can then be converted to a probability of fatality using the error function transform:

$$\text{Probability} = 0.5(1 + \text{erf}(\frac{Pr - 5}{\sqrt{2}}))$$

A 6.3.2. Toxic Injury/Irritation

HIPAP 4 injury and irritation risk criteria for toxic gas exposure are shown below.

Injury:

"Toxic concentrations in residential areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure at a maximum frequency of 10 in a million per year."

Irritation:

"Toxic concentrations in residential areas should not cause irritation to eyes or throat, coughing or other acute physiological response in sensitive members of the community over a maximum frequency of 50 in a million per year."

Establishing the appropriate criteria for a particular chemical necessitates determination of the terms "seriously injurious", "sensitive", "relatively short" and "irritation".

The concentrations used to represent toxic injury and irritation thresholds were established by referring to human exposure data available in the Acute Emergency Guideline Levels (AEGLs) documentation published by the US EPA. The AEGL (10 min) values were chosen as these correspond most closely to a relatively short exposure and converted to an equivalent dose (within the Riskcurves software) to account for variation in exposure duration for different scenarios.

A 6.3.3. Reduced dose experienced by indoor population

The concentration of gas inside a building engulfed by a gas cloud will rise gradually until the release has stopped and the cloud passed. The indoor concentration then falls gradually towards zero. The peak concentration inside will be much less than that outside, (unless the duration of the release is very long or the building has very high ventilation rates). Hence, a person inside will be exposed to significantly lower gas concentrations than someone outside and the risk of fatality from a toxic gas will be significantly less for a person indoors than risk in the open at the same location.

This affect is accounted for in the QRA within the risk model using the ventilation rate. Natural ventilation rate was assumed which is 1 air change per hour.

Note that the previous QRA used a modified probit approach to model the reduced dose to indoor populations for inclusion in the societal risk calculations as the software version at the time was not able to explicitly account for indoor dose reduction.

A 6.3.4. Changes in toxic impact modelling since 2012 QRA

In summary the changes made in toxicity modelling since the 2012 QRA are:

1. AEGL (10min) equivalent dose used for toxic injury and irritation. This replaces the ERPG (60min) values extrapolated to 15 minutes and various other values which were used in the previous QRA. The change in approach generally results in smaller effect distances hence smaller toxic injury / irritation risk contours. It is regarded as a more realistic approach than the previous exceedance of threshold concentration (regardless of exposure duration) approach. This change has also been made as:
   a. AEGLs are defined for a range of exposure periods from 10 minutes to 8 hours whereas ERPGs are defined for 60 mins only. AEGL (10 mins) more closely reflects the HIPAP 4 toxic injury / irritation assessment criteria of "*a relatively short period of exposure"* compared to ERPG (60 mins).
   b. AEGLs as toxic assessment criteria are consistent with the operator MHF safety cases, hence provides a more consistent basis for assessing the cumulative toxic injury risk as part of the BIP QRA.
   c. Riskcurves v 10 is able to model frequency of exceeding toxic dose (non-fatal) which was functionality not available in earlier versions of the software.
2. Toxic dose to indoor population is calculated based on ventilation rate within the Riskcurves software instead of using a modified probit (Fielding, Ref 14) to reflect the reduced dose to indoor populations. This option was not available in previous versions of the software and is believed to be more accurate than the modified probit approach as it more accurately accounts for the exposure duration of the toxic dose calculation. This change affects societal risk estimates only. For this QRA, this change generally results in a lower toxic dose indoors than the previous methodology as some scenarios are fairly short duration due to the limited inventory of chlorine released for the majority of toxic release scenarios.

TABLE A6.2: TOXIC FATALITY, INJURY AND IRRITATION CRITERIA

Plant	Material	Probit -	Effect	BIP QRA 2018	Basis	Comments
ChlorAlkali	**Chlorine**	$-4.86 + 0.5\ln(c^{2.75}t)$	Fatality	103 ppm	1% fatality at 10 mins)	
			Injury	50ppm	AEGL 3(10 min)	
			Irritation	2.8 ppm	AEGL 2(10 min)	
	Hydrogen Chloride	$-35.76 + 3.69\ln(ct)$	Fatality	3334 ppm	1% fatality at 10 mins)	
			Injury	620 ppm	AEGL 3(10 min)	
			Irritation	100 ppm	AEGL 2(10 min)	
Olefines	**Ethyl Mercaptan**	n/a - no fatality	Fatality	-	-	
			Injury	360 ppm	AEGL 3(10 min)	10 and 30 mins AEGLs same value
			Irritation	120 ppm	AEGL 2(10 min)	
	1,3-Butadiene	n/a - no fatality	Fatality	-	-	
			Injury	27000 ppm	AEGL 3(10 min)	10 and 30 mins AEGLs same value
			Irritation	6700 ppm	AEGL 2(10 min)	
	DMDS	n/a - no fatality	Fatality	-	-	
			Injury	250 ppm	ERPG 3 (60 min)	AEGL not available
			Irritation	50 ppm	ERPG 2 (60 min)	AEGL not available
Surfactants	**Ethylene Oxide**	$-6.8 + 1\ln(ct)$	Fatality	-	-	UK HSE SLOD ($1.8x10^{5}$ppm.min) suggests fatality range 18,000 ppm for 10 mins. This is approaching the LEL. Given the high ignition probability of EO, fatality due to toxicity (ie unignited case) is not modelled in QRA, injury/ irritation only for unignited case.
			Injury	360 ppm	AEGL 3(10 min)	
			Irritation	80 ppm	AEGL 2(10 min)	
	Propylene Oxide	Not available	Fatality	-	-	Not highly toxic compared to EO and few PO scenarios

Plant	Material	Probit -	Effect	BIP QRA 2018	Basis	Comments
						Fatality due to unignited releases not modelled.
			Injury	1300 ppm	AEGL 3(10 min)	
			Irritation	440 ppm	AEGL 2(10 min)	
GTP	**Chlorine dioxide**	Not available - use chlorine	Fatality	as for chlorine	as for chlorine	
			Injury	3 ppm	AEGL 3(10 min)	
			Irritation	1.4 ppm	AEGL 2(10 min)	

A.6.4. Societal Risk Mitigation Factors

Mitigation factors are applied to the vulnerability of people in the societal risk calculations as per the following table for different types of effect.

TABLE A6.3: SOCIETAL RISK MITIGATION FACTORS

Effect	Comments	Factor Outdoor Population	Factor Indoor Population
Pool fire/ jet fire - heat radiation	No effect indoors as walls provide adequate shielding. As per TNO Purple Book QRA guidance effect of clothing accounted for outdoor population	0.14	0
Pool fire/ jet fire – within flame zone	Engulfment with sustained fuel supply No additional factors applied	1	1
Flashfire – engulfment	Short duration event. Indoor populations shielded from effect.	1	0
BLEVE - heat radiation	Short duration event. Indoor populations shielded from effect.	1	0
Explosion Overpressure	The difference in exposure for indoor or outdoor population is already covered in the vulnerability correlations in Table A6.1. No additional factors applied	1	1
Toxic releases	Outdoor is maximum exposure (ie maximum dose) Indoors reduced toxic dose calculated in risk model based on ventilation rate. Assumed to be 1 air change per hour (natural ventilation).	1	Variable Reduced dose calculated within Riskcurves based on ventilation rate

APPENDIX 7. METEOROLOGICAL DATA

A.7.1. Data source

Historical meteorological weather data for the BIP was obtained from the Bureau of Meteorology (BoM). The acquired data sets were based on hourly readings from the Automatic Weather Station (AWS) at Sydney Airport (AWS 66037) located approximately 2 km away from the BIP. Data for the period from January 2006 to January 2017 was obtained and consolidated into the format required by the QRA software.

A.7.2. Pasquill stability class

Gifford (Ref. 15) defines the conditions for different stability classes as summarised below.

TABLE A7.1: STABILITY CLASS ALLOCATION

Surface wind speed, m/s	Daytime insolation			Night time conditions	
	Strong	Moderate	Slight	Thin overcast or >4/8 low cloud	≥ 3/8 cloudiness
<2	A	A-B	B	F	F
2-3	A-B	B	C	E	F
3-4	B	B-C	C	D	E
4-6	C	C-D	D	D	D
>6	C	C	D	D	D

A.7.3. Representative stability class and wind speed

Analysis of the obtained raw data was performed to obtain the representative weather conditions (including wind speed and stability classes) appropriate for the QRA. For the purposes of the study, the data were consolidated into six different representative weather conditions which are:

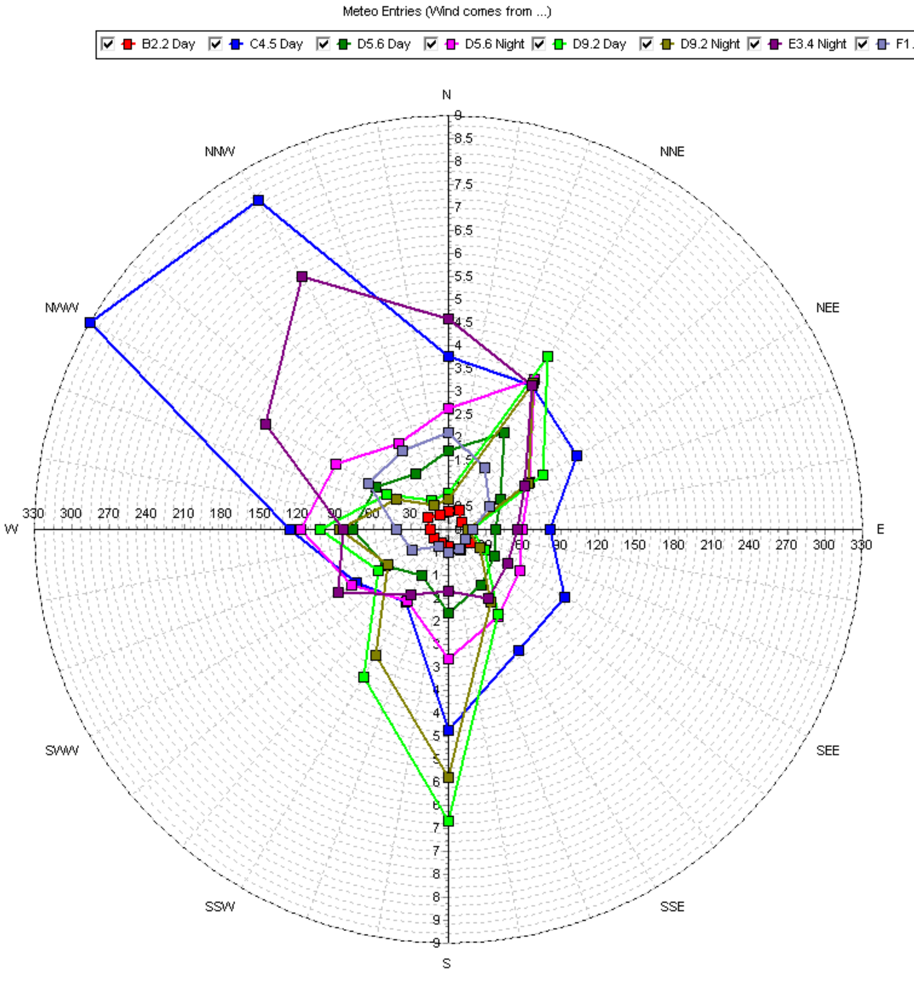
- Pasquill Stability Class: B; wind speed 2.2 m/s (B2.2)
- Pasquill Stability Class: C; wind speed 4.5 m/s (C4.5)
- Pasquill Stability Class: D; wind speed 5.6 m/s (D5.6)
- Pasquill Stability Class: D; wind speed 9.2 m/s (D9.2)
- Pasquill Stability Class: E; wind speed 3.4 m/s (E3.4)
- Pasquill Stability Class: F; wind speed 1.7 m/s (F1.7).

The meteorological data sets used for the QRA are presented in Table A7.2. The wind rose map is provided in Figure A7.1.

TABLE A7.2: METEOROLOGICAL DATA SETS USED FOR THE QRA

		% occurrence								Total	
Direction wind from		B2.2 Day	C4.5 Day	D5.6 Day	D5.6 Night	D9.2 Day	D9.2 Night	E3.4 Night	F1.7 Night	Day	Night
(degrees true)											
345-015	N	0.39	3.76	1.70	2.64	0.79	0.67	4.59	2.11	6.65	10.02
015-045	NNE	0.50	3.61	2.43	3.76	4.34	3.69	3.61	1.56	10.88	12.63
045-075	NEE	0.34	3.21	1.31	2.03	2.36	2.00	1.91	1.02	7.22	6.97
075-105	E	0.47	2.22	1.04	1.61	0.49	0.42	1.51	0.54	4.22	4.08
105-135	SEE	0.56	2.93	1.17	1.81	0.92	0.78	1.49	0.44	5.59	4.52
135-165	SSE	0.52	3.05	1.40	2.18	2.14	1.82	1.72	0.48	7.11	6.20
165-195	S	0.37	4.37	1.83	2.83	6.35	5.40	1.34	0.50	12.92	10.08
195-225	SSW	0.32	1.84	1.16	1.80	3.70	3.15	1.65	0.44	7.02	7.04
225-255	SWW	0.36	2.31	1.57	2.42	1.77	1.51	2.76	0.91	6.01	7.61
255-285	W	0.40	3.45	2.08	3.22	2.80	2.38	2.28	1.13	8.73	9.01
285-315	NWW	0.51	9.01	1.83	2.83	1.55	1.32	4.58	2.00	12.90	10.73
315-345	NNW	0.37	8.27	1.40	2.17	0.72	0.62	6.35	1.99	10.76	11.13
Total		**5.11**	**48.04**	**18.92**	**29.31**	**27.93**	**23.76**	**33.80**	**13.14**	**100.00**	**100.00**

FIGURE A7.1: WIND ROSE DISTRIBUTION



APPENDIX 8. POPULATION DATA

A.8.1. Updates compared to 2012 QRA

The population data used in the 2012 QRA was based on the Australian Bureau of Statistics (ABS) Census 2006 data projected estimates for 2010. (There was a Census in 2011 however that data was not available in the required format at the time the 2012 QRA was done).

The population data has been completely updated for the 2018 QRA. The population data for the 2018 QRA is largely based on the 2016 Census which contains the most recent available population estimates, supplemented by details of additional developments that have occurred in the area since the Census was completed. The data has been used as explained in the following sections of this appendix.

A.8.2. Source Data 2018 QRA

Residential population data from the 2016 Census was obtained from the ABS.

Employment population (ie industrial/commercial) was obtained from Transport for NSW (TfNSW). The Travel Zone (TZ) Projection 2016 developed from the 2011 Census was used. (Note that the equivalent TZ data from the 2016 Census data was not available from TfNSW).

The data was initially obtained for areas within approximately a 2km radius of the centre of the BIP site. This is greater than the largest estimated impact area to the 1% fatality consequence for any scenario the BIP QRA, so is sufficient to account for all potentially affected populations.

This data was then supplemented by specific data for particular locations such as Eastgardens and Bunnings.

Two cases were considered:

1. 'Current case' largely based on 2016 Census data. This does not include known approved developments that are not yet occupied.
2. 'Approved development' case which represents data from the Census 2016 plus population estimates for developments that have been approved around the BIP but are not yet occupied or were likely to be occupied only after the collection date of the 2016 Census (ie data not captured in Census). This includes the BIP subdivision on Denison St and Corish Circle, Bunnings on Denison St opposite the BIP, and the Meriton redevelopment of the former tobacco sites adjacent to Eastgardens. The populations assumed for these developments are thought to be conservative estimates, ie likely to overestimate the populations once occupancy commences.

Table A8.1 summarises the various data sources used to compile the population data input to the QRA.

Table A8.2 summarises the specific data sources used for both the 'current case' and 'approved development' case and also compares it to the 2012 QRA data sources.

Table A8.3 lists the raw TfNSW TZ data used for employment populations.

Table A8.4 lists the raw ABS Census data used.

TABLE A8.1: DATA SOURCES

Data	Source	Comments
Data for general area:		
Residential population	Aust Bureau of Stats (www.abs.gov.au)	Latest available ABS Census data is 2016. The data projections for 2017 have been used in the QRA. This data represents the maximum residential population (i.e. night time). Data was supplied by ABS as a centroid for each Census Statistical Area (SA) Level 1 (X,Y, no of people).
Employed population (ie commercial / industrial)	Transport NSW	Data was supplied by TfNSW for each Travel Zone around the BIP site as a centroid (X,Y, no of people). This data represents the number of people who travel into the area close to the BIP for work, i.e. the commercial / industrial population. The data is produced from information collected in the 2011 Census. The values projected for 2016 were used.
BIP site		
Population on BIP site (i.e. BIP, Nant St)	Convention used in QRA as focus is risk to external populations, not employee risk.	The population of the BIP (505 during, 51 at night) has been removed from the employment data for the TZ that covers the BIP and the populations on the BIP site and Nant St set to 0. The remaining population from the employment data (TZ400: 3052 – 505 = 2547 people) has been reallocated over the remaining area of the travel zone that the BIP is within.
Additional point sources:		
Schools	-	No specific data was entered for schools as the pupils are assumed to be largely local and covered by the Census data. The nearest school is Matraville Public around 400m to the east of Denison St.
Eastgardens shopping centre	Joint Regional Planning Panel report (JRPP Number 2014SYDE076) for DA 2017/1107 by Bayside Planning Panel states carspaces as 3089 (though 418 are for staff)	Eastgardens Shopping Centre population is assumed as 3089 shoppers (in addition to the staff who are identified in travel zone data TZ423) for day time only. Note: that this is regarded as a best estimate and could be an over or underestimate for shoppers as there would be multiple people in some cars and public transport usage, but people are not present all day.

Data	Source	Comments
Bunnings development, Denison St east side	Dangerous Goods Transport QRA, Denison St, Hillsdale (Systra Scott Lister Issued: 12th February, 2015)	200 people (day time only)
BIP subdivision, Denison St west side	Statement of Environmental Effects (SEE) Botany Industrial Park Staged 20-Lot Subdivision 20 Dec 2010	DA 10/486 approved by Land and Environment Court on 13/09/2012 for 20 lot subdivision. Number of people over whole area (including former Masters site on Corish Circle) originally estimated at 523 based on parking spaces (SEE, Section 3.4.4) 200 day time only on the southern part of the subdivided area along Denison St as advised by the DPE (compared to ~260 which was in some previous studies) (ie Department and Bayside Council have agreed in 2017 based on Scott Lister transport QRA study that a maximum population of 200 should be allowed at the closest to BIP ten lots). Zero population on lots with covenant (ie R1 and R2 restrictions as per Deposited Plan 1204999) 265 day time only on former Masters site Note this total is lower than SEE assumption, (remaining total in QRA is ~ 465 cf 523 in SEE)
Meriton development Former BATA Site, Banks Avenue, Heffron Road & Bunnerong Road, Eastgardens	Planning Proposal, Prepared for Meriton, 128 and 130-150 Bunnerong Road Pagewood, URBIS April 2017	Tobacco workers removed from TZ423 data as BAT/ Wills has shut down Construction phase: 2000 workers from Urbis Meriton: 2000 residential units behind Eastgardens shopping centre. QRA assumes 2.2 people per unit as per DPE advice for high density residential . Up to 5000m^2 retail floor space. Not specifically accounted for. Up to 30,000m^2 business (office) floor space. Not specifically accounted for.

A 8.2.1. Data entry

To compile the overall population in the Riskcurves software the method is:

1. Identify the risk affected area within the $1x10^{-11}$ per year individual fatality risk contour (as any populations outside this will have no impact on the societal risk as the relevant criteria extend down to $1x10^{-10}$ per year across all N).
2. TZ and SA shapes only within the risk affected area are imported to minimise model run times.
3. Import the relevant data as shape files with a population attached to them. This can be done for multiple data sets with different shape files and numbers of people.

4. Once all data entered, these are transformed within the software into a cumulative population dataset in X,Y,Z grid point form, ie location (X,Y) population (Z), within the software.
5. For areas where there is specific data available, a shape can be overlaid on to the grid and the population zeroed out within the shape and replaced with whatever value is applicable. A population at specific X,Y points can also be added.
6. The population data is entered separately for day and night populations.
7. A factor is input to spilt the resulting populations between indoor and outdoor.

For the BIP QRA there were two main data sets:

- Data Set 1 - Residential Population from ABS
- Data Set 2 – TfNSW Travel Zone Data

Therefore the process was:

1. Data Set 1 was input to the model by importing the known population from the Census and the statistical area (SA) shapes, ie the ABS defined geographical areas.
2. Similarly, data Set 2 is input and combined in the model by defining/adding the known number of employment/workforce based on the travel zones (TZ) shapes, which is a Transport NSW defined geographical area (different shape and size to the SAs).
3. For specific areas such as Bunnings or the BIP, a new shape is drawn over the cumulated data in the relevant location and the population within that set to zero. This is then replaced with the correct value for the area, eg 200 in Bunnings case, left as 0 for the BIP as onsite population is not included in a societal risk calculation).
4. Any remaining population is then redistributed over the relevant area if required. For example, the BIP is in TZ400. This has been split into 3 custom polygon shapes: the BIP shape with population set to zero and two shapes TZ400N and TZ400S covering the remaining area of TZ00, with the remainder of the TZ400 population allocated to each polygon based on area (ie the population density in TZ400N and TZ400S is assumed to be the same).

A 8.2.2. Multilevel developments

For multi-level developments (ie Meriton) all population has been allocated to ground level, ie height is not accounted for. This is regarded as a conservative best estimate approach as mitigation factors are already applied to societal risk calculations for indoor populations as per APPENDIX 6, Section A.6.4 as follows:

1. Fires: no heat radiation impact on inside populations (so no effect on results).
2. Flashfires/BLEVEs: no engulfment / heat radiation impact on inside populations (so no effect on results).

3. Explosions: An explosion event that causes serious structural damage will have the potential to result in collapse of buildings and affect populations on many floors not just lower floors. A conservative best estimate is to assume all population in a building is potentially affected in a building structural collapse, ie overpressures > 30kPa. There is already a factor of 2.5% applied for overpressures below 30kPa as per APPENDIX 6.
4. Toxicity: In the absence of any details around air conditioning / ventilation design it can be assumed that air conditioning would potentially distribute a reduced toxic dose throughout the entire building. There is already a reduced toxic dose applied to inside populations accounting for ventilation rate as per APPENDIX 6.

A 8.2.3. Comparison Between 2012 and 2018 QRA population data

The population data cannot be directly compared between the 2018 and 2012 QRAs.

This is because the area which the data covers has changed and the shapes used in the Census data collection have completely changed between the 2006 Census (used for the 2012 QRA) and the 2016 Census (2018 QRA).

TABLE A8.2: SUMMARY OF DATA USED IN QRA

Legend:

Change between 'Current' and 'Approved Development' cases

Area	2012 QRA		Updated Data Set 2018 QRA			
			Current Case		Approved Development	
	Residential/Other	Employment	Residential/Other	Employment	Residential/Other	Employment
1. General - Residential	2010 estimated population based on 2006 Census	-	2017 Estimated Population (ABS 2016 Census)	-	2017 Estimated Population (ABS 2016 Census)	-
2. General - Employment	-	2011 JTW	-	2016 Employment (TfNSW TZ Projection 2016 from 2011 Census)	-	2016 Employment (TfNSW TZ Projection 2016 from 2011 Census)
3. Westfield Eastgardens	Shoppers - 4500	2011 JTW	Shoppers - 3089 (JRPP)	2016 Employment (TfNSW TZ Projection 2016 from 2011 Census minus BAT tobacco workers)	Shoppers - 3089 (JRPP)	2016 Employment (TfNSW TZ Projection 2016 from 2011 Census)
4. Meriton Apartments	- (None. Part of industrial area BAT site)	2011 JTW	.-	2000 (assumed construction based on Urbis report)	2.2 people/ household (fully developed all towers) DPE Urban Team recommended a floor space of 2.2 people/household for similar high-rise developments in Sydney, eg Carter St and Camelia Precinct	2016 Employment (TfNSW TZ Projection 2016 from 2011 Census minus BAT tobacco workers)
5. Bunning's Warehouse	0		200		200	
6. BIP 20-lot subdivision (this is only the area along Denison St)	0		0 (not yet occupied)		200 (with zero population on lots with R2 restriction on title)	
7. Corish Circle Development	0		0 (not yet occupied)		265	

			Updated Data Set 2018 QRA			
Area	**2012 QRA**		**Current Case**		**Approved Development**	
	Residential/Other	**Employment**	**Residential/Other**	**Employment**	**Residential/Other**	**Employment**
8. Schools	As per Dept Ed and school websites (NOTE: probably double counted as most would be within area covered by Census data however nearest is Matraville public ~ 400m away from BIP boundary so minimal effect)		0		0	

TABLE A8.3: TfNSW TRAVEL ZONE DATA USED IN QRA

Transport NSW TZP2016 Employment Projections								
TZ	**Description**	**Area (m2)**	**Employment (2016)**	**Population (Day time)**	**Pop Density (psn per 2500m2)**	**Pop Density (psn per ha)**	**Population (Night time)**	**Adjustments made**
400	Orica Australia	1388925	3052	0	0.0	0.0	0	remove BIP population of 505 and allocate remainder over remainder of TZ area
401	Discovery Cove Industrial Park	1175009	2741	2741	5.8	23.3	0	
402	Caltex Sydney Terminal	803974	781	781	2.4	9.7	0	
406	Botany William St	410737	476	476	2.9	11.6	0	
408	Botany Industrial Area	1724401	2930	2930	4.2	17.0	0	
421	Bonnie Doon Golf Club	941517	187	187	0.5	2.0	0	
422	Pagewood_Wentworth Av and Page St	605693	440	440	1.8	7.3	0	
423	Eastgardens Shopping Centre	300664	3479	0	0.0	0.0	0	Split into shape for Eastgardens and shape for Meriton (former BAT/ Wills). Remove tobacco workers from data (616 people). All remaining population to Eastgardens. For Meriton residential density ('approved case' only) as per DPE advice and construction workers as per Urbis report ('current case' only)
424	South Point Shopping Centre	512840	1041	0	0.0	0.0	0	Split into shape for Bunnings and remainder polygon. 200 extra people to Bunnings and all TZ population to remaining shape
425	Matraville Public School	270005	181	181	1.7	6.7	0	
428	Port Botany Business Park_West	347920	917	917	6.6	26.4	0	
429	Military Rd	1275115	2521	2521	4.9	19.8	0	
430	Port Botany_Southern Container Terminal	1180796	1721	1721	3.6	14.6	0	
624	Matraville_Eastern Rd and Beauchamp Rd	527346	187	187	0.9	3.5	0	
625	Matraville	405871	1672	1672	10.3	41.2	0	
627	Matraville_Menin Av and Flinders St	686839	278	278	1.0	4.0	0	
628	Port Botany Business Park_East	454679	293	293	1.6	6.4	0	
629	Matraville High School	1339005	426	426	0.8	3.2	0	
640	South Sydney High School	852112	740	740	2.2	8.7	0	
645	Heffron Park	789884	25	25	0.1	0.3	0	
				16516			0	
				Max	10.3	41.2		
				Min	0.0	0.0		

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TABLE A8.4: ABS CENSUS SA DATA USED IN QRA

ABS Estimated Resident Population 2017								
SA1 2016	**Estimated Resident Population 30 Jun 2017**	**Total Area (sq km)**	**Pop Density (psn per sq km)**	**Population (Day time) 1/3 of total**	**Population (Night time)**	**Pop Density (psn per 2500m2)**	**Pop Density (psn per ha)**	**Adjustments made**
1132001	14	1.1751	11.91387967	5	14	0.029784699	0.119138797	
1132002	7	1.3892	5.038871293	3	0	0.012597178	0.050388713	BIP. Population zeroed out
1132003	0	0.804	0	0	0	0	0	
1132108	487	0.1111	4383.438344	163	487	10.95859586	43.83438344	
1132113	463	0.0985	4700.507614	155	463	11.75126904	47.00507614	
1132121	0	0.4215	0	0	0	0	0	
1132124	393	0.0546	7197.802198	131	393	17.99450549	71.97802198	
1132125	78	0.0168	4642.857143	26	78	11.60714286	46.42857143	
1132126	350	0.0719	4867.872045	117	350	12.16968011	48.67872045	
1132127	1346	0.0883	15243.48811	449	1346	38.10872027	152.4348811	
1132128	343	0.089	3853.932584	115	343	9.634831461	38.53932584	
1132129	411	0.0723	5684.647303	137	411	14.21161826	56.84647303	
1132130	228	0.1619	1408.276714	76	228	3.520691785	14.08276714	
1132302	300	0.0847	3541.912633	100	300	8.854781582	35.41912633	
1132309	863	0.0623	13852.32745	288	863	34.63081862	138.5232745	
1132310	489	0.1714	2852.975496	163	0	7.13243874	28.52975496	Bunnings zeroed out and reallocated to custom shapes
1132311	409	0.0172	23779.06977	137	409	59.44767442	237.7906977	
1132312	357	0.0158	22594.93671	119	357	56.48734177	225.9493671	
1132313	430	0.0233	18454.93562	144	430	46.13733906	184.5493562	
1132314	444	0.042	10571.42857	148	444	26.42857143	105.7142857	
1132318	280	0.0719	3894.297636	94	280	9.735744089	38.94297636	
1132319	401	0.0973	4121.274409	134	401	10.30318602	41.21274409	
1132320	517	0.1393	3711.414214	173	517	9.278535535	37.11414214	
1132321	0	0.3007	0	0	0		0	Eastgardens
1132322	466	0.0238	19579.83193	156	466	48.94957983	195.7983193	
1132323	376	0.0359	10473.5376	126	376	26.18384401	104.735376	
1132324	0	0.5611	0	0	0	0	0	
1132325	498	0.0197	25279.18782	166	498	63.19796954	252.7918782	
1132326	361	0.0611	5908.346972	121	361	14.77086743	59.08346972	
1132327	619	0.0384	16119.79167	207	619	40.29947917	161.1979167	
1132328	546	0.0353	15467.4221	182	546	38.66855524	154.674221	
1132329	251	0.0547	4588.665448	84	251	11.47166362	45.88665448	
1132401	7	2.8044	2.496077592	3	7	0.006240194	0.024960776	
1135001	413	0.0847	4876.033058	138	413	12.19008264	48.76033058	
1135002	567	0.0695	8158.273381	189	567	20.39568345	81.58273381	
1135006	514	0.1495	3438.12709	172	514	8.595317726	34.3812709	
1135020	665	0.0999	6656.656657	222	665	16.64164164	66.56656657	
1135021	745	0.1453	5127.32278	249	745	12.81830695	51.2732278	
1135022	714	0.1195	5974.895397	238	714	14.93723849	59.74895397	
1135023	547	0.1567	3490.74665	183	547	8.726866624	34.9074665	
1135041	441	0.1283	3437.25643	147	441	8.593141076	34.3725643	
1135042	384	0.1543	2488.658458	128	384	6.221646144	24.88658458	
1135043	352	0.0859	4097.788126	118	352	10.24447031	40.97788126	
1135044	568	0.1209	4698.097601	190	568	11.745244	46.98097601	
1135047	307	0.1922	1597.294485	103	307	3.993236212	15.97294485	
1135048	569	0.1071	5312.791783	190	569	13.28197946	53.12791783	
1135050	451	0.0444	10157.65766	151	451	25.39414414	101.5765766	
1135053	347	0.0711	4880.45007	116	347	12.20112518	48.8045007	
1135056	436	0.0696	6264.367816	146	436	15.66091954	62.64367816	
1135057	380	0.0495	7676.767677	127	380	19.19191919	76.76767677	
1156805	485	0.1413	3432.413305	162	485	8.581033263	34.32413305	
1156815	613	0.1111	5517.551755	205	613	13.79387939	55.17551755	
1156821	0	0.4941	0	0	0	0	0	
			TOTAL	7096	20736			
					Max	63.197970	252.791878	
					Min	0	0	

A.8.3. Day and Night Populations

Weighting factors have been applied to the raw data to distribute population between day and night and inside and outside populations. The factors used are summarised in the following table. Note that these factors have been agreed with DPE in previous studies and have not changed since the previous QRA.

TABLE A8.5: POPULATION FACTORS

Factor	Value	Comments
Day and Night Time Weighting Factor	0.5	Assumed that day is 7am to 7pm
Night Time population		Residential only. Census data values used for residential population. All industrial / commercial population = 0 at night
Fraction of population outside at night	0.05	No particular basis. Has been used before in previous studies approved by DPE and is consistent with previous BIP QRAs.
Day Time Population		No particular basis. Has been used before in previous studies approved by DPE and is consistent with previous BIP QRAs. Residential - use 1/3 of Census value. (Remaining 2/3 assumed at work out of area) Other industrial / commercial - use values in Travel Zone data and additional sources (eg Eastgardens shoppers) in Table A8.2.
Fraction of population outside during day	0.10	No particular basis. Has been used before in previous studies approved by DPE and is consistent with previous BIP QRAs.

A.8.4. Population Data Compilation

Figures A8.1 and A8.2 give a graphical representation of the resulting total population data used as an input to the 2018 QRA for societal risk calculations. These show day and night time population densities.

NOTE: the legend scales in the day and night population figures are not the same, ie the night time populations are higher than the maximum daytime population in some areas, and the nigh time scale therefore has a higher upper limit than the day time population scale.

FIGURE A8.1:TOTAL POPULATION DAY TIME

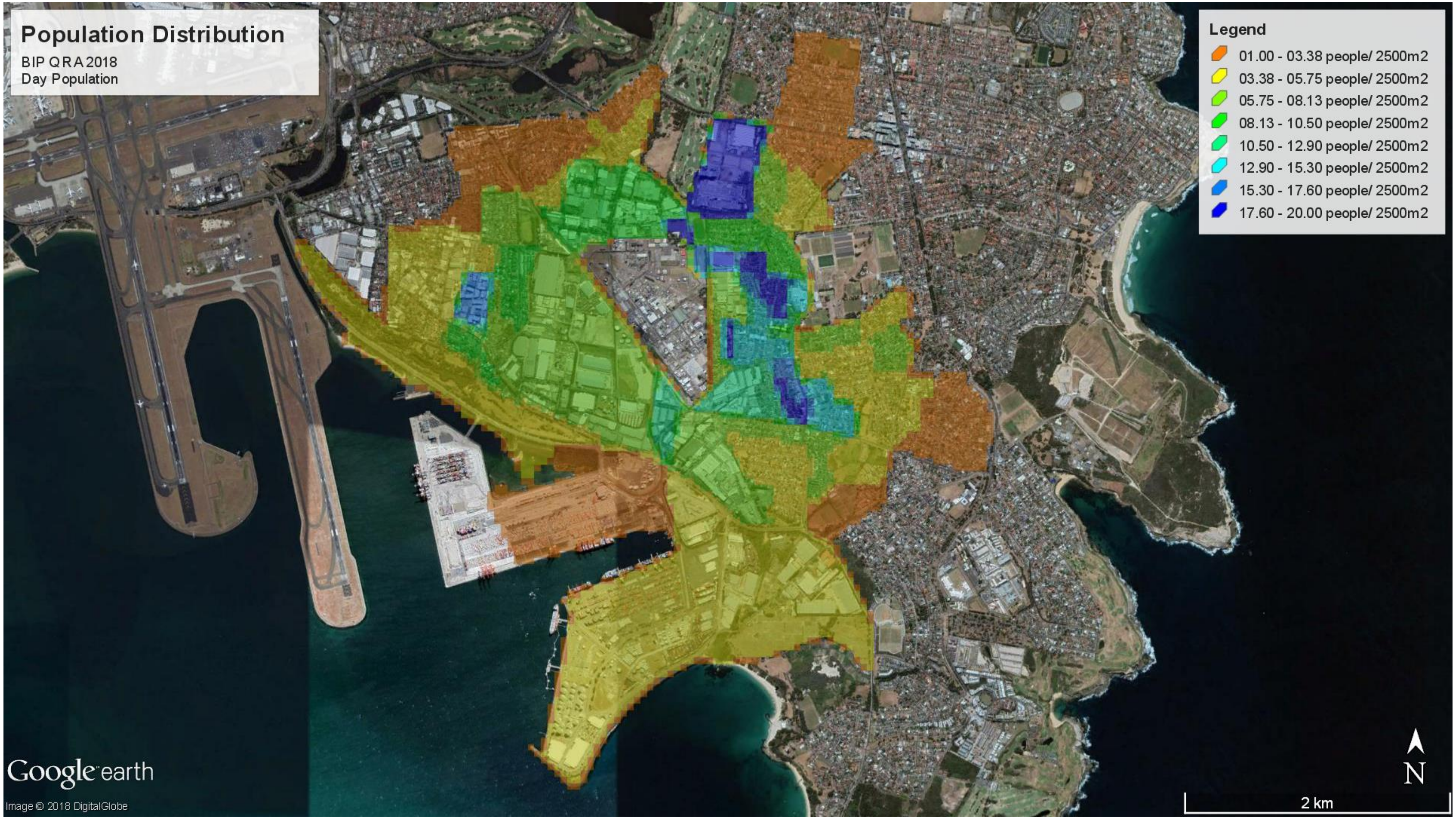
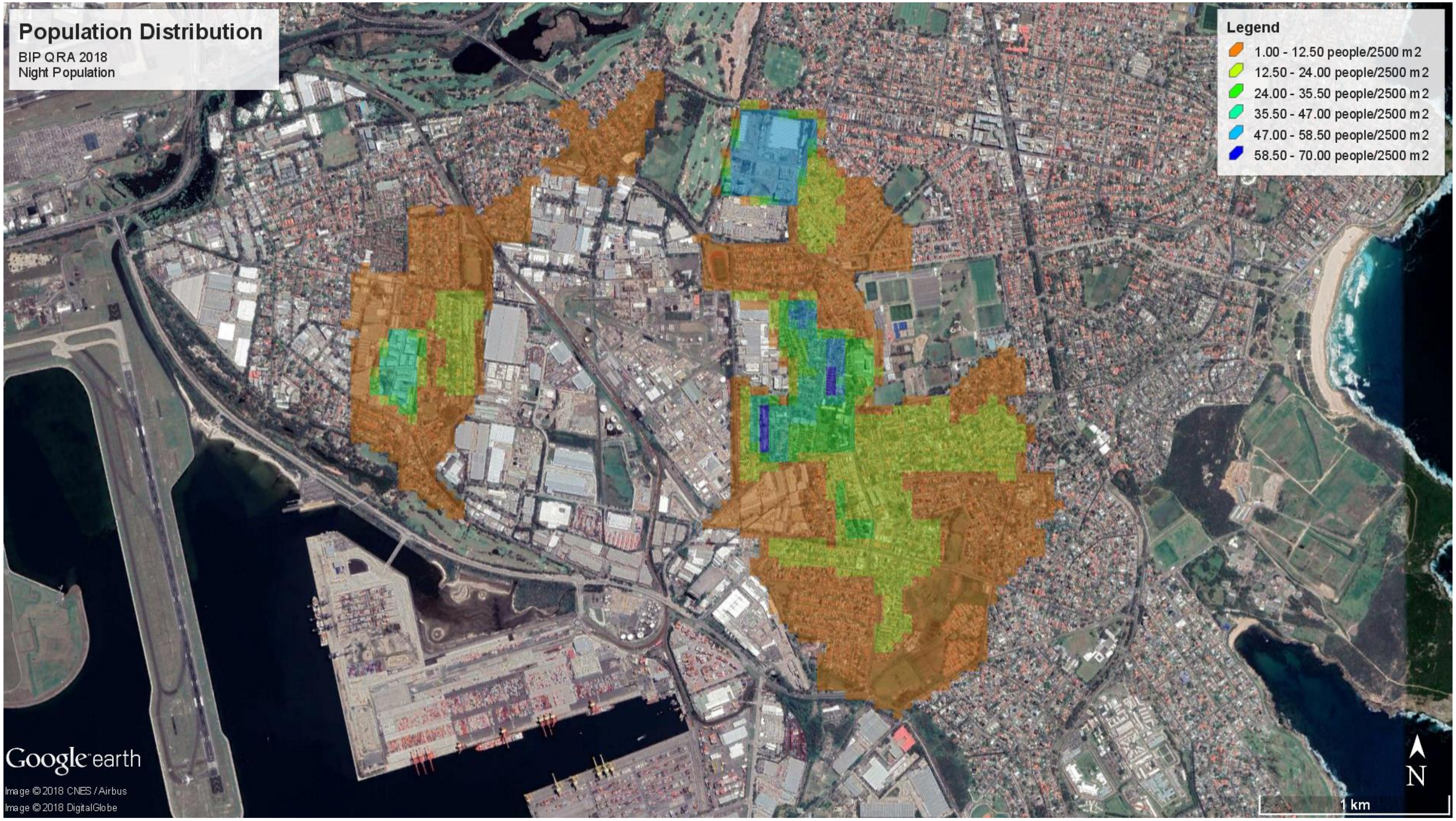


FIGURE A8.2: TOTAL POPULATION NIGHT TIME



APPENDIX 9. FREQUENCY ASSESSMENT DATA

A.9.1. Overview

The base data used in the QRA frequency assessment is summarised in this appendix.

A.9.2. Generic Equipment Failure Frequencies

In the previous QRAs, piping and equipment mechanical failures frequencies have been estimated from data compiled and originally published for internal use by ICI (Ref 16) from frequency estimates published by the Institution of Chemical Engineers (Ref 17) or the CCPS (Ref 18). For the QRA update this data was generally updated to more recently published data (UK HSE, Ref 19, OGP Ref 12).

The base frequencies are usually expressed on a per m of pipe or per equipment item basis per year or per million operating hours. The previous QRA used PIDs to estimate the number of flanges, and pipe lengths were estimated from layout and mechanical drawings. There have been minimal changes to the plant equipment and layout so these estimates are unchanged from the previous QRA.

Where equipment has been decommissioned the parts count has been reduced accordingly.

TABLE A9.1: BASE FAILURE FREQUENCIES

Equipment type and size	Frequency (per year) by Hole Size[#]				Source
	3 mm	25 mm	50 mm	Full bore/ Rupture	
Pressure Vessel	4.0E-05	5.0E-06	5.0E-06	2.0E-06	UK HSE
Chemical Reactor	4.0E-05	5.0E-06	5.0E-06	2.0E-06	UK HSE
Pump (Generic)	-	5.0E-04	-	3.0E-05	UK HSE Single seal plus casing
Compressor (Centrifugal)	1.2E-02	-	2.7E-04	2.9E-06	UK HSE
Compressor (Reciprocating)	8.6E-02	-	3.3E-03	1.4E-05	UK HSE
Flanges	1.0E-07	-	-	-	UK HSE
Loading Hose (Per Operation)	-	-	-	4.0E-06	UK HSE (Guillotine; Average) [###]
Process piping (25 mm)	1.0E-05	5.0E-06		1.0E-06	UK HSE (Size: 000-049mm)
Process piping (40 mm)	1.0E-05	5.0E-06		1.0E-06	UK HSE (Size: 000-049mm)
Process piping (50 mm)	2.0E-06	1.0E-06		5.0E-07	UK HSE (Size: 050-149mm)
Process piping (80 mm)	2.0E-06	1.0E-06		5.0E-07	UK HSE (Size: 050-149mm)
Process piping (100 mm)	2.0E-06	1.0E-06		5.0E-07	UK HSE (Size: 050-149mm)
Process piping (150 mm)	1.0E-06	7.0E-07		2.0E-07	UK HSE (Size: 150-299mm)
Process piping (200 mm)	1.0E-06	7.0E-07		2.0E-07	UK HSE (Size: 150-299mm)
Process piping (250 mm)	1.0E-06	7.0E-07		2.0E-07	UK HSE (Size: 150-299mm)

Equipment type and size	Frequency (per year) by Hole Size#				Source
	3 mm	25 mm	50 mm	Full bore/ Rupture	
Process piping (300 mm)	8.0E-07	5.0E-07		7.0E-08	UK HSE (Size: 300-499mm)
Process piping (350 mm)	8.0E-07	5.0E-07		7.0E-08	UK HSE (Size: 300-499mm)
Process piping (450 mm)	8.0E-07	5.0E-07		7.0E-08	UK HSE (Size: 300-499mm)
Bellows (expansion joint failure 150mm)	-	-	-	1.5E-06 ##	Alkatuff QRA J20082-001 Rev 1
IBC failure	-	-	-	1.0E-05	VROM
Note: # Piping release frequencies are per metre-year ## Bellows frequency is per joint/year ### Hose leak frequency is per operation					

A.9.3. Drum and Cylinder Failure Frequencies

Chlorine drum failure rates are based on a study conducted by ICI UK into failures associated with chlorine drum storage and handling operations (Ref 20).

TABLE A9.2: DRUM AND CYLINDER FAILURE FREQUENCIES

Type of Failure	Failure Rate
Static Drum Failures: Catastrophic failure – drum 3mm hole – drum Catastrophic failure – cylinder	 0.1 x 10^{-6} per year / drum 5 x 10^{-6} per year / drum 0.1 x 10^{-6} per year / cylinder
Drum Handling Failures: Probability of dropping drum during transfer Probability of valve damage per drop Probability of plug damage per drop	 1 x 10^{-6} / transfer 0.001 / drop 0.002 / drop

A.9.4. Safeguard Failure Probability

Safeguards were applied at the following Probability of Failure on Demand (PFD_{avg}) to reduce frequency where applicable.

TABLE A9.3: SAFEGUARDS PFD_{AVG}

Item	PFD_{avg} / Frequency Multiplier	Comments
Deluge on vessels – BLEVE mitigation	0.1	Estimate Applied for radiant heat only, not impingement

Item	PFD$_{avg}$ / Frequency Multiplier	Comments
Passive Fire protection – BLEVE mitigation	0.01	CCPS LOPA factor
Manual isolation failure (assuming there is fire or gas detection remote isolation assume 90% success, or attended not in impact zone so included for RT loading) Trips / auto shutdown failure via SIS and independent EIV / SDV	0.1 typically 0.01 (or actual PFD value if SIL verification available)	Only has an effect for escalated scenarios such as BLEVE impingement scenario. Isolatable inventories are quite big so it doesn't make a large difference whether isolated or not isolated as maximum cloud footprints establish within a few minutes (more of an asset protection function) (ie isolated and unisolated consequence for fatality calculation is essentially the same)
Underground piping protection factor - compared to aboveground process piping / pipelines	0.1	Estimate – not exposed to impact. Excavation on BIP is controlled and all pipelines have cathodic protection
Critical piping	0.1	As per previous BIP QRA for Olefines to account for additional inspections
XSFV – clean service and maintained	1.3×10^{-2}	UK HSE Ref 19 C3s are clean service (If not maintained no credit given)
XSFV – dirty service	0.1	Estimated C4s are an example of dirty service as they tend to polymerise

A.9.5. Ignition Probability

In the case of a release, an event tree can be derived to determine the probability of:

- No ignition (i.e. safe dispersal or toxic impact)
- Immediate ignition (jet fire, pool fire)
- Delayed ignition (vapour cloud explosion, flash fire).

The ignition probability values used in this study were based on the assessment by Cox, Lees and Ang, Ref (28). The probabilities are based on the release rate and the phase of the fluid assessed. The ignition probability values to be used in the QRA are provided in Table A9.3.

No specific fixed ignition sources were included in the QRA.

TABLE A9.3: IGNITION PROBABILTIES

Mass Flow Rate (Kg/S)	Total Ignition Probability Of A Gas Or Mixture	Total Ignition Probability Of A Liquid	Fraction Of Explosions Given Ignition Of A Gas, Liquid Or Mixture	Explosion Probability Of A Gas Or Mixture	Explosion Probability Of A Liquid
< 1	0.01	0.01	0.04	0.0004	0.0004
1 - 50	0.07	0.03	0.12	0.0084	0.0036
> 50	0.3	0.08	0.3	0.09	0.024
Rupture	1	0.08	0.3	0.3	0.024

A.9.6. Process Specific Incident Frequencies

The frequencies of specific process incidents (i.e. release scenarios related to control system failure, complex failure dependencies or human error) have been estimated and incorporated into the risk analysis using fault tree, event trees or LOPA/bowtie analysis. These have generally been extracted from the most recent MHF Safety Cases for each facility.

A.9.7. Domino or Escalated Events

BLEVEs

Scenarios that can impact a target that has potential to BLEVE (pressurized liquefied gas storage vessel) based on a consequence of impinging fire or heat radiation of $23kW/m^2$ reaching the target were identified. The cumulative un-isolated frequency of impingement or radiant heat adjusted by a directional factor (divided by 6) is applied to estimate the potential initiation frequency for a BLEVE.

Note that escalation within plant areas (ie within same isolatable inventory of adjacent small inventories 10 tonnes or less was not assessed).

Between plants on BIP

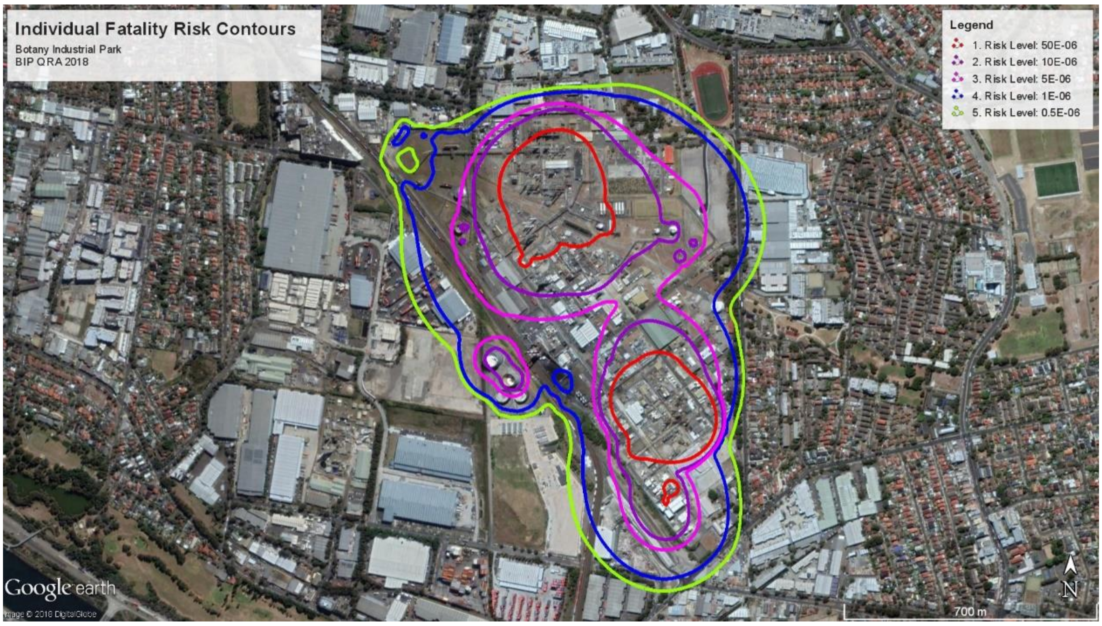
As per Figure 9.6 and Figure 9.7 there is no interaction between the escalation risk contours for the Huntsman and Qenos Olefines facilities, for either overpressure or heat radiation impacts, hence the risk of escalation between the major flammable inventories for different facilities within the BIP is low and is not quantified.

The contours also do not extend to the Chloralkali Facility so the probability of an explosion event resulting in toxic gas release is regarded as low and is not quantified.

APPENDIX 10. COMPARISON TO 2012 QRA RESULTS

A.10.1. Individual Fatality Risk

2018 QRA Results



2012 QRA Results

A.10.2. Toxic Injury Risk

2018 QRA Results

2012 QRA Results

A.10.3. Toxic Irritation Risk

2018 QRA Results

2012 QRA Results

A.10.4.Heat Radiation Injury Risk

2018 QRA Results

2012 QRA Results

A.10.5.Overpressure Injury Risk

2018 QRA Results

2012 QRA Results

A.10.6. Heat Radiation Escalation Risk

2018 QRA Results

2012 QRA Results

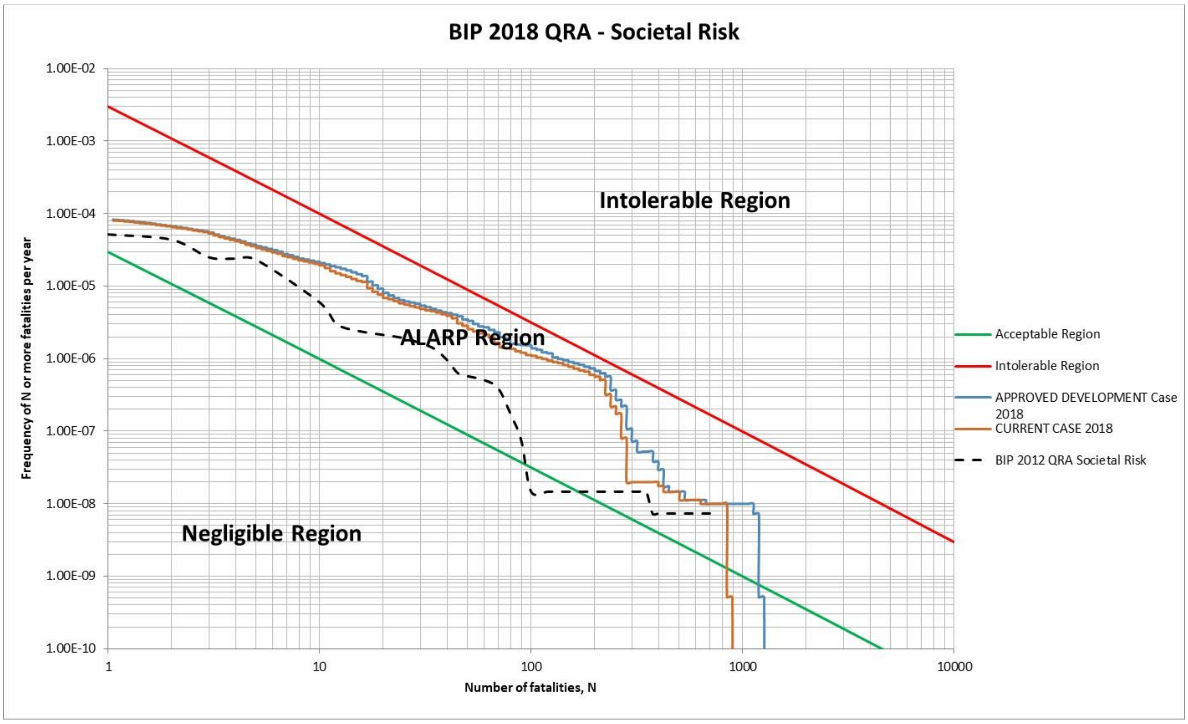
A.10.7. Overpressure Escalation Risk

2018 QRA Results

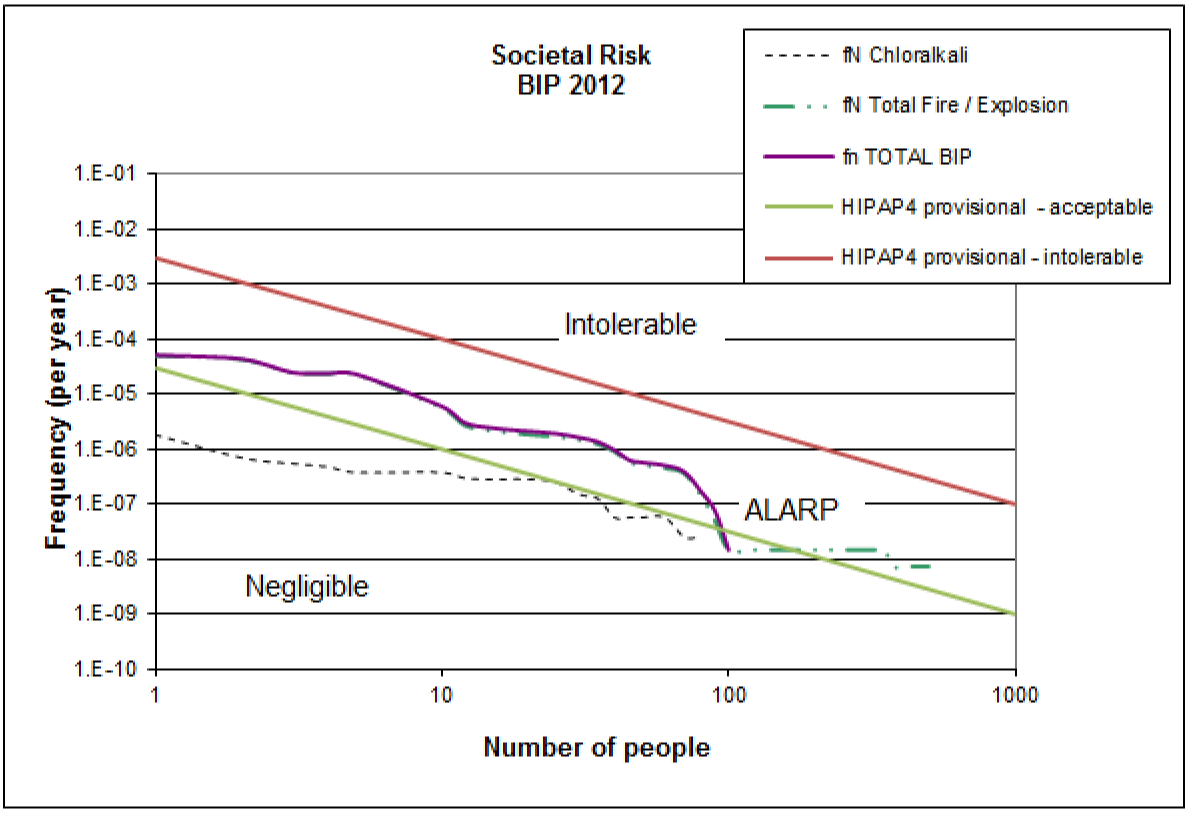
2012 QRA Results

A.10.8. Societal Risk Comparison

a) 2018 results for 'current case' and 'approved development' case compared against 2012 results



b) Extract from 2012 QRA report



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