APPENDIX 10

PRELIMINARY HAZARD ANALYSIS

COFFS HARBOUR CITY COUNCIL

Coffs Infrastructure Alliance

PRELIMINARY HAZARD ANALYSIS

Water Treatment Plant

140 Upper Orara Road
Karangi NSW

Prepared By: __________________________

Stefan Everingham
Environmental Engineer
Coffs Infrastructure Alliance
& GHD Pty Ltd

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1 INTRODUCTION

Coffs Harbour City Council are proposing to build a Water Treatment Plant (WTP) with a present day capacity of 42 ML/d near the existing Karangi Dam. The proposed WTP will treat the water to the Australian Drinking Water Guidelines, 2004 (ADWG) and have the capacity to cope with the regions future water demands.

Substances that are used in the treatment processes are required to be stored on the proposed site and some are potentially hazardous. This Preliminary Hazard Analysis (PHA), documents the process of screening hazardous substances, identifying risks within the plant and providing an assessment as to whether the level of risk is acceptable.

1.1 Objectives

The objectives of this PHA are to develop a comprehensive understanding of the hazards associated with the site. Through this understanding, and through the evaluation of the consequences and likelihoods of each of these hazards, the risks involved in operation of the facility may be predicted. Through this process the site risks may be shown to be acceptable, or if necessary, may be reduced to acceptable levels.

The scope of this report/PHA covers the following points;

- Systematic identification and documentation of the major hazards (based on the information supplied and site orientation/familiarisation);
- Establishment of the consequence of each identified hazard and a determination as to their offsite effects. This process is generally qualitative, with relevant calculations/modelling being completed where necessary;
- Where offsite effects are identified, the frequency of occurrence is estimated based on historical data. If such data is unavailable, assumptions and qualitative arguments are presented.
- Determination of the acceptability (or otherwise) by comparison of the qualitative or quantitative assessment of the identified risks with the criteria specified in the NSW Department of Planning (formally DUAP) HIPAP No. 4 Multi-level Risk Assessment (DUAP, 1997)
- Identification of risk reduction measures as deemed necessary.

In the course of completion of a PHA, both qualitative and quantitative assessment methods are utilised. These techniques provide the mechanisms that allow;

- formal identification of hazards;
- analysis of the consequence and frequency of possible hazardous incidents;
- consideration of the relevance and adequacy of proposed safeguards.

In addition, they allow quantification of the levels of risk which can then be used as a basis for judgement regarding the acceptability of the risks imposed by the facility as well as for consideration of opportunities for risk reduction.

Under the Department of Planning (DoP) guidelines, quantification of the identified hazards is not undertaken (or necessary) in all cases. It is only undertaken where it adds rigour to the analysis. Thus, hazards identified or evaluated by both quantitative and qualitative processes should be considered on an equal basis, rather than one method being considered more definitive.

DoP requires that the hazard analysis process be based on the following principals. It should;

- Be comprehensive, holistic and systematic;
- Be qualitative, quantitative and site-specific;
- Be complementary to other safety studies;
- Use consistent and well-documented data collection methods; and
- Utilise all opportunities for risk reduction.

In situations where information which could impact on the PHA was not available, assumptions were made to bridge the gaps. Where assumptions have been made, they are intentionally conservative and have been stated in the report. As a result of this conservatism, the results of the PHA are also inherently conservative, and this should be noted in their interpretation/application beyond the scope of this work.

2 STATUTORY REQUIREMENTS

SEPP 33 requires developments that are potentially hazardous to undertake a PHA to determine the risk to people, property and the biophysical environment at the proposed location and in the presence of controls. Should such risk exceed the threshold criteria, the development is classed as 'hazardous industry', which is prohibited under the current Rural 1A Zoning.

Offensive developments are defined in SEPP 33 as being developments that when in operation and with all control measures in place the development would emit a polluting discharge. For developments identified as potentially offensive the minimum test for such developments is meeting the requirements for licensing by the Department of Environment and Conservation (DEC). If a development cannot obtain the necessary pollution control licences for any polluting discharge then it may be classified as an 'offensive industry' and would be prohibited development within the current Rural 1A Zoning.

In addition to applying SEPP 33, this PHA was prepared in general accordance with the DoP publications *Hazardous Industry Advisory Paper No. 6 - Guidelines for Hazard Analysis (1992)* and *Hazardous Industry Advisory Paper No. 4 – Risk Criteria for Land Use Safety Planning (1990)*.

This PHA has considered risks associated with the development in terms of accidental loss scenarios and their potential for hazardous incidents. General handling of waste materials are dealt with elsewhere in the Environmental Assessment.

In Summary the purpose of this PHA is to:

- Identify all potential hazards associated with the proposal;
- Analyse their consequences for people and the environment, and their probability of occurring;
- Estimate the resultant risk to the surrounding land uses and environment; and
- Ensure the proposed safeguards are adequate, and thus demonstrate that the operation will not impose a level of risk that is intolerable to the surrounding environment.

3 SITE DESCRIPTION

3.1 Site Information and Surrounding Land Use

The proposed WTP is located on Upper Orara Road, 11 km to the west of Coffs Harbour on the NSW Mid North Coast, at 120 m elevation and approximately 600 metres north east of the Karangi Dam (refer to Figure 1 and Figure 2). The WTP is within a rural area with the surrounding land use zonings shown in Figure 3 and location of adjacent properties shown in Figure 4. The surrounding areas are summarised as follows:

- Orara River and the adjacent riparian zone is situated on the north western boundary of the site. The riparian strip is zoned 7A Environmental Protection Habitat and Catchment and would remain unaffected by the WTP construction.
- Upper Orara Road winds past the southern edge of the site and will be used for site and construction access.
- The properties adjoining the site are zoned 1A Rural Agriculture, with a large electricity substation to the north east along Casuarina Lane.
- The Orara River riparian zone, the south western section of the site and the property to the south west of the site are mapped as being tertiary koala habitat. These sections would remain unaffected by the WTP construction works.
- The raw water reservoir (Karangi Dam) is situated approximately 600 m to the south west of the site and has a top water level 144.0 m elevation. The reservoir is supplied by a pump station on the Orara River situated at Cochranes Pool 1 km to the west of the Karangi Dam Inlet, and from the Nymboida River near Nymboida via the Regional Water Supply Pipeline.

Figure 1 – Site Location – Coffs Harbour WTP

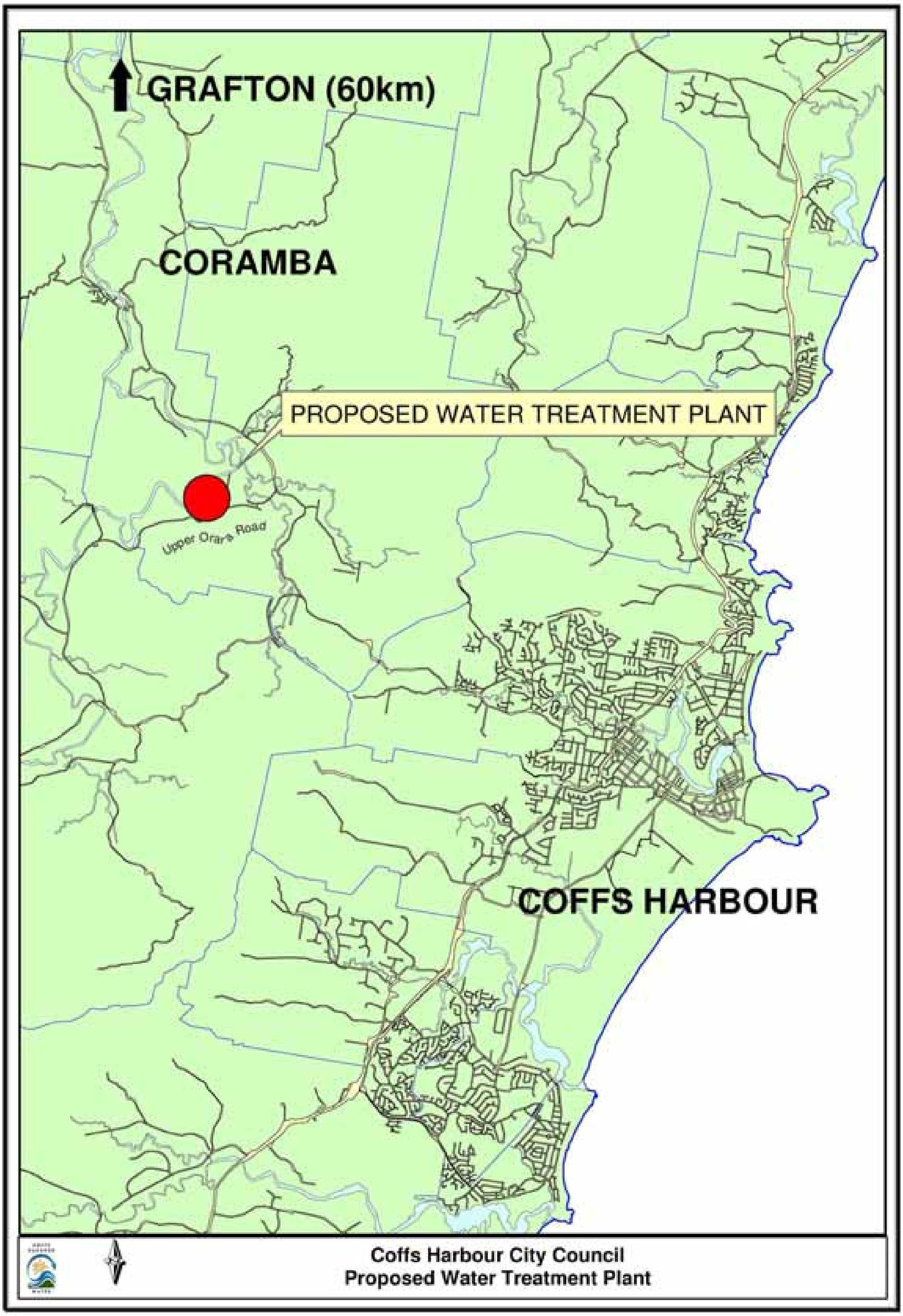


Figure 2 – Site Location – Coffs Harbour WTP

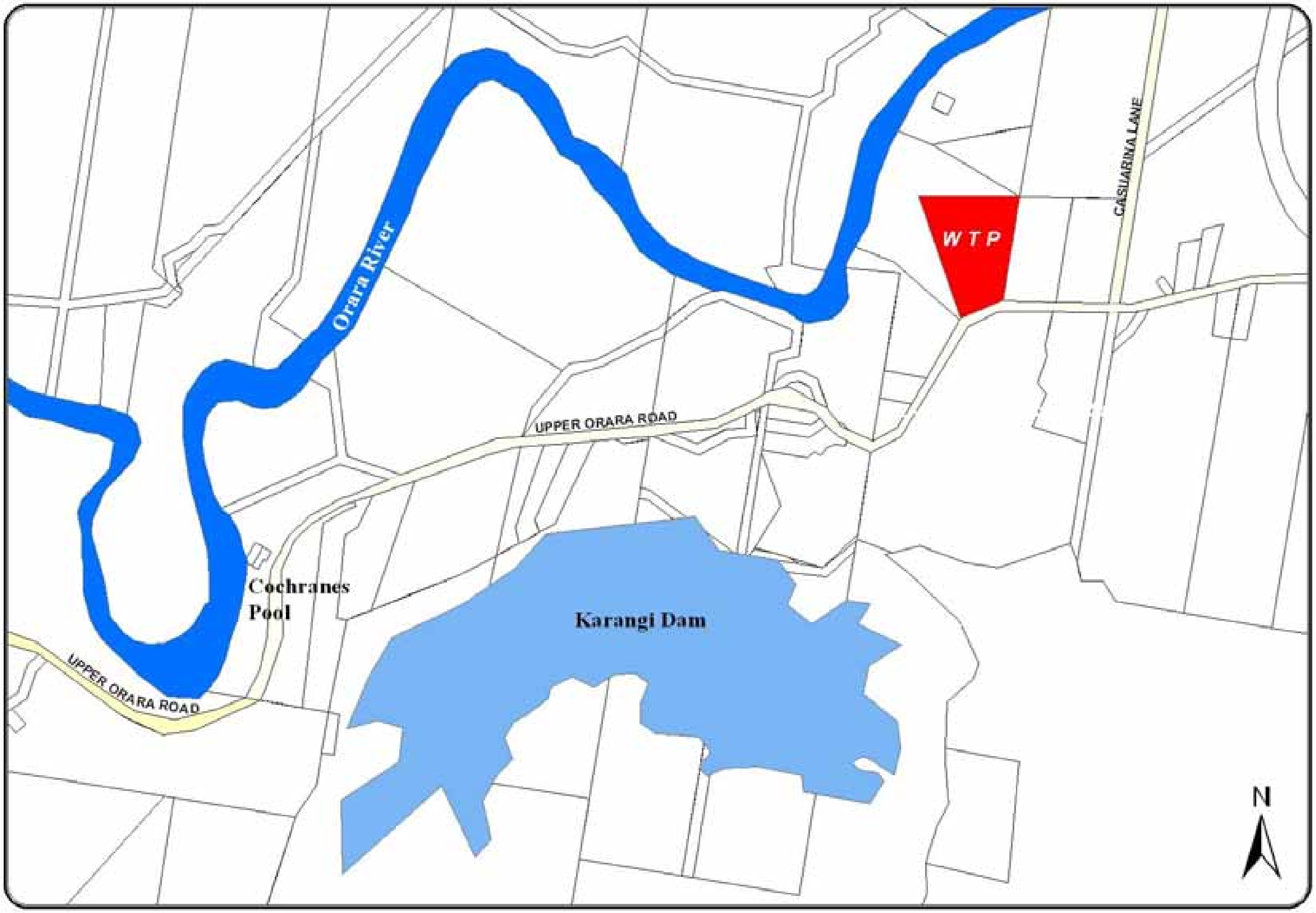


Figure 3 – Land Use Zonings Around WTP Site

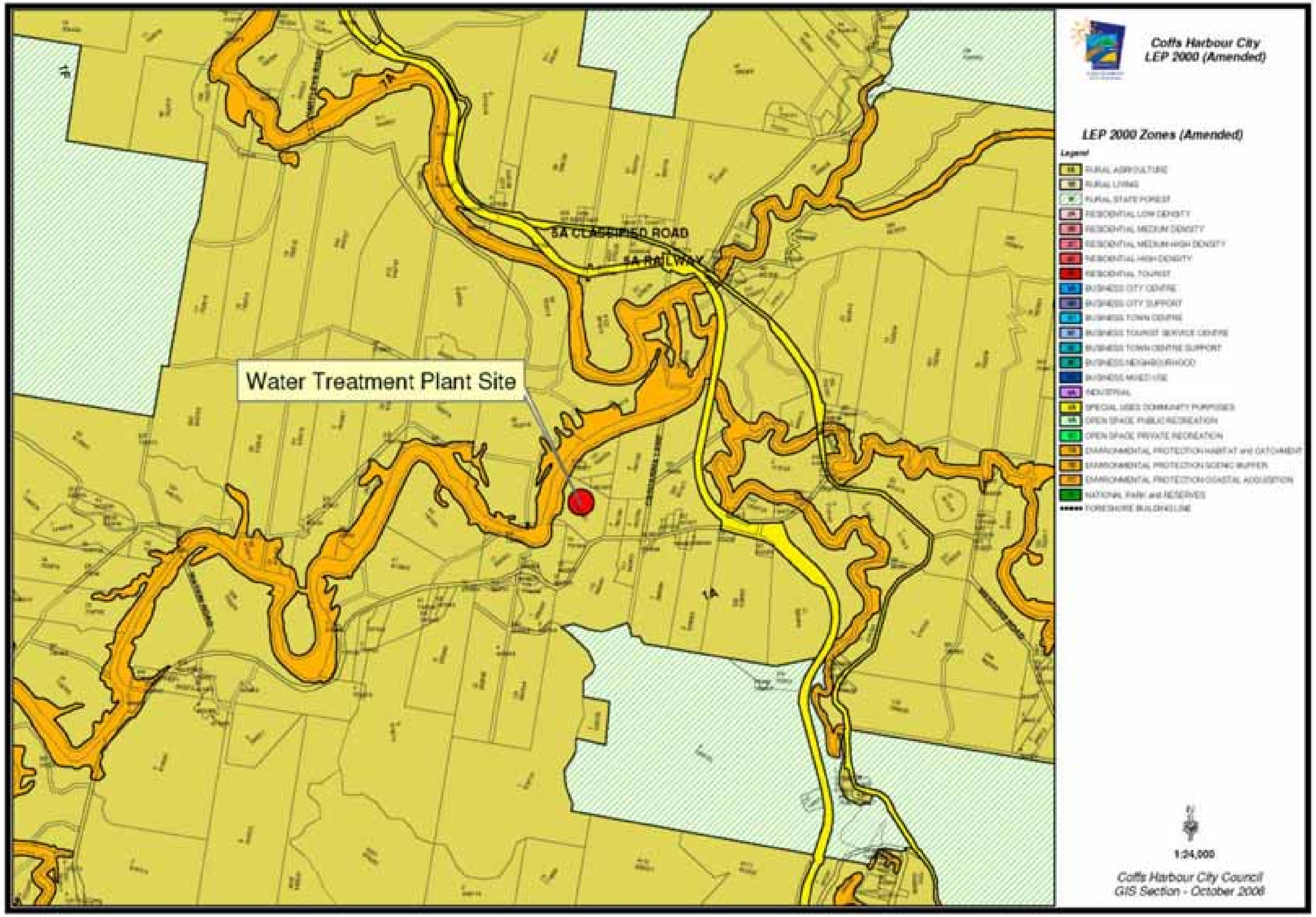
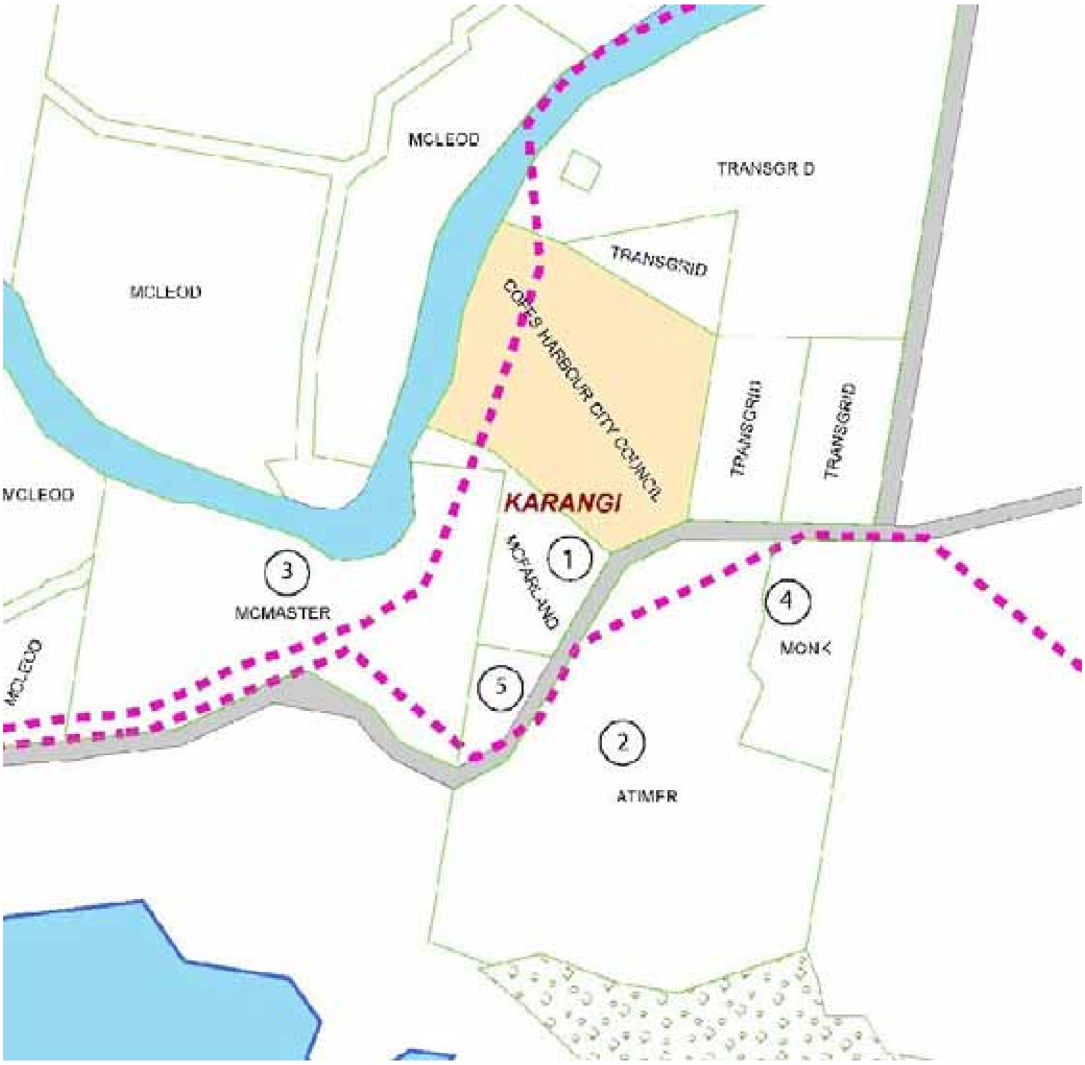


Figure 4 – Adjacent Properties



There are 5 residential buildings within 500 metres of the WTP site (identified within Figure 4), they are situated as follows;

- Property adjacent to the west, with house 100 metres south west of site entrance (No. 1 - McFarland).
- Property 200 metres south of site entrance (No. 2 - Latimer).
- Property 200 metres west of the western site boundary (No. 3 – McMaster).
- Property 190 metres to the south east of site entrance (No. 4 - Monk).
- Property 190 metres to the south west (No. 5 – Stransfield and Bell).
- Property building 360 metres to the north east (Transgrid Offices).
- Property building 280 metres to the south east of entrance (No. 6 - Cash).

There is one house on the site that will need to be demolished and removed.

3.2 Site Process Description and Layout

The key features of the proposed facility and construction activities are provided below.

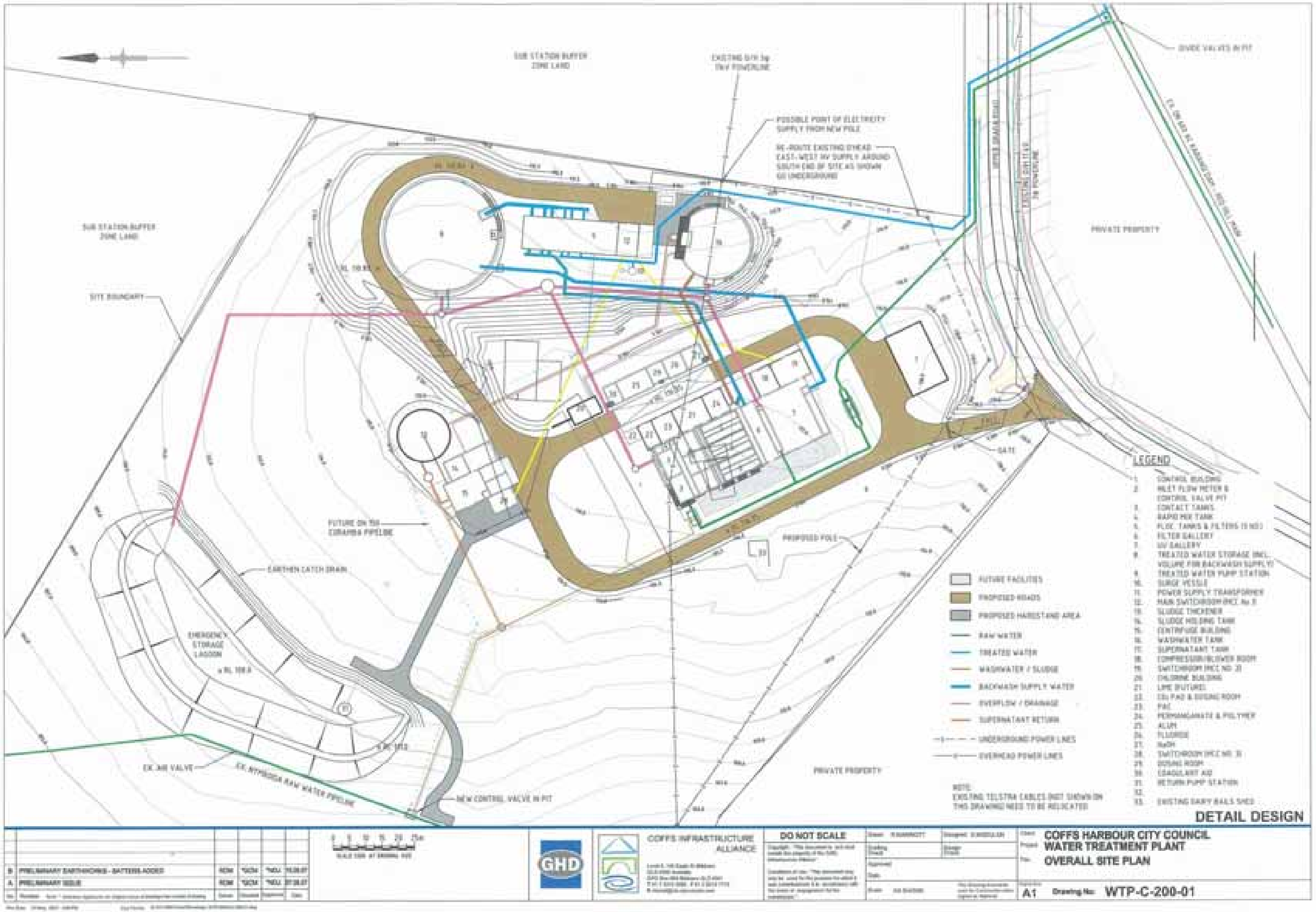
- A dissolved air floatation filtration (DAFF) treatment plant would be constructed within the proposed above-ground concrete water retaining structures at the new WTP site;
- All the following chemical storage and dosing facilities would be provided at the new WTP site:
    - lime and carbon dioxide for corrosion control and for pH correction;
    - potassium permanganate dosing for oxidation of dissolved manganese;
    - powdered activated carbon (PAC) for control of any intermittent taste or odour problems;
    - aluminium sulphate (alum) dosing for coagulation and flocculation of colloidal material;
    - polymer dosing as a coagulation aid;
    - polymer dosing as a flocculant aid;
    - sodium hydroxide (caustic soda) dosing for post filtration pH correction;
    - chlorine dosing system to provide a post filtration chlorine residual for disinfection purposes (and also for pre-chlorination);
    - fluoride dosing to meet the requirements of NSW Health;
    - polymer dosing for washwater thickening; and
    - polymer dosing for sludge dewatering.
- Ultra-violet disinfection would be provided for the filtered water;
- Washwater recycling, sludge thickening and sludge dewatering facilities would be constructed. Supernatant water separated from wash waters and sludges would be routinely returned to Karangi Dam via the existing 600 mm diameter regional pipeline, or would otherwise be recycled back to the WTP inlet main, if the regional pipeline is unavailable for operational reasons;
- Above-ground water storage tanks would be constructed at the new WTP site for:
    - treated water storage (approximately 5.8 ML); and
    - washwater holding (approximately 1.5 ML).
- An earth walled emergency storage containment lagoon would be constructed at the new WTP site to provide for the (unlikely) event of either a plant overflow or sludge dewatering system failure;
- Construction of a combined control building, testing laboratory and meeting room at the new WTP site;
- Construction of a treated water pump station at the new WTP site to house the backwash pumps and the treated water pumps to transfer treated water to the existing Red Hill balance tanks for distribution into the existing Coffs Harbour water supply system;
- A kiosk-style power supply transformer would be installed at the new WTP site to provide electrical power to the various plant at the site;

- The locations of existing high voltage power lines would need to be diverted across the site;
- A backup diesel generator would need to be provided;
- A paved access road would be constructed around the new WTP site; and
- Extensive landscaping would also be undertaken around the new WTP site.

All the proposed structures are proposed to be built on the new WTP site and would be contained wholly within the site boundaries of the 140 Upper Orara Road site, on the higher ground above the expected (1-in-100 year) Orara River flood levels.

The conceptual layout is shown in Figure 5 below.

Figure 5 Site Layout – Proposed Coffs Harbour WTP



4 METHODOLOGY

4.1 *Study Scope*

This study was performed following the guidelines set out in the DoP's 'Guidelines for Hazard Analysis', contained in the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6.

Adherence to this approach encompasses the identification of all hazards associated with the operations of a potentially hazardous facility, and analysis of these hazards in terms of their consequences to offsite people and property.

The scope incorporates the following studies;

- Preliminary Risk Screening / Transportation Risk Screening
- Risk Assessment, including;
    - A Quantitative Risk Analysis including a consequence analysis and frequency analysis of the identified hazards that have the potential to cause offsite effects;
    - Production of risk data (indicative risk contours) for the facilities and critical assessment of these results.

4.2 *Study Methodology*

Each of the points above is explained in detail in the methodology below.

4.2.1 Preliminary Risk Screening / Transportation Risk Screening

SEPP 33 requires a preliminary risk screening to determine whether a PHA is required. The preliminary screening documents the following:

- The class and quantity of dangerous goods to be used, stored or produced on site;
- The distances from site boundaries that certain classes of dangerous goods are to be stored; and
- Comparison of these results with the screening threshold quantities contained in Applying SEPP 33 - Hazardous and Offensive Development Application Guidelines (1994).

Additionally a transportation risk screening was conducted. The transportation risk screening documents the following

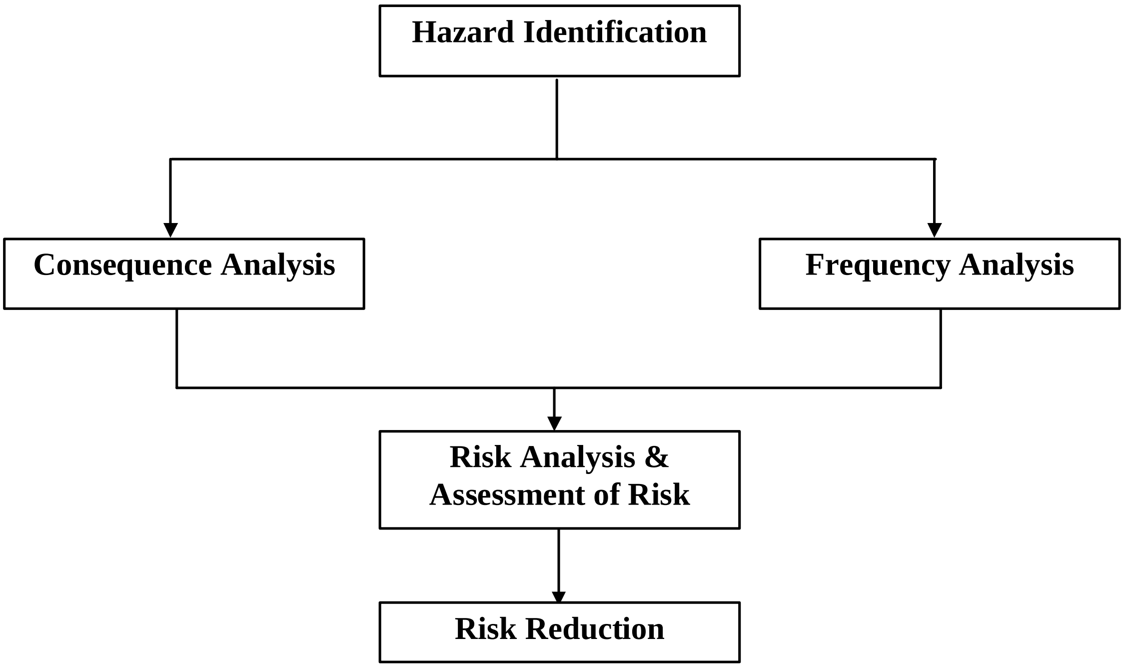
- The class and quantity of dangerous and hazardous goods transported to and from site;
- The estimated number of traffic movements involving dangerous goods to and from site;
- Comparison of these results with the screening threshold quantities contained in Applying SEPP 33 - Hazardous and Offensive Development Application Guidelines (1994).

The output of the preliminary risk screening and transportation risk screening is included in **Appendix A**.

4.2.2 Risk Assessment

The stages in the risk assessment methodology are summarised in Figure 6.

Figure 6 Risk Assessment Process



The methodology for each of the steps in the above flow diagram is described in the following paragraphs.

4.2.2.1Hazard Identification and Scenario Development

Hazard identification (HAZID) is a systematic review of potential hazards associated with all dangerous and hazardous goods to be stored, used and produced at the WTP. The HAZID review includes a comprehensive identification of possible causes of potential incidents and their consequences to public safety and the environment as well as an outline of the proposed passive and active controls required to mitigate the likelihood of the hazardous events from occurring. The output of this analysis was later used as a basis for further consequence modelling and risk analysis of the hazardous events identified as being capable of having an offsite effect.

The hazard identification study was conducted in a desktop session with members of the Coffs Harbour WTP design team and was facilitated by independent GHD risk consultants. The tabulated results of the hazard identification exercise are included in **Appendix A**.

All areas of the site were reviewed and the hazards documented. All hazard scenarios that could credibly have an offsite impact were evaluated further as described in the following sections.

4.2.2.2Consequence Analysis

The objectives of the consequence analysis are to:

- determine relevant toxic / flammable inventories;
- analyse a representative set of release cases;

- determine the consequences of each release with regards to their potential to cause offsite fatalities.

The processes used to complete the analysis were;

- discharge rate modelling;
- dispersion modelling
- toxic impact modelling.

Release, dispersion, and subsequent toxic effect calculations are performed using SAFETI (Software for the Assessment of Fire Explosion and Toxic Impact) commercial software package. The SAFETI package models have been extensively validated and a description of the consequence models employed in SAFETI is provided in **Appendix C**. The consequences of scenarios modelled can be seen in **Appendix D**.

4.2.2.3Frequency Analysis

For those scenarios identified as having offsite impact the likelihood of their occurrence is estimated. This is accomplished by looking at historical records in order to develop appropriate event frequency data for the Coffs Harbour facility. Failure of safeguards is also considered. Event frequency data is obtained from a number of sources including; Orica failure rate data, the UK HSE data for offshore facilities and Lees.

The statistical data for the event frequencies, together with the derived frequencies can be seen in **Appendix E**.

4.2.2.4Risk Calculation Methodology

The risk assessment was conducted using the commercial software tool SAFETI.

4.2.2.5Assessment of Results

In NSW a quantified risk assessment is required to fully assess the consequence and likelihood of potentially hazardous events to understand the risk impacts to / from a proposed or an existing development on adjacent land users. The calculated risk levels are compared against the risk acceptance criterion accepted by the NSW DoP (formally DUAP) as reasonable for land use planning purposes. The criterion covers both individual risk (risk contours) and societal risk (FN Curves).

- Individual risk contours – These contours show how risk varies according to location in an area around the regulators. They are independent of land use and actual exposed populations, simply showing the risk to which a person would be exposed if they were fixed at a given location. Risk contours do not take into account any actions that might be taken by people in the area to escape from an event, or the actual time that people are present. NSW DoP guidelines specify two measures of individual risk, that of individual fatality risk and individual injury risk.
- The FN Curves used in societal risk – the plot of frequency (F) versus number of fatalities (N) takes that risk contour information and adds information about the number of people in surrounding areas to give an indication of the actual number of fatalities that could be caused by the hazardous events

Only by completing the individual and societal risk calculations can the true nature of a facilities risk be truly understood.

4.2.2.5.1 NSW Risk Criteria

Risk is measured against two criteria in NSW individual risk and societal risk (FN Curves). For a more detailed description of individual fatality risk, societal risk and individual injury and irritation risk please refer to **Appendix B**.

Individual Risk

Individual risk is the risk experienced by a hypothetical individual assumed to be continuously present at a specific location. Individual risk is normally presented in the form of individual risk of fatality or injury contours over a map of a facility and its surrounds.

Individual risk criteria are best at establishing exclusion zones or defining an area of limited desirable population density: in other words in relatively high-risk areas.

Site risks have been assessed against the DoP acceptable individual fatality risk criteria and injury risk criteria as detailed in HIPAP No. 4. The criteria is as follows:

Table 1 DoP Individual Fatality Risk Criteria

Exposure Type	Risk Levels
Hospitals, schools, child-care facilities and old age housing developments	half in a million per year (0.5×10^{-6} per year)
Residential developments and places of continuous occupancy (hotels/resorts)	one in a million per year (1×10^{-6} per year)
Commercial developments, including offices, retail centres, warehouses with showrooms, restaurants and entertainment centres	five in a million per year (5×10^{-6} per year)
Sporting complexes and active open space areas	ten in a million per year (10×10^{-6} per year)
Industrial sites	fifty in a million per year (50×10^{-6} per year)

Figure 7 – DoP Individual Fatality Risk Criteria

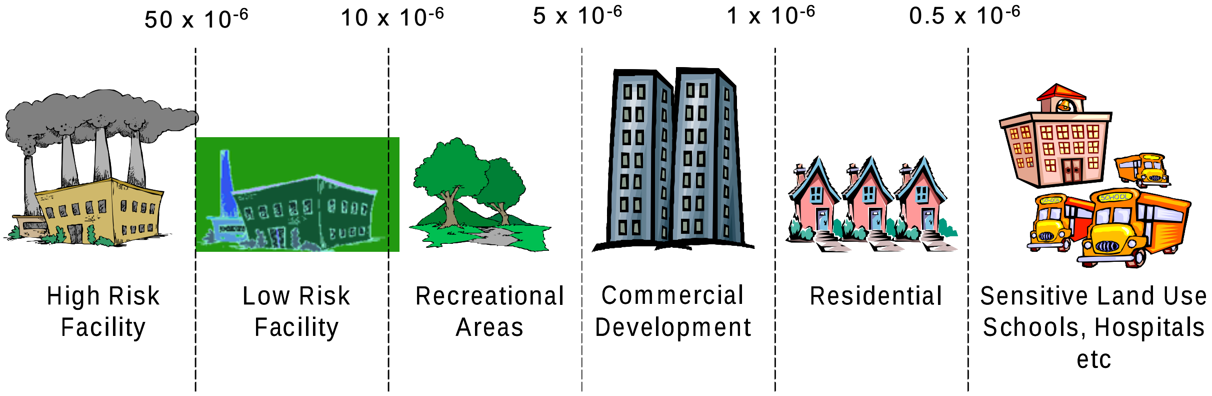


Table 2 DoP Injury Risk Criteria

Exposure Type	Risk Levels
Toxic concentrations in residential areas should not exceed a level that would be seriously injurious to sensitive members of the community following a short period of exposure.	ten in a million per year (10 x 10^{-6} per year)
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.	fifty in a million per year (50 x 10^{-6} per year)

Societal Risk

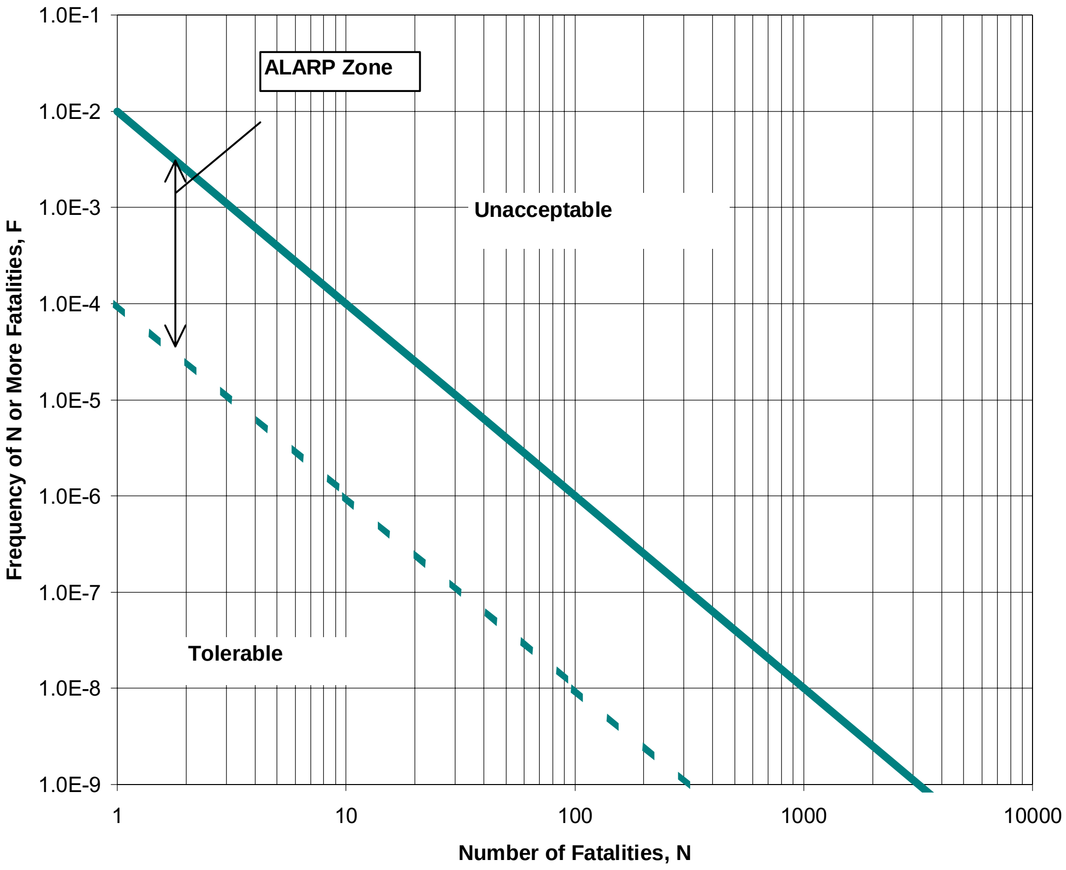
The NSW DoP do not specify societal risk criteria, although in the HIPAP No 4 of 1992, it is indicated that - “ The department’s experience of implementation of societal risk criteria F-N approach indicates that much more research is needed before adopting that approach here. As societal risk is specific to each society, it is very important that allowance be made to reflect differences between societies and cultures. The department suggest that judgements on societal risk be made on a qualitative approach on the merits of each case rather than on specifically set of numerical values.”

Nevertheless, it is also indicated that the accident frequency and number of people affected should be estimated wherever practicable.

In Australia all states specify that societal risk should be reviewed however the only state that has published any guidance is the Victorian WorkCover Authority in 2006. The values for the societal risk limits were established by DNV (Det Norkse Veritas) in 1984 (believed to be based on work from the Netherlands).   In the absence of other local guidance, Australian States and New Zealand authorities have tended to use the published WorkCover criteria or established overseas criteria as the basis for societal risk limits.

For the purposes of this study the published Victorian WorkCover criteria will be used to assess the societal risk posed by the WTP.

Figure 8 F-N Curve Victorian Interim Societal Risk Criteria



Information of surrounding populations can be seen in **Appendix B**.

5 Hazard Identification

A *preliminary risk screening* was conducted on the proposed development to determine whether there was a requirement for a PHA. The full preliminary risk screening assessment is presented in **Appendix A**. Based on the preliminary risk screening the proposed development exceeds the SEPP33 storage screening thresholds for chlorine, powdered activated carbon and the combined storage of dangerous goods class 8 materials (sodium hydroxide, fluorosilicic acid and lime). Therefore a more detailed risk assessment should be conducted.

A *transport risk screening* was conducted examining all movements of dangerous goods into and out of the proposed development. The transport risk screening was conducted in order to determine whether the development requires a route evaluation study in accordance with the DoP *Route Selection Guidelines*. The complete transport risk screening is presented in **Appendix A**. Based on the transport risk screening the number of generated traffic movements involving significant quantities of hazardous materials does not warrant a route evaluation study.

A *hazard identification workshop* (HAZID) was conducted on the Coffs Harbour WTP qualitatively reviewing the potential hazards associated with dangerous and hazardous goods to be stored, used and produced onsite. The HAZID review included a comprehensive identification of the possible causes of potential incidents, their consequences and the proposed operational control measures that would reduce the likelihood of the incident. The HAZID study was conducted by personnel with operational, design, environment and risk assessment expertise, with the aim of determining whether any potential incidents could result in offsite impacts to public safety or the environment. The full HAZID study is documented in **Appendix A**. Those risks identified as having a potential impact that could extend across the site boundary were carried forward for further analysis.

6 Consequence Analysis

The HAZID study identified a number of events that had the potential for off site consequences (see **Appendix A**). These scenarios are summarised below;

- Loss of containment of washwater tank or treated water tank resulting in washwater / treated water flowing off the site; and
- Toxic release from chlorine storage drums or dosing equipment resulting in toxic cloud.

6.1 Loss of Containment - Water

Loss of containment of washwater or treated water could result in water flowing eastwards off the site into an adjacent drainage gully, which flows into the Orara River some 500 meters to the north. Although the washwater is not of potable water quality the water is not contaminated with any chemical or biological pollution and does not present any safety or environmental impacts. As such these scenarios are not carried forward to the quantitative consequence analysis.

6.2 Loss of Containment - Chlorine

The potential for offsite risk with regards to chlorine is due to the potential for a chlorine release that results in a toxic vapour cloud. If released the chlorine gas, which is toxic if inhaled, can disperse downwind and offsite from the release point. These toxic releases can involve pressurised vapour or material held in the liquid phase under pressure, which would boil rapidly upon exposure to the atmosphere. The impact of such releases is a function of the material type, the exposure concentration and the duration of exposure. The chlorine release scenario has the potential to generate a significant safety hazard offsite therefore it will be subject to a quantitative consequence analysis.

Consequence impact criteria have been established in order to measure the effect on people of exposure to a potentially toxic chlorine gas cloud. Details of the consequence impact criteria are provided in **Appendix B**.

Release, dispersion, and subsequent toxic effect calculations are performed using SAFETI (Software for the Assessment of Fire Explosion and Toxic Impact) commercial software package. The SAFETI package models have been extensively validated and a description of the consequence models employed in SAFETI is provided in **Appendix C**.

Chlorine releases could potentially occur either within the chlorination building during static storage and chlorination operations or outside the chlorination building during delivery operations. The chlorine release scenarios that were carried forward for consequence analysis are outlined in **Appendix D**. Additionally a full derivation of the consequence modelling, including all modelling assumptions, can also be found in **Appendix D**.

The magnitude of dispersion will be greatest in the most unstable weather conditions, therefore consequence distances are only reported for the more stable 1.5F weather conditions.

The fatality probabilities reported are 50%, 10% and 1%, a summary of which is presented in Table 3and Table 4 for the inside and outside building hazardous scenarios. The full fatality probability distance table for each hazardous scenario modelled is presented in **Appendix D**.

Table 3 Consequence Distances for Outside Building Scenarios

Scenario	Distances to Fatality (m)		
	50 % Fatality	10 % Fatality	1 % Fatality
Valve Damage (6 mm hole) in full drum	106	201	340
Valve Damage (6 mm hole) in empty drum	-	45	62
Plug Dislodgment (20 mm hole) in full drum	200	250	305
Plug Dislodgment (20 mm hole) in empty drum	29	48	72

Table 4 Consequence Distances for Inside Building Scenarios

Control Operations	Release Inside Building, Extraction System Effective, Automatic Shut-off System Fails			Release Inside Building, Extraction System Fails, Automatic Shut-off System Fails		
Scenario	Distances to Fatality (m)			Distances to Fatality (m)		
	50 % Fatality	10 % Fatality	1 % Fatality	50 % Fatality	10 % Fatality	1 % Fatality
	Release from Extraction System			Release from Ground Vents		
Corrosion (3 mm hole) in full drum	60	146	280	131	264	386
Valve Damage (6 mm hole) in full drum	96	175	260	79	144	240
Catastrophic rupture of full drum	247	443	754	247	446	754
Corrosion (3 mm hole) in manifold equipment	-	-	-	48	89	130
Joint Failure (6 mm hole) in manifold equipment	96	175	260	79	144	240
Impact or Rupture (>6 mm hole) in manifold equipment	96	175	260	79	144	240

The nearest residence is 200 metres to the south of the chlorination building. The results presented in Table 3 and Table 4 indicate that chlorine releases are capable of impacting offsite these areas. As a result, the chlorine release scenarios are carried forward for further consideration.

7 Frequency Analysis

The frequency analysis used in this study considers drum failures related to static events (corrosion) and handling incidents such as dropping and damaging drums. The analysis for the drum failures uses time and movement based data combined with event likelihoods to calculate the frequency of a given event. Orica has provided GHD with failure rate data for chlorine drums.

Failures of the manifold pipelines, the pigtail lines and the manual/automatic valves are primarily based on HSE data for offshore facilities (these equipment failure rates are considered conservative for this relatively small scale land based facility). Data on failure rates for pneumatic shut-off valves and chlorine detectors is taken from Lees.

The statistical data for the event frequencies, together with the derived frequencies can be seen in **Appendix E**.

8 RISK ASSESSMENT

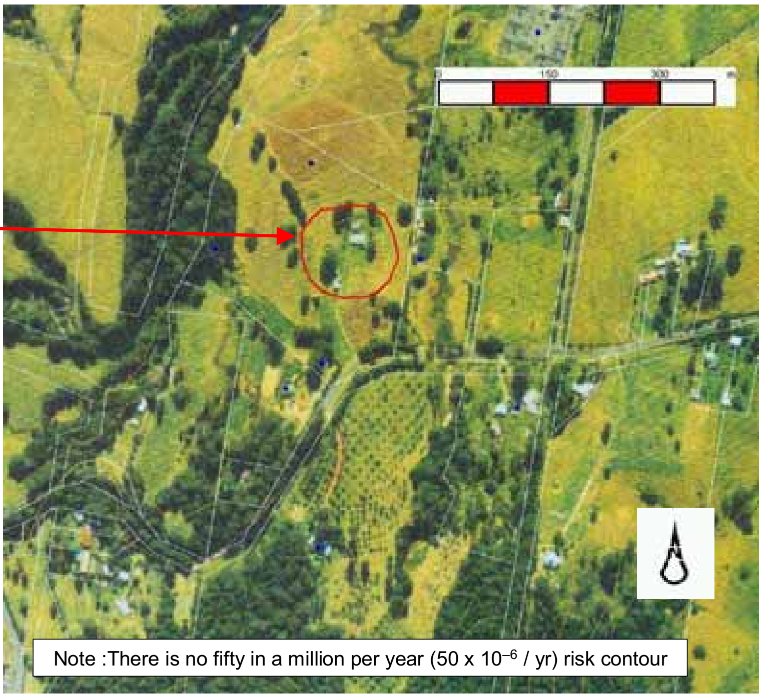
8.1 Individual Fatality Risk

The fatality risk assessment uses SAFETI to combine the consequence and frequency analysis (**Appendices D and E**) with the site layout and meteorological conditions (**Appendix B**) in order to develop individual risk per annum (IRPA) contours for the facility with regards to the chlorine release scenarios. These contours were then assessed against the key individual fatality risk criteria of;

- 50 in a million per year (50 x 10^{-6} per year) should not exceed the site boundary
- 1 in a million per year (1 x 10^{-6} per year) should not impact adjacent residential properties.

The individual fatality risk contours are shown in Figure 9.

Figure 9 Individual Fatality Risk Criteria for the Proposed WTP



1 in 1 million/ year (1 x 10^{-6} / yr)

Note :There is no fifty in a million per year (50 x 10^{-6} / yr) risk contour

Figure 9 shows that the proposed WTP meets the NSW DoP individual fatality risk criteria. There is no 50 in a million per year (50 x 10^{-6} per year) contour (which should not exceed the site boundary). Whilst the 1 in a million per year (1 x 10^{-6} per year) contour does not leave the site boundary therefore the proposed WTP does not impact adjacent residential properties.

8.2 Societal Risk

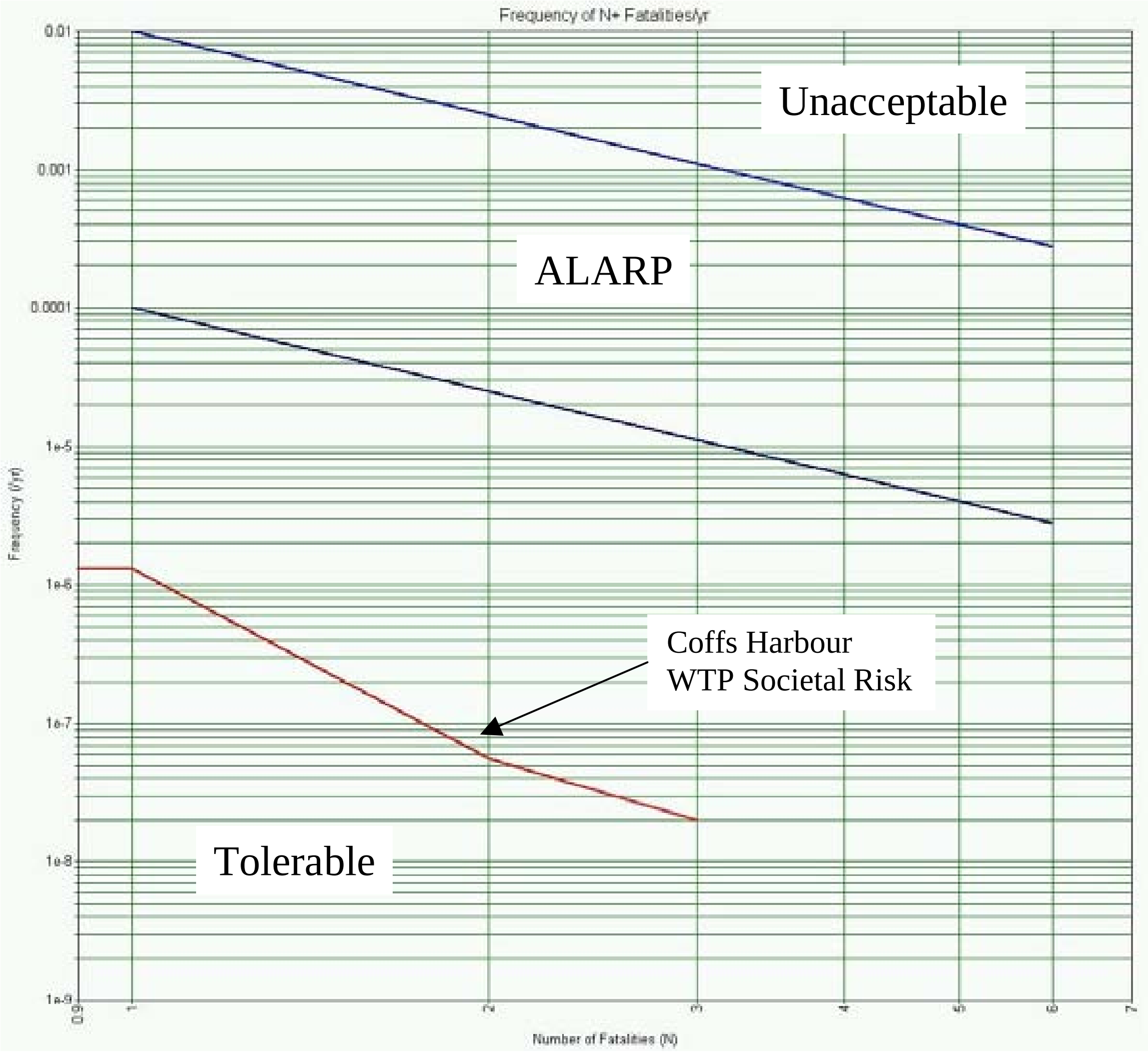
In determining the societal risk it was conservatively assumed that there were 4 occupants in each residence with approximately half outdoors and that they were on the property all of the time. In practice occupants would be off the property for work and social engagements significantly reducing their exposure. Additionally, the population at the substation was conservatively assumed to be 2 with all persons outside. The full population density derivation is presented in **Appendix B**.

The societal risk results for the WTP are presented in Figure 10 the upper blue line represents the limit between the unacceptable and tolerable risk level and the intermediate purple line represents the limit between the tolerable and negligible risk level. The red line is the results for the chlorine release scenarios.

These lines indicate that the societal risk from the WTP is very low for the occupants in the adjacent residential development and is in the region of the FN curve associated with negligible risk. Hence, the societal risk results fall well within the tolerable region of the societal risk criteria.

The results are reflective of the very low likelihood of a major chlorine release and the small number of persons that would be affected.

Figure 10 Societal Risk for the Coffs Harbour WTP



8.3 Injury Risk

The definition of concentration at which 'injury' or 'irritation' occurs is open to debate and consideration of all available toxicological data and standards is used to define the concentrations of interest for in this case chlorine. Throughout Australia the most common way of establishing injury and irritation risk criteria is to use Emergency Response Planning Guideline (ERPG) levels as specified by the American Industrial Hygiene Association (AIHA). The ERPG series provides values as estimates of concentration ranges where one might reasonably anticipate observing adverse effects as a consequence of exposure to a specific substance. These levels are considered to be an authoritative source for anyone responsible for responding to an emergency and accepted by regulating bodies in NSW, Victoria, West Australia, and Queensland.

Appendix B identifies the difference between the three specified levels of response. It is imperative to note that ERPG concentrations are nominated concentration levels that individuals can be exposed to for a one-hour period without developing life-threatening health effects and making a full recovery. Exposure to less than a one-hour period assumes that the ERPG criterion is not met. For the purpose of this study, ERPG 3 levels (20 ppm for a one hour period) are used in this report to represent serious injury and ERPG 2 levels (3 ppm for a one hour period) are used to indicate levels at which irritation may occur. An ERPG 1 level (set at 1 ppm for a one hour period) does not have any adverse health effects, it is likened to a strong swimming pool odour.

The closest residence to the chlorination building is approximately 200 m to the south, although the facility is surrounded by small holdings with single residences on them. In the unlikely event of a release the consequence modelling indicates that ERPG 3 and 2 level consequence footprints could impact on surrounding residences.

A review of the consequence modelling and likelihood shows the following:

- Only in cases where the inventory of the whole drum is available to be released will ERPG 3 and 2 levels be achieved outside of the site boundary. The presence of an automated shut-off valve on the chlorine drums reduces the likelihood of this event significantly. The ERPG 3 and 2 level consequence footprints can reach up to 770 m and 800 m respectively in distance, although it should be noted that despite the distance the cloud width is highly directional.
- Plug failure from drum transfers can produce ERPG 3 and 2 level consequence footprints on surrounding residences in all weather conditions, however the likelihood of occurrence is 0.01 in a million per annum significantly less than the irritation threshold (10 in a million pa) or injury threshold (50 in a million pa).
- Drum and manifold cases can produce ERPG 3 and 2 level consequence footprints on surrounding residences but only in calm weather conditions. The likelihood of occurrence of scenarios is estimated to be 3.96×10^{-4} pa. Combining this likelihood of occurrence conservatively with the largest calm wind direction segment 1.8% of the time (see **Appendix B**) the likelihood of injury/irritation occurrence then becomes (3.96×10^{-4} pa x $0.018 = 7.1 \times 10^{-6}$ per annum). This is also less than the specified irritation threshold (10 in a million pa) or injury threshold (50 in a million pa).

The frequency of chlorine failures and conducive weather conditions capable of producing ERPG 3 and 2 level consequences at nearby residences is lower than the specified irritation threshold (10 in a million pa) or injury threshold (50 in a million pa) and thus these criteria can be considered met.

8.4 Model Conservatisms

There are a few areas within this study which are conservative:

- Frequency analysis
- Consequence modelling

8.4.1 Frequency Analysis

The most appropriate failure / leak frequency data available for such a facility is taken from a combination of Orica and the UK HSE (2005). The Orica data utilises information from operational experience and that is appropriate to the conditions of use. However it does not have data for all equipment items such as valves and as such UK HSE data is used.

The UK HSE data incorporates information from a known collection of equipment, which allows for a reasonable estimate of failure to be derived (statistically valid). Although it should be recognised that the differences between the off-shore petroleum industry in the North Sea and a chlorination building facility in New South Wales are considerable. The offshore operations are operating at higher pressures in a hostile environment, whereas a chlorine facility in Coffs Harbour can allow for greater access to equipment and systems for maintenance in a more moderate environment. This is believed to result in a conservative estimate of frequency for scenarios involving manual valves.

8.4.2 Consequence Modelling

The dispersion model makes no allowances for the surrounding topography aiding dispersion or restricting drifting vapour clouds. In reality as chlorine is heavier than air once released to atmosphere it accumulates in valleys and low points, hence consequence footprints are expected to be significantly smaller

9 CONCLUSION

SEPP33 threshold levels were exceeded through the quantity of liquefied chlorine gas, corrosive substances (sodium hydroxide, fluorosilicic acid and lime) and powder activated carbon required to be stored on site. The exceedance of the threshold levels classifies the WTP as a potentially hazardous industry and thus prior to any approval, a Preliminary Hazard Analysis (PHA) has been undertaken.

Although there were a number of other hazardous materials stored and used onsite the hazard identification process only identified release scenarios involving chlorine gas as having the potential to impact across the site boundary.

The chlorine release scenarios were subsequently subject to a quantitative risk assessment, which determined that the risk generated by the proposed WTP meets the NSW DoP criteria for;

- Individual fatality risk; and
- Individual injury and irritation risk.

Additionally, the societal risk presented by the proposed WTP was assessed and determined to fall well within the tolerable region of widely accepted societal risk criteria.

It should be noted that the presence of the automatic shut-off valves (‘Chlorguard’ system), building and the chlorine extraction system significantly reduces the impact of chlorine releases on the surrounding populations. The automatic shut-off valves reduces the amount of inventory to be released (through isolation), the building contains small spurious releases from leaving the site and the extraction system aids dispersion of small contained releases due to the dilution and release from height with momentum. These controls add an additional layer of protection to the Coffs Harbour WTP operation.

It is recommended that the consequence footprints identified in this study be used to develop an appropriate Emergency Response Plan for this facility.

10 REFERENCES

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AS/NZS 3788: 2006. Pressure Equipment – In Service Inspection.

AS 3780: 1994. The Safe Handling and Storage of Corrosive Substances.

AS 4332: 2004. The Storage and Handling of Gases in Cylinders.

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A. Appendix A

Hazard Identification

PRELIMINARY RISK SCREENING

A preliminary risk screening is required by SEPP 33 to determine the need for a PHA. The methodology is described in DoP *Applying SEPP 33 - Hazardous and Offensive Development Application Guidelines (1994).*

Substances to be stored at the facility are listed in Table A1**.** Potentially hazardous materials that exceed the preliminary risk screening thresholds are highlighted***.***

In undertaking the Hazard Identification Study a number of assumptions were made including:

- All plant and equipment is operated and installed in accordance with appropriate Australian Standards, codes and guidelines; and
- Dangerous goods are stored in accordance with the ADG Code, relevant standards and guidelines even if not a licensable quantity

Table A1: Dangerous Goods Storage Screening

Product	*Proposed Inventory*	*ADG Class*	*Packaging No.*	*Use*	*SEPP 33 Threshold*	*Storage Type*	**Distance from Site Boundary**
Chlorine Gas	**3.68 tonnes (4 × 920 kg containers)**	**2.3**	**III**	**Disinfection**	**2.5 tonnes when stored in containers >100 kg**	**Pressure vessels**	**70 m**
Sodium Hydroxide	**25 kL**	**8**	**II**	**pH correction**	**25 kL**	**25 m^3 above ground tank**	**50 m**
Aluminium Sulphate	50 kL	N/A	N/A	Precipitates dissolved organics	N/A	2 × 25 m^3 above ground tanks	N/A
Flourosilicic Acid	**25 kL**	**8**	**II**	**Department of Health Requirement**	**25 kL**	**25 m^3 tank**	**66 m**
Lime (calcium hydroxide)*	**30 tonnes**	**8**	**III**	**pH and alkalinity control**	**50 tonnes**	**Above ground silo**	**68 m**
Carbon Dioxide	25 tonnes	2.2	N/A	pH correction	N/A	Pressure vessels	N/A
Potassium Permanganate	600 kg	5.1	II	Treats taste/odour, manganese, trihalomethane problems	5 tonnes	Above ground hopper	68 m
Powdered activated carbon (PAC)	**17 tonnes**	**4.2**	**III**	**Taste & odour and algal toxin removal**	**1 tonne**	**3 m^3 in hopper, 35 m^3 in storage sacks on pallets**	**70 m**
Coagulant aid polymer (likely to be Ciba Geigy Magnafloc LT35 or equivalent)	3 kL	N/A	N/A	Assist coagulation of dispersed material prior to DAFF	N/A	Delivered to site in 1 kL bulki-boxes and transferred to 3 kL tank onsite.	N/A
Filter aid polymer (likely to be Ciba Geigy Magnafloc LT20 or equivalent)	1 tonne	N/A	N/A	Promote flocculation prior to DAFF	N/A	Delivered to site on a pallet (assume 40 x 25 kg bags)	N/A
Sludge thickening polymer (likely Ciba Zetag series polymer or equivalent).	1 tonne	N/A	N/A	Thicken sludge prior to off site disposal	N/A	Delivered to site on a pallet (assume 40 x 25 kg bags)	N/A
Sludge dewatering polymer (likely Ciba Zetag series polymer or equivalent).	1 tonne	N/A	N/A	Thicken sludge prior to off site disposal	N/A	Delivered to site on a pallet (assume 40 x 25 kg bags)	N/A
Diesel	2 kL	3	III	Operate 1.5 MVA emergency generator for an eight hour period.	N/A	Storage within generator fuel tank.	N/A

Note shading indicates product exceeds the SEPP 33 thresholds for the hazardous industry classification.
***Lime exceeds SEPP 33 threshold due to requirement to add all ADG of the same class together for comparison with threshold values.**

Applying SEPP33 states;

- If any of the screening thresholds are exceeded then the proposed development should be considered potentially hazardous and a PHA is required to be submitted with the development application.
- If the quantities are close to the screening values and the development site is near a sensitive receiver then the proposed development is also considered to be potentially hazardous and a PHA is required.

Based upon the above assessment the proposed development exceeds the storage threshold for Chlorine, powdered activated carbon and the combined storage of dangerous goods class 8 materials (sodium hydroxide, fluorosilicic acid and lime).

In addition the emergency storage lagoon, wash water tank and treated water storage are also considered due to the potential large volumes of liquids involved.

TRANSPORTATION SCREENING

The proposed movement of hazardous materials (including both incoming and outgoing) is assessed in Table A2 against the transportation screening thresholds in *Applying SEPP 33*.

Table A2 Estimated Vehicle Movements of Dangerous Goods

Substance	DG Class	Vehicle Movements (Cumulative Annual)	Typical Quantity (tonne)	*Screening Threshold*
Sodium Hydroxide	8	24	25	>500
Potassium Permanganate	5.1	4	0.6	NA
Lime	8	12	30	> 500
Carbon Dioxide	2.2	24	25	NA
Fluorosilicic Acid	8	4	25	>500
Powder Activated Carbon	4.2	10	10	>100
Chlorine	2.3	10	1.84	> 100

The vehicle movements outlined in Table A2 indicate that the number of generated traffic movements (for significant quantities of hazardous material entering or leaving the site) does not warrant a route evaluation study in accordance with the *Route Selection Guidelines* prepared by the Department of Planning and hence is not considered further.

HAZARD IDENTIFICATION

The hazard identification (HAZID) includes a review of potential hazards associated with all dangerous and hazardous goods to be stored, used and produced at the WTP. The HAZID review includes a comprehensive identification of possible causes of potential incidents and their consequences to public safety and the environment as well as an outline of the proposed operational controls required to mitigate the likelihood of the hazardous events from occurring.

The identified hazard scenarios were workshopped with input from people with operational, design, environmental and risk assessment experience. The results of the HAZID are presented in Table A3. The hazards identified are a result of deviation from normal operation. Risks identified as having potential consequences extending across the site boundary were carried forward for further analysis.

The members of the team who reviewed the identified hazards were;

- Carlo Modulon (GHD Design Team Leader)
- Nigel Johnston (GHD Process Design Engineer)
- Steve Cooper (GHD Risk Consultant)
- Rebecca Freeman (GHD Risk Consultant)

Table A3 Hazard Identification

Area / Task	Possible Event	Possible Consequence	Potential Offsite Impact / Carried Forward	Prevention and Protective Measures
Chlorine storage and chlorination process	Loss of containment of chlorine from stores or dosing equipment from damaged equipment Physical damage drums or piping / fitting through impact with object / vehicle / dropped drum Cold catastrophic failure of chlorine drum	Storage drum ruptures releasing toxic gas Potential for chlorine release impacts offsite	Yes	Chlorine drums stored in dedicated chlorine building (building designed to contain small releases only) Chlorine building located centrally in facility away from site boundary (75 m) Extraction system for capturing small releases and releasing them at height Automatic shut-off valves (Chlorguard) activate upon chlorine detection in the chlorination building and limit the inventory of chlorine released. Chlorine dosing requirements are low for operation. Hence a vapour dosing system is only required – this restricts consequence footprint size Chlorine drums supplied from Orica Orica drum testing program eliminates damage drums from circulation Dedicated chlorine lifting device as highlighted in AS/NZS 2927:2001
Dangerous Goods (DG) Storage Area	Loss of containment of dangerous goods from store Cross contamination of product Rupture of storage vessel due to collision impact. Fittings damaged or inadequately installed Overfilling of storage vessels Sodium Hydroxide solution (46%), Aluminium Sulphate Solution [26% $Al_2(SO_4)_3$], Flourosilicic Acid (15%)	Spill will have localised consequences only Minor fuming, possible acid burns to operator / tanker driver	No	DG storage area located centrally away from site boundary (closest boundary 50 m for NaOH and for 70 m Aluminium Sulphate solution) Each chemical has own designated bund to contain at least 110% of largest tank volume. Bund provides secondary containment in case of spills however also protects equipment from vehicle damage. Bund wall one metre in height. Dedicated road tanker unloading bays and dedicated tanker Acid and alkali bulk stores in a well-ventilated area separated by a concrete building (containing dosing system) DG bulk storage area has roof providing protection from the elements Cross contamination limited by different nozzle fittings for each stored chemical Tertiary spill containment control on site pumped into the filter washwater system for treatment and recycled through process

Area / Task	Possible Event	Possible Consequence	Potential Offsite Impact / Carried Forward	Prevention and Protective Measures
(Liquid) Coagulant Aid Storage Area	Loss of containment of liquid coagulant aid (cationic polymer, probably Ciba Geigy 'Magnafloc LT35')	Spill will have localised consequences only	No	Storage area located centrally away from site boundary (closest boundary 65 m) Chemical has its own designated bund to contain at least 110% of largest tank volume. Bund provides secondary containment in case of spills however also protects equipment from vehicle damage. Bund wall one metre in height. Dedicated road tanker unloading bays and dedicated tanker
(Powdered) Coagulant Aid / Sludge Thickening Polymers Storage Areas	Loss of containment of (powdered) coagulant aids Filter aid polymer, Sludge thickening polymer, Sludge dewatering polymer,	Spill will have localised consequences only	No	Filter aid coagulant storage area located centrally away from site boundary (closest boundary 70 m) Sludge dewatering polymers storage area located centrally away from site boundary (closest boundary 100 m) Coagulants are solids in package sizes limited to 10 or 25 kg capacity bags Coagulant storage area protected by roof Solid product limits spill size
Diesel fuel supply for treatment plant emergency generator	Loss of containment of diesel leads to fire	Localised spill could lead to pool fire. Ground contamination.	No	Fuel supply limited to a maximum of approx. 2000 L Fuel tank integral with generator base. Bunding around generator area to capture any fuel spills, containment volume at least 2000 L. Generator area located 20 m away from site boundary and in a covered carport style annexe of the treated water pump station Control of ignition sources on site Dedicated vehicle access routes

Area / Task	Possible Event	Possible Consequence	Potential Offsite Impact / Carried Forward	Prevention and Protective Measures
Powdered Activated Carbon System	Release of powder / dust during loading, as a result of collision impact or failure of storage vessel.	Localised spill leads to dusting Inventories involved too small to have offsite impacts Possible localised dust explosion	No	Storage site located centrally in facility away from site boundary (70 m) Storage quantity limited to 35 m^3 in 500 kg (1 m^3) bulki-bags stored on pallets in building Small quantity stored out of bags within a hopper (3m^3) Bags loaded individually and components designed to minimise escape of dust into room. PAC hopper sealed with bulki-bag slide gate connection Dedicated dust extraction on hopper when loading bulki-bags Building designed to contain dust within building – limited dust exposure outside building – building size 8 m x 6.8 m x 5.5 m high = 300 m^3 Presence of potential ignition sources minimised
Storage of Carbon Dioxide	Collision with storage vessel. Fittings damaged or inadequately installed Cold catastrophic failure of pressure vessel	Pressure vessel ruptures diluting oxygen content of air, potential for asphyxiation. Due to open nature of the site a build up of carbon dioxide at asphyxiation levels is not credible at the site boundary (80m away)	No	Storage located centrally in facility away from site boundary (80 m to closest boundary) Stored as liquefied carbon dioxide under pressure in open area with surrounding chain mesh fence Bollards on road side of enclosure to provide vehicle impact protection Dedicated road tanker unloading bays and dedicated tanker Designated vehicle access routes Carbon dioxide vessel supplied by BOC or Air Liquide under a long-term lease agreement Pressure vessel storage isolation
Potassium Permanganate	Ignition of flammable materials due to being strong oxidiser	Spill will have localised consequences only Minor fuming, possible burns to operator	No	Small quantities are stored and handled on site (total of 500 kg in 25 kg bags) Solid product limits spill size Stored in building located centrally in facility away from site boundary (70m to closest boundary) Separated within own storage building away from other chemicals Presence of potential ignition sources minimised

Area / Task	Possible Event	Possible Consequence	Potential Offsite Impact / Carried Forward	Prevention and Protective Measures
Loss of containment of washwater tank	Pump or pipe damage caused by vehicle contact	Loss of containment of tank would result in water flowing eastwards off the site into an adjacent drainage gully, which then flows into the Orara River some 500 metres to the north. .	Yes	Tank constructed of concrete to minimise likelihood of catastrophic failure. Limited vehicle access to tank area – protection off pipes designated vehicle access ways Tank is periodically filled and emptied over the course of any given day, i.e. it is not always full. Tank overflow is piped to the emergency storage lagoon. Water in the tank is recycled and recirculated into the treatment process Potential for water to leave site, however consequences do not provide any adverse safety or environmental issues. Adjacent site is unoccupied and is buffer zone land for the nearby Transgrid electricity substation
Loss of containment of treated water storage tank	Pump or pipe damage caused by vehicle contact	Loss of containment of tank would result in water flowing eastwards off the site into an adjacent drainage gully, which then flows into the Orara River some 500 metres to the north.	Yes	Tank constructed of concrete to minimise likelihood of catastrophic failure. Limited vehicle access to tank area – protection off pipes designated vehicle access ways Water in the tank is treated and of potable quality. Tank overflow is piped to the emergency storage lagoon. Potential for water to leave site, however consequences do not provide any adverse safety or environmental issues. Adjacent site is unoccupied and is buffer zone land for the nearby Transgrid electricity substation.
Emergency storage lagoon	Inadequate capacity of lagoon. Rain levels in lagoon capacity Lagoon wall failure	Loss of containment of emergency storage lagoon Potential for water to leave site however consequences do not provide any adverse safety or environmental issues	No	Emergency storage lagoon normally empty Emergency storage lagoon designed to contain full plant inflow for one hour. It will also contain overflows from smaller process tanks should they occur. Surface water (rainfall) runoff diverted away from lagoon. Lagoon will be lined with a low permeability clay (or similar) liner. Lagoon storage maintained empty nearly all of the time.

B. Appendix B

Background Data

Background Data

This appendix contains background data used in this study in relation to the site location, local meteorological conditions and hazardous material properties.

Population Density

The figure below shows the areas of population around the Coffs Harbour WTP chlorination facility. Residential properties and a school building were considered in determining the populations around the site.

Figure B1 Designated Population Areas Surrounding the Coffs Harbour WTP

All population points indicated on the figure above were modelled as point populations. The residential estates were conservatively assumed to house 4 people each, present onsite 100% of the time, with 50% of the time spent outside. The substation area was conservatively assumed to contain 2 people all of the time and they are considered to be in the open. This population data is summarised in the table below.

Table B1 Population Density Data for Coffs Harbour WTP

Area	Time Spent Indoors (%)	Permanent Population
Residential Estates	50	4
Substation	0	2

Weather Data

The weather data used in the risk model is based on local meteorological data collected at Coffs Harbour automatic metering station, which is the nearest data collection point to the proposed site. The wind rose was created from meteorological data collected from 1996 to 2006. The average atmospheric conditions are listed below:

Relative Humidity	65.5 %
Surface / Ground Temperature	20.15 °C

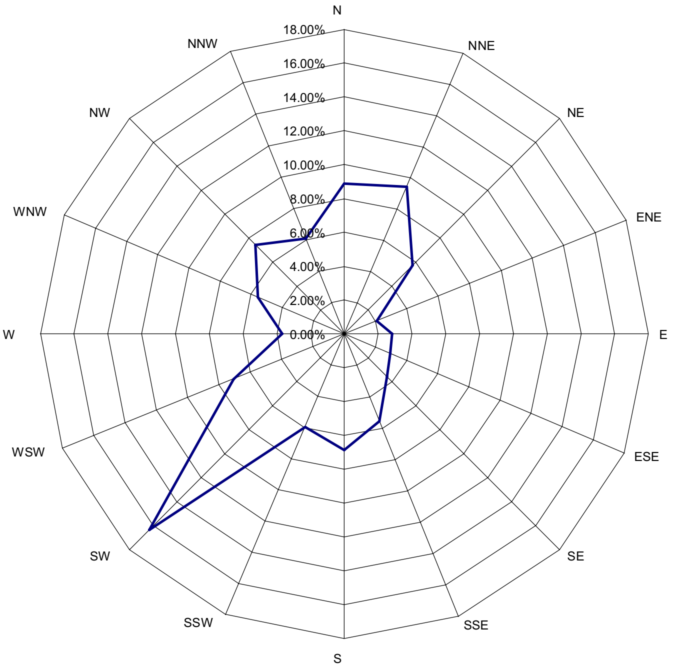
The weather categories (i.e. wind speed, direction and weather class) affect dispersion distances and the extent of a toxic region following a release. Humidity changes do not significantly affect the modelling results. Stability class descriptions can be seen Table B2.

Table B2 Stability Class Definitions

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

The wind rose in Figure B2 was manipulated to provide four weather conditions for modelling hazardous scenarios, i.e. 1.5F, 3C, 5D and 7D. These are calculated to occur 14%, 32%, 29% and 25% of the time per year, respectively. These weather categories have been combined to determine the wind rose used in the modelling, as shown in Figure B2.

Figure B2 Wind Rose for Coffs Harbour



Data From: 1996 – 2006
Readings taken hourly

Australian Government
Bureau of Meteorology

Hazardous Material Properties

This section compiles information about the proposed hazards associated with chlorine at the WTP chlorination facility.

Chlorine

Chlorine (Cl_2) is a greenish-yellow gas or clear amber liquid (under pressure) with a pungent suffocating odour. It is shipped in 920 kg drums as a compressed liquefied gas under a pressure of approximately 650 kPa at 21.1 deg C. It is available in a number of grades having a purity of at least 99.5 wt %. Table B3 shows some of the properties of chlorine.

Table B3 Properties of Chlorine

Dangerous Goods Class:	2.3 Poisonous (Toxic) Gases, Subsidiary Risk 8
Molecular Weight:	70.9
Boiling Point:	-34.6°C at 1 atmosphere
Melting Point:	-101°C
Flammability:	Non-flammable
Vapour Pressure at 20°C:	673 kPa
Relative Density (water = 1):	1.4 at 20°C, 6.86 atmosphere (liquid)
Relative Vapour Density (air = 1):	2.5
Relative Density to Air:	2.473 at 20°C
Solubility in Water, g/100 ml at 20°C:	0.7

Table B4 illustrates the harmful effects likely to be experienced by humans exposed to various concentrations of chlorine.

Table B4 Effects of Chlorine

Chlorine Concentration (ppm)	Effect
1	Minimum concentration causing slight symptoms after several hours.
3.5	Minimum concentration detectable by odour.
4	Minimum concentration that can be breathed for 1 hour without damage.
15	Minimum concentration causing throat irritation.
30	Minimum concentration causing coughing.
40-60	Concentration dangerous in 30 minutes.
1000	Concentration likely to be fatal after a few deep breaths.

It is recognised that the concentrations for fatalities may not agree with those predicted using probits (discussed next) but they are a useful general guide.

Measuring Fatalities

A quantitative risk assessment of this nature is primarily measuring the potential for fatalities. In the case of chlorine it is the potential for toxic effects via inhalation, which is measured.

Toxic Effects

If the release is a toxic material, then it is necessary to attempt to relate the estimated atmospheric concentrations and durations of exposure following a release to the level of toxicity produced within the surrounding population. The data used should therefore be principally those contained in reports of accidental single exposure of humans to the airborne substance, or generated in single exposure inhalation studies in animals. Almost all the data available in this area relate to toxic effects which become apparent soon after exposure.

Other effects, including mutagenicity, carcinogenicity and teratogenicity, may also arise as a result of a single exposure. However, for most Major Hazards substances, single exposure dose-effect data are not available for effects such as these.

GHD has found that commonly used secondary sources of information may be unreliable, in that the toxicological values given may be inaccurate representations of the original results, or that the primary sources of such values are either difficult to verify or of doubtful quality. Therefore, all the data used in the assessment of individual substances should be obtained from the original reports.

However, for most substances, existing reliable data on acute effects arising from a single exposure in humans are sparse.

For a few substances some information is available from their use in warfare (e.g., chlorine, phosgene). Nevertheless, for most substances the data are limited to a few reports of accidental exposures, often involving only a few people and rarely containing accurate measurements or even estimates of exposure concentrations and times.

Consequently, heavy reliance has to be placed on the results of experiments on animals, in attempting to predict the responsiveness of a human population. In general, extrapolation from laboratory animals to humans with any degree of accuracy and reliability is fraught with difficulties, principally because of the inadequate information.

Even so, for most substances it is be necessary to make the assumption that results from animal experiments will be representative of effects on the human population, in terms of both the nature of the effects produced and the dose-effect relationships observed.

In some cases the paucity of data on certain substances will make any analysis extremely tenuous, and in these situations further experimental work by manufacturers or their trade associations would be advisable if important decisions depend on the results.

Probit Functions

A second method of measuring toxic effects is to use the probit function. The probit function is a measure of the time dependent probability of fatality from exposure to toxic chemicals. For toxicity it is a function of concentration of exposure and time exposed to this concentration. The general form of the function presented in Equation B1.

Equation B1 Probit Function

$$\Pr = k_1 + k_2 \ln\left[C^n t\right]$$

Where Pr = Probit value

C = Concentration of interest

t = time exposed to concentration, C

k_1, k_2, n = constants specific to each material

It is converted to a probability of fatality via Equation B2.

Equation B2 Probability of Fatality

$$P(death) = \frac{1}{2}\left[1 + erf\left(\frac{\Pr - 5}{\sqrt{2}}\right)\right]$$

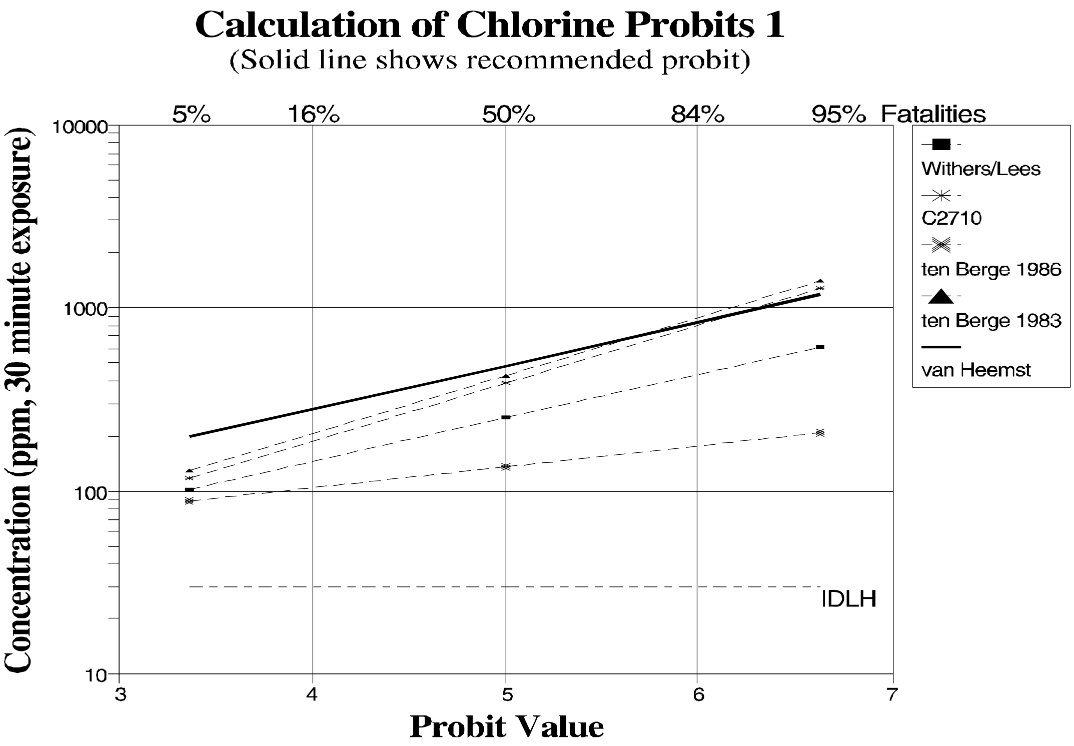
Table B5 shows the constants for chlorine probits referenced or used in chlorine study risk assessments; the units of concentration are ppm.

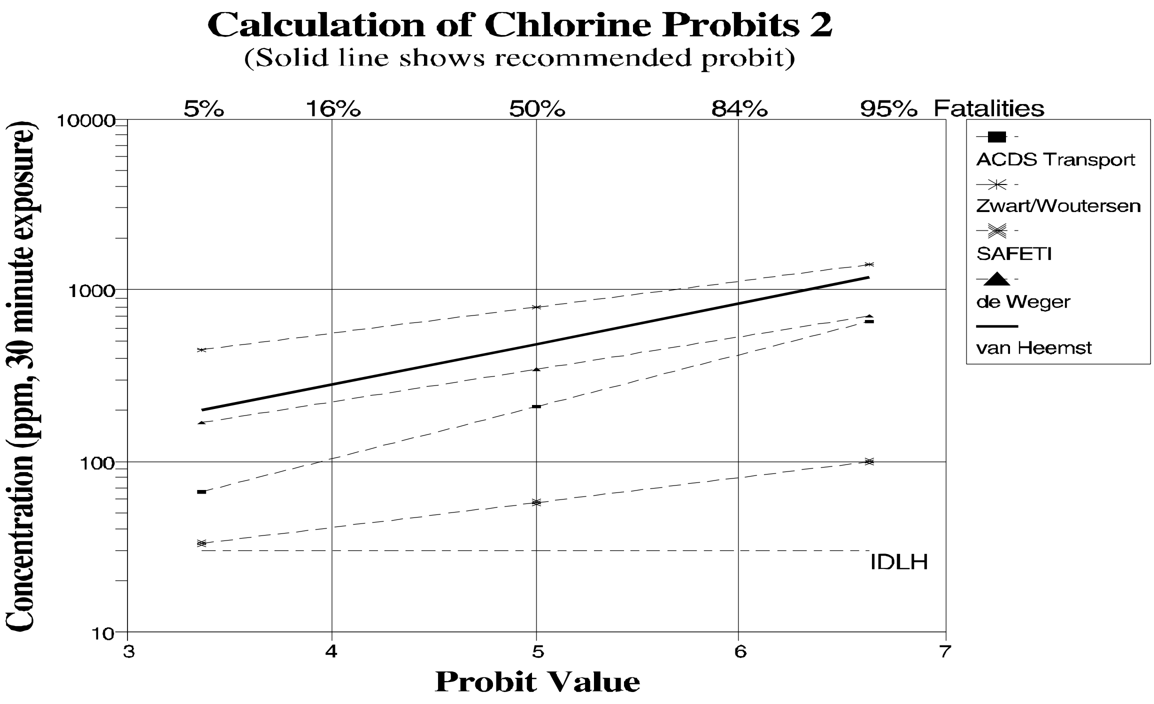
Table B5 Chlorine Probits used in Risk Assessments

Constant			**30 Min LC_{50}**	**LC_{90}/LC_{10}**	**Reference**
a	b	n			
-8.29	0.92	2	250	4.0	Withers and Lees 85
-4.9	0.5	2.75	390	6.4	GEP QRA C2710
-17.63	1.1	3.5	140	1.9	Ten Berge 1986
-5.036	0.5	2.75	430	6.4	Ten Berge 1983
-23.76	2.78	1.04	800	2.4	Zwart and Woutersen 1988
-4.4	0.52	2.75	210	6.0	ACDS Transport Risk Report 1992
-10.1	1.11	1.65	490	4.0	Van Heemst
-11.85	1	2.3	350	3.0	De Weger 1991/Green Book
-13.05	1.69	1.8	60	2.3	SAFETI V6.4.2

Figure B3 illustrates these probits graphically over the range of fatality limits between 5% and 95%. Note Figure B3 also includes the IDLH for chlorine.

Figure B3 Graphical Comparison of Probits





The most recent work on chlorine probits puts the LC50 values at higher concentrations. In selecting the chlorine probit, judgement was used based on analogies with other probits, key factors being: a realistic slope of the probit (i.e. ratio of LC90 to LC10), the LC05 should be a factor of 3-5 above the IDLH, the LC50 should be a factor of 3-4 above the LC05. This correlates to the Dow Chemical Exposure Index Guide (1st Ed, 1994) which relates ERPG-3, similar to IDLH, to LC-50 divided by 30 (note the different time bases of IDLH and ERPG).

The Zwart and Woutersen probit was derived recently, however it is based on only one animal species. In explaining why their values were much higher than other published data, the authors speculate that past concentration estimates may have been invalid. Van Heemst, another recently derived probit, was developed after Zwart and Woutersen but it is not clear whether their experiments were taken into account by van Heemst.

There is still considerable debate amongst toxicologists about this recent data and until this debate has been completed no probit is mandatory. However the van Heemst probit is currently recommended, as this represents the most recent work on chlorine toxicity and although it is less conservative than much previous work, it is more conservative than the single data of Zwart and Woutersen.

The van Heemst chlorine probit is accepted as valid for chlorine risk assessments by the regulator in throughout Australia.

For this study the chlorine probit used is that developed by van Heemst in 1990. The parameters for the probit equation are shown in Table B6.

Table B6 Chlorine Probit Parameters

PROBIT	a	b	n
Van Heemst, 1990	-10.1	1.11	1.65

Individual Fatality Risk

Individual risk is defined by the I.Chem.E (1992) as the frequency at which an individual may be expected to sustain a given level of harm from the realisation of specified hazards. In this report it is taken to be the risk of death and is expressed as a risk per year. The purpose of criteria based upon this risk measure is to ensure that no single person is overexposed to risk.

Individual risk may be derived in various ways, leading to different results from different risk analyses. The primary measure sought in this study was an assessment of Location-Specific Individual Risk (LSIR) in response to land-use planning requirements.

The Location Specific Individual Risk (LSIR) is a measure of the level of risk an individual would be exposed to, if continuously present in a particular location for a whole year. The risk exposure is calculated for all relevant hazards and summed to give the overall level of risk in each location. The location specific risk is then plotted on a grid from which the risk contours may be drawn.

The risks are determined for each hazardous event by combining each event frequency with the associated hazardous consequences. The LSIR for any given location, failure case and associated consequence outcomes (eg. toxic impact) can be represented as per Equation B3.

Equation B3 Location Specific Risk

$$LSIR = R \times \sum (M \times C \times F)$$

The total LSIR at any location may be calculated by summing the frequency of fatal impact of all release events and consequence outcomes for that location. The coefficients are defined as follows:

$\sum$ = Summation of probability of fatality for each failure case consequence (toxic release) for the location for which the LSIR is calculated.

R = Release frequency.

M = Fractional probability of each alternate type of consequence occurring (governed by the SAFETI MPACT parameter file(s)).

C = Consequence result for each type of consequence in terms of the level of toxic impact experienced at the location.

F = Fractional probability of fatality for each alternate type of consequence result, based on exposure level / event duration, experienced at the location.

Individual Injury Risk

The definition of concentration at which ‘injury’ or ‘irritation’ occurs is open to debate and consideration of all available toxicological data and standards is used to define the concentrations of interest for in this case chlorine. Throughout Australia the most common way of establishing injury and irritation risk criteria is to use Emergency Response Planning Guideline (ERPG) levels as specified by the American Industrial Hygiene Association (AIHA). The ERPG series provides values as estimates of concentration ranges where one might reasonably anticipate observing adverse effects as a consequence of exposure to a specific substance. These levels are considered to be an authoritative source for anyone responsible for responding to an emergency and accepted by regulating bodies in NSW, Victoria, West Australia, and Queensland.

Three ERPG values are given:

ERPG–3 is the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects. This is the level used to represent serious injury.

ERPG–2 is the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

ERPG–1 is the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odour.

An ERPG level of exposure is only achieved if the nominated concentration level is for a duration equal or greater than a one hour period. Exposures less than one hour do not meet the ERPG criteria.

ERPG 3 levels are used in this report to represent serious injury and ERPG 2 levels are used to indicate levels at which irritation may occur. ERPG 1 values do not have any adverse health effects.

The appropriate ERPG levels for chlorine, according to the AIHA are shown in the table below.

Table B7 Nominated ERPG Levels for a One Hour Exposure

	ERPG-1	ERPG-2	ERPG-3
Chlorine	1	3	20

For the purpose of this study, ERPG 3 levels (20 ppm for a one hour period) are used in this report to represent serious injury and ERPG 2 levels (3 ppm for a one hour period) are used to indicate levels at which irritation may occur. An ERPG 1 level (set at 1 ppm for a one hour period) and does not have any adverse health effects, it is likened to a strong swimming pool odour.

Societal Risk

Societal risk sets out how risks to the public vary with changing levels of hazard severity. It is generally represented graphically as a curve on log-log axes, called an F-N curve, with the frequency (F) on the vertical axis plotted against the cumulative fatalities (N) on the horizontal axis.

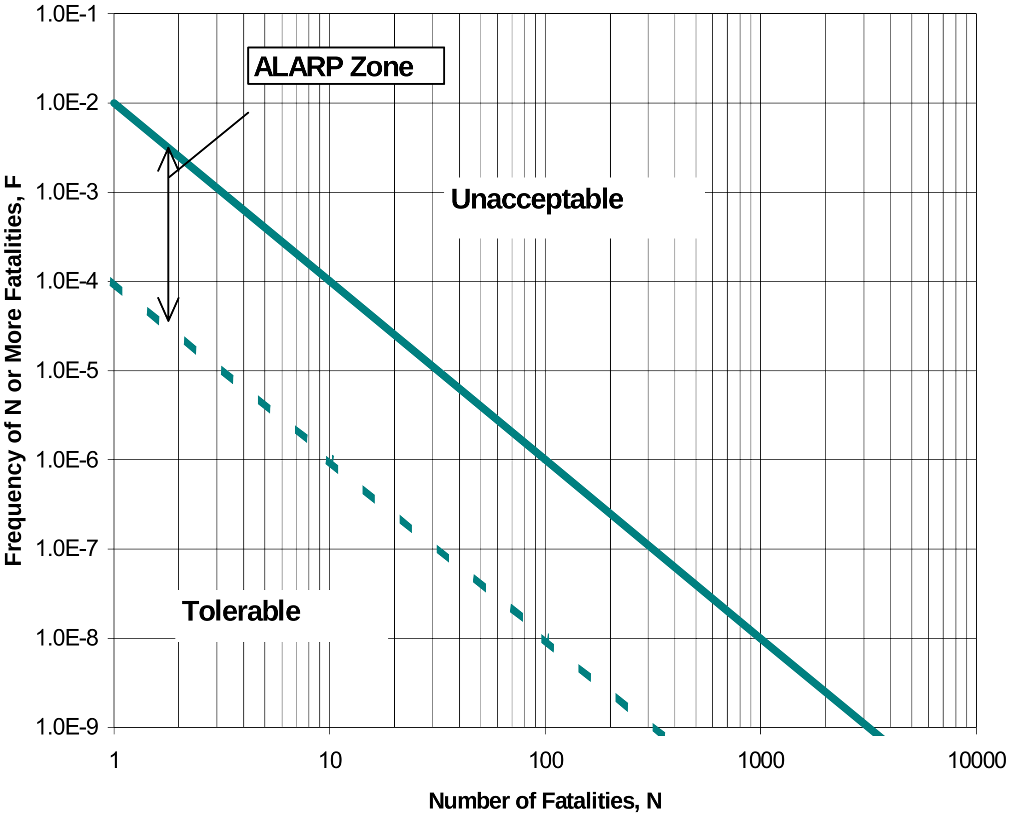
The F-N curve is often plotted against two regulatory risk limits, the tolerable and negligible risk limits, and therefore three zones are defined on the F-N plot. By convention, the negligible risk limit is taken as two orders of magnitude below the tolerable risk limit. Figure 8 shows an F-N curve.

The three risk zones defined on an F-N curve are:

- a) above the tolerable risk limit, i.e. the risk level is unacceptable
- b) between the tolerable and negligible risk limits, the risk level is tolerable . In this zone, the risk level should be "as low as reasonably practicable" (ALARP), i.e. reduced so that the gain from the reduction is less than the cost of accepting the risk at its current level. The ALARP principle arises from the fact that it would be possible to spend an inordinate amount of time, effort and/or money attempting to reduce a negligible risk to near to zero.
- c) below the negligible risk limit, i.e. the risk level is considered negligible and therefore there is no need to consider any risk reduction measures.

By applying tests (a), (b) and (c), a series of tolerability limits can be proposed for incidents involving a defined number of casualties, ranging from tolerable risks for individual to involuntary societal risks.

Figure B4 F-N Curve Use For Societal Risk Comparison



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C. Appendix C

Consequence Models

SAFETI Consequence Models

This study was undertaken using the proprietary SAFETI (Software for the Assessment of Fire Explosion and Toxic Impact) package, Version 6.42. The SAFETI package has been extensively validated; interested parties can contact the authors of this report if any clarification is required in this regard.

A part of the risk assessment process involves generating consequences for the release events identified. The steps involved in determining consequences are:

1. Determine release conditions based upon materials involved, storage conditions and available inventory etc;
2. Based on release conditions, determine the types of events which will occur (eg toxic cloud, evaporating pool etc);
3. Calculate the extent of the consequences; and
4. Establish the impact of the consequence (e.g. proportion of people killed when exposed to a toxic dose)

The consequences are calculated using empirically derived models, which can then be used to determine which release cases generate offsite effects and should be included in the risk model. The level at which fatal consequences are considered to occur will directly influence the risks.

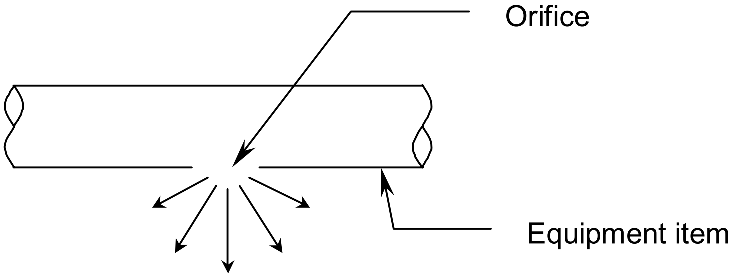
This Appendix discusses basic concepts and theory behind the various consequence models used in the analysis. The models discussed are:

- Discharge Modelling
- Dispersion
- Toxic Effects

Discharge Modelling

If there is a hole in a pipeline, vessel, flange or other piece of process equipment, the fluid inside will be released through the opening, provided the process pressure or static head is higher than ambient pressure. The properties of the fluid upon exiting the hole play a large role in determining consequences, eg, vapour or liquid, velocity of release etc. Figure C1 illustrates an example scenario.

Figure C1 Typical Discharge



The discharge can be considered to have two stages, the first is expansion from initial storage conditions to orifice conditions, the second from orifice conditions to ambient conditions.

The conditions at the orifice are calculated by assuming isentropic expansion, ie, entropy before release = entropy at orifice. This allows enthalpy and specific volume at the orifice to be calculated.

The equations for mass flow rate ($\dot{m}$) and discharge velocity (u_0) are then given by:

$$\dot{m} = C_d A_o \rho_o \sqrt{-2(H_0 - H_i)}$$

And $$u_0 = C_d \sqrt{(-2(H_0 - H_i))}$$

Where

- C_d = Discharge coefficients
- A_o = Area of the orifice
- ρ_o = density of the material in the orifice
- H_o = Enthalpy at the orifice
- H_i = Enthalpy at initial storage conditions

The discharge parameters passed forward to the dispersion model are as follows:

- release height (m) and orientation;
- thermodynamic data: release temperature (single phase) (°C) or liquid mass fraction (two-phase), initial drop size (m);

other data:

- for instantaneous release: mass of released material (kg), expansion energy (J)
- for continuous release: release angle (degrees), rate of release (kg/s), release velocity (m/s), release duration (s).

Dispersion

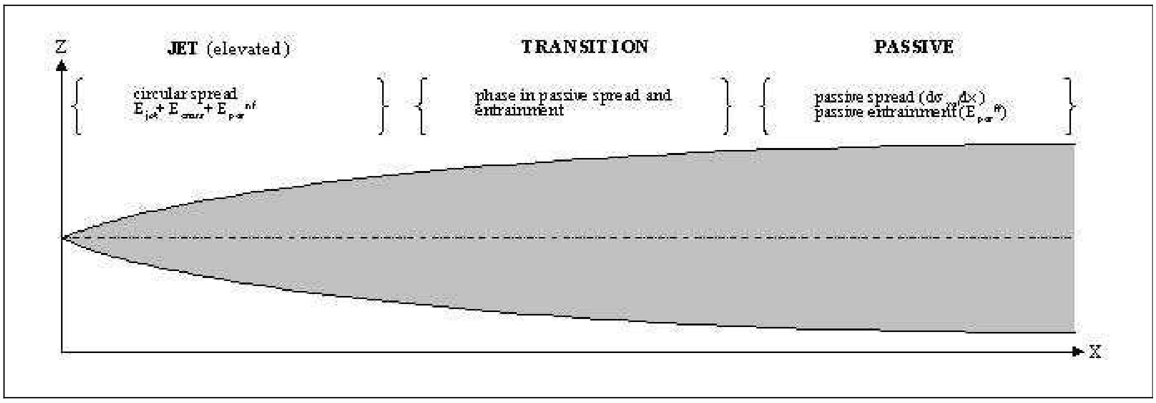
When a vapour leak occurs, some material will be released into the atmosphere. Upon being released it will start to disperse and dilute into the surrounding atmosphere. The limiting (lowest) concentration of interest is related to flammable and toxic limits for flammable and toxic substances respectively. The model used to determine extent of release is described below, along with some of the key input parameters.

The consequence modelling package PHAST utilises the Unified Dispersion Model (Witlox *et al*, 1999). This models the dispersion following a ground level or elevated two phase unpressurised or pressurised release. It allows for continuous, instantaneous, constant finite duration and general time varying releases. It includes a unified model for jet, heavy and passive two phase dispersion including possible droplet rain out, pool spreading and re-evaporation. SAFETI is built on the base models in PHAST.

Jet Dispersion

For a continuous, pressurised release, a vapour is released as a jet, ie, high momentum release. The jet eventually loses momentum and disperses as a passive cloud. Figure C2 below shows a typical release and the various phases involved.

Figure C2 Jet Dispersion



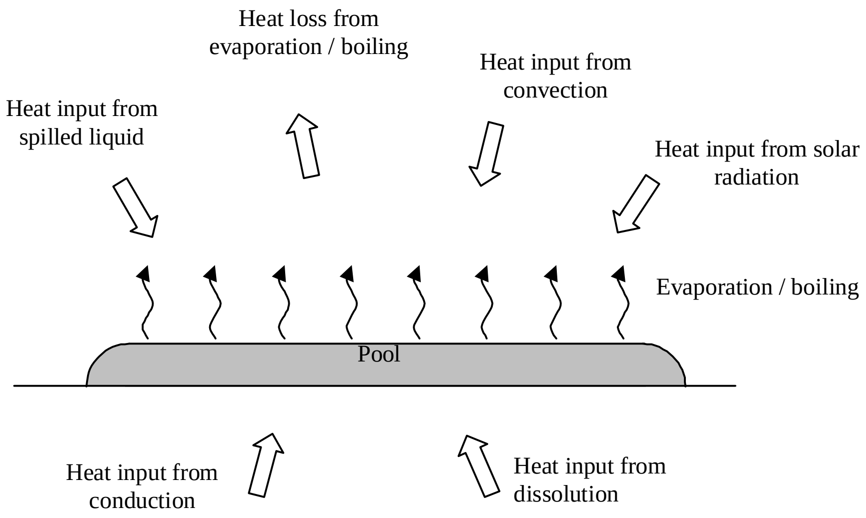
The cloud is diluted by air entrainment until it eventually reaches the lower limit of concern. During the jet phase, the mixing is turbulent and much air is entrained. In the passive phase, less air is potentially entrained, and it occurs via a different mechanism to the turbulent jet phase. The calculation of the plume therefore depends on many factors, the key parameters being:

- Vapour released, specifically molecular weight;
- Discharge conditions including phase(s) of release, velocity etc;
- Atmospheric conditions (a cloud will generally travel further in more stable conditions with lower wind speeds).

Dispersion from Pool Evaporation

If a rupture occurs from a tank or vessel containing a liquefied gas, the liquefied gas pools on the ground whilst rapid vaporisation occurs forming a vapour cloud, which ultimately disperses, as a low momentum cloud. Due to the low momentum, the cloud is not turbulent, which is a significant factor in air entrainment and dilution of the cloud. Figure C3 below shows a typical release and some of the inputs into the calculation.

Figure C3 Pool Evaporation Heat Balance



The rate of the evaporation depends on numerous factors, the most important ones being:

- Surface it is released onto (eg its thermal properties and temperature);
- Atmospheric conditions (a cloud will generally travel further in more stable conditions with lower wind speeds).
- Boiling point of the liquid;
- Pool size.

The concentration of interest is normally related to the flammable, or toxic limits or specified Emergency Response Planning Guideline (ERPGs) limits set for the contained hazardous material. .

References

DNV, Software for the Assessment of Fire, Explosion and Toxic Impacts (SAFETI), version 6.4.2

D. Appendix D

Consequence Modelling

Consequence Modelling

The WTP is located on Upper Orara Road, 11 km to the west of Coffs Harbour on the NSW Mid North Coast. The WTP is within a rural area with a number of surrounding residential properties. The WTP chlorination dosing facility contains a maximum of four x 920 kg of chlorine drums at any one time.

Based on the outcomes of the hazard identification process (**Appendix A**) the hazardous scenario development process focuses only on scenarios where a loss of containment of chlorine could occur potentially resulting in toxic effects offsite. Chlorine related activities at the facility include loading / unloading of drums outside of the building, and normal operation of the chlorination dosing process, involving pipe work, valves, and regulators inside the building. The following chlorine release scenarios are to be considered:

Outside Building

Release of 920 kg chlorine liquid from a full drum during transfer;

- Release from a 6 mm hole (valve damage);
- Release from a 20 mm hole (plug dislodgment); and

Empty drum scenarios – as above but only up to 20 kg vapour released

Note there are no hazardous scenarios associated with corrosion (3mm) and drum rupture during transfer; this is consistent with the failure mechanisms associated with these activities.

Inside Building

Release of 920 kg of chlorine liquid from a full drum

- Release from a 3 mm hole (corrosion);
- Release from a full drum rupture;

Release of 920 kg of chlorine vapour from a full drum

- Release from a 6 mm hole (valve damage)

Note there are no hazardous scenarios associated with plug dislodgement (20 mm) in the building, as the drums are static. This is a failure mechanism only associated with drum transfer.

Releases from flanges, valves, manifold pipelines (incl. catch-pot) and chlorinator;

- Release from a 3 mm hole;
- Release from a 6 mm hole;
- Release from a 12.5 mm hole; and
- Release from a 25 mm hole

In the event of a chlorine release from the associated piping from the drum through to the chlorinator, the chlorine release rate is controlled by the internal bore of the 25 mm valve connected to the vapour line of the chlorine drum (this has an internal diameter of 6 mm in size), hence scenarios >6 mm have been grouped together.

Chlorine releases within the chlorination building have been considered with the building extraction system and chlorine detection and automatic shut-off system operable and inoperable.

Upon chlorine detection the extraction system will start withdrawing chlorine from the chlorination building ejecting it from a height of approximately six meters. Release from such a height allows the chlorine to partially disperse before reaching ground level where it will have a potential toxic impact.

However if the extraction system fails then chlorine will exit the building at ground level and have an immediate potential toxic impact.

Upon chlorine detection the automatic shut-off system (Chlorguard) will operate, shutting off chlorine flow from the chlorine drums. In the event of a manifold release this will limit the inventory of chlorine lost from the system and therefore limit the consequences of such a release. In the event that the shut-off system fails the inventory of chlorine released and corresponding toxic consequences will be much greater.

General Assumptions

- The risk assessment is conducted using the SAFETI modelling package;
- The only hazardous material considered in this study is chlorine (liquid & vapour);
- Fatality rates for chlorine exposure are based on the Van Hemst probit (established as most appropriate following a review of chlorine probits – refer to **Appendix A**). The probit assumes a minimum 600 s exposure time for a fatality to occur;
- Weather data is from a 10 year period (1996-2006) from the Coffs Harbour weather station (closest and most appropriate to the WTP site);
- Temperature assumed to be an average of 20.15°C and 65.5 % humidity;
- No allowance is taken for topography outside of the facility (all results are assumed to be for dispersion over bush land) and any chlorine release is assumed to occur into the surrounding atmosphere;
- Releases inside the chlorination building are vented either mechanically or naturally to the external atmosphere. Releases outside the building are released with no containment;
- In the event of a full drum rupture within the chlorination building the building is assumed to fail due to the pressure generated by the volumetric expansion of chlorine;
- Only toxic releases were considered, fire is not a credible scenario as the fuel load is low (good housekeeping and minimal combustibles) and a fire of sufficient size to damage the storage drums or ignite any chlorine release is extremely unlikely. Chlorine is combustible but not flammable and needs a large amount of heat input to sustain a fire;
- All fatality calculations in this assessment were based on chlorine concentrations at 1 m.
- All releases are modelled from likely handling positions. Releases from the building are modelled through the stack at the centre of the building.

In the event of a chlorine release the consequence distance is dependant on the inventory released, the rate and height of release and the prevailing weather conditions. Corresponding toxic footprints for each chlorine scenario are calculated using a probit equation, as outlined in **Appendix B**. The probit equation calculates a probability of fatality based on exposure at a given distance and chlorine from the release source. The dispersion of the toxic chlorine vapour will be greatest in the most stable weather conditions, therefore consequence distances are only reported for the 1.5F weather conditions, i.e. the most stable weather conditions.

The fatality probabilities reported are 50%, 10% and 1% and are presented for the hazardous scenarios.

Consequences of Scenarios Outside of Chlorination Building

The scenarios modelled that can occur outside of the building are related to drum handling from the truck to the dosing location. A review of failure modes specific to drum handling shows that releases can occur from a damaged valve (corresponding 6 mm hole size) or from a damaged plug (corresponding 20 mm hole size).

In addition to the general assumptions the following specific assumptions also apply to scenarios occurring outside of the chlorination building.

- The maximum drum interchange at the facility is a maximum of 20 drums every year i.e. a throughput of 20 full drums and 20 empty drums per year;
- Drums are moved from the delivery truck to the ground and then from the ground into the storage room and returned from storage via a monorail to the truck; - 2 transfers per drum delivery
- Orica approved failure data for chlorine storage drums has been used in this assessment;
- A full drum contains 920 kg of liquid chlorine and an empty drum contains 20 kg of vapour only;
- Outside drum releases occur below the gantry outside the building at a height of 0.5 m.

In the event of a chlorine release from a drum the rate of chlorine release is determined by the pressure in the drum and the corresponding hole size. Chlorine being a liquefied gas absorbs heat quickly from the atmosphere and rapidly vaporises, small releases tend not to pool and large releases may form small pools before vaporising quickly.

The model input data used for modelling these scenarios is summarised below. Table D1 gives the data for the base chlorine release cases outside the chlorination building.

Table D1 Model Input Data for Hazardous Scenarios – Outside Building

Scenario	Inventory (kg)	Release Time (sec)	Release Rate (kg/s)
6 mm hole in full drum	920	1458	0.63
6 mm hole in empty drum	20	385	0.05
20 mm hole in full drum	920	131	7.01
20 mm hole in empty drum	20	35	0.58

Table D2 summarises the consequence results from the scenarios identified above.

Table D2 Consequence Distances for Outside Building Scenarios

Scenario	Distances to Fatality (m)		
	50 % Fatality	10 % Fatality	1 % Fatality
6 mm hole in full drum	106	201	340
6 mm hole in empty drum	-	45	62

20 mm hole in full drum	200	250	305
20 mm hole in empty drum	29	48	72

Note there are no hazardous scenarios associated with corrosion (3 mm) and drum rupture during transfer; this is consistent with the failure mechanisms associated with these activities.

The above results indicate that near field toxic consequences from full and empty drums for the large hole size release are greater than that of small hole size releases, as would be expected. However, the consequence distance for the 6 mm valve full drum release is greater than that of the 20 mm plug full drum release. This phenomenon is attributed to the release durations of the two scenarios. The 20 mm release duration is significantly shorter than that of the 6 mm release. Consequently a given concentration is maintained for a greater period of time, at a greater distance hence higher far field consequences.

Consequences of Scenarios Inside Chlorination Building

The scenarios modelled that can occur inside the building are related to maintenance and operation of the equipment inside the building. Once the drums are located in position the system is very static and there is very limited interaction with the equipment. A review of failure modes specific to chlorine dosing are summarised below:

Release of 920 kg of chlorine liquid from a full drum

1. Release from a 3 mm hole (corrosion);
2. Release from a full drum rupture;

Release of 920 kg of chlorine vapour from a full drum

3. Release from a 6 mm hole (valve damage)

Releases from flanges, valves, manifold pipelines (incl. catch-pot) regulator and chlorinator;

4. Release from a 3 mm hole;
5. Release from a 6 mm hole; and
6. Release from a >6 mm hole.

Release cases 1 to 6 have been considered with the extraction fan operational and inoperable. Where the extraction system operates chlorine has been released from the extraction vent, when the extraction system fails the chlorine has been released from the building intake vents.

In addition to the general assumptions the following specific assumptions also apply to scenarios occurring inside of the chlorination building.

Drum Storage Room Assumptions

- Chlorine storage facility contains a maximum of 4 full 920 kg drums at any one time;
- For chlorine releases in the drum room, the leak detectors, Chlorguard system and extraction fans are assumed to activate at 60 s. The system detects chlorine and activates the extraction fans at 2 ppm, the Chlorguard valves operate at 12 ppm, therefore 60 s is considered a conservative activation time;
- The Chlorguard system failure rate is assumed to be 1 in 40 as outlined in **Appendix E**;

- For the release scenarios where the release rate is not controlled by the Chlorguard automatic shut-off valves, e.g. release from a storage drum or when the Chlorguard system fails, it is estimated that the intervention time for a service staff member to close the system is 60 minutes, i.e. 3,600 s. For these scenarios, the amount of chlorine released is limited by the lesser of the inventory or the intervention time;
- The chlorine release rate from the drum room is based on the capacity of the extraction system, i.e. 220 L/s. Where the chlorine release rate into the room is less than 220 L/s, the release was considered to be diluted, assuming that the entire volume of the chlorine released was taken directly into the extraction ducts with air making up the remainder of the 220 L/s was air;
- Base case chlorine releases from the drum storage room extraction system are assumed to be vertical at a height of 6 m above ground level;
- The release velocity for chlorine extraction system extraction from the drum room was taken as 3 m/s, based on a 300 mm diameter and the 220 L/s flow rate for each of the extraction fans.
- The drum room has natural vents at low level in the front/rear doors and side wall. In the event of a release inside the room, the detection system activates the extraction system and draws the chlorine into the low level intake ducts rather than leak to the atmosphere via the natural vents. The natural vents will provide inlet air for the extraction system and prevent chlorine loss via the vents;
- The extraction system failure rate is assumed to be 1 in 30. This value is consistent with previous chlorine risk assessment studies;
- When the extraction system fails chlorine releases from the building vents are assumed to be horizontal at a height of 0.2 m above ground level;
- If chlorine is released into the drum store room, it is assumed that the building can withstand any overpressure resulting from the chlorine becoming a gas after release, with the exception of the full drum rupture cases where the building is assumed to be destroyed and therefore offer no containment.

In the event of a chlorine release from a drum the rate of chlorine release is determined by the pressure in the drum and the corresponding hole size. Chlorine being a liquefied gas absorbs heat quickly from the atmosphere and rapidly vaporises, small releases tend not to pool and large releases may form small pools before vaporising quickly.

The model input data used for modelling these scenarios is summarised below. Table D3 gives the data for the base chlorine release cases inside the chlorination building with controls in place and with extraction system failure.

As indicated above the consequence distances have been reported for the 1.5F weather conditions, i.e. the most stable conditions and therefore causing the least chlorine dispersion.

Table D4 summarises the consequence footprints from a chlorine release as it leaves the building.

Table D4 shows that equipment failures have relatively minor consequences compared to drum failures, given the smaller quantity of chlorine released in these cases. The consequence footprints show that events involving large inventories of chlorine have substantially bigger consequence envelopes than smaller inventories in stable conditions.

Table D3 Input Data for Hazardous Scenarios – Inside the Building

Control Operations	Release Inside Building, Extraction System Effective, Drum Isolation			Release Inside Building, Extraction System Fails, Drum Isolation			Release Inside Building, Extraction System Effective, Drum Isolation Fails			Release Inside Building, Extraction System Fails, Drum Isolation Fails		
Scenarios	**Inventory (kg)**	**Release Time (sec)**	**Release Rate (kg/s)**	**Inventory (kg)**	**Release Time (sec)**	**Release Rate (kg/s)**	**Inventory (kg)**	**Release Time (sec)**	**Release Rate (kg/s)**	**Inventory (kg)**	**Release Time (sec)**	**Release Rate (kg/s)**
	Release from Extraction System			**Release from Ground Vents**			**Release from Extraction System**			**Release from Ground Vents**		
3 mm hole in full drum	618	3600	0.172	618	3600	0.172	618	3600	0.172	618	3600	0.172
6 mm hole in full drum	224	3600	0.0621	224	3600	0.0621	224	3600	0.0621	224	3600	0.0621
Rupture of full drum	920	1.2	763	920	1.2	763	920	1.2	763	920	1.2	763
3 mm hole in manifold equipment	1	60	0.016	1	60	0.016	56	3600	0.016	56	3600	0.016
6 mm hole in manifold equipment	3.73	60	0.0621	3.73	60	0.0621	224	3600	0.0621	224	3600	0.0621
>6 mm hole in manifold equipment	3.73	60	0.0621	3.73	60	0.0621	224	3600	0.0621	224	3600	0.0621

Table D4 Consequence Distances for Hazardous Scenarios - Inside the Building

Control Operations	Release Inside Building, Extraction System Effective, Drum Isolation			Release Inside Building, Extraction System Fails, Drum Isolation			Release Inside Building, Extraction System Effective, Drum Isolation Fails			Release Inside Building, Extraction System Fails, Drum Isolation Fails		
Scenario	**Distances to Fatality (m)**			**Distances to Fatality (m)**			**Distances to Fatality (m)**			**Distances to Fatality (m)**		
	50 % Fatality	**10 % Fatality**	**1 % Fatality**	**50 % Fatality**	**10 % Fatality**	**1 % Fatality**	**50 % Fatality**	**10 % Fatality**	**1 % Fatality**	**50 % Fatality**	**10 % Fatality**	**1 % Fatality**
	Release from Extraction System			**Release from Ground Vents**			**Release from Extraction System**			**Release from Ground Vents**		
3 mm hole in full drum	59	148	280	130	263	380	60	146	280	131	264	386
6 mm hole in full drum	97	175	256	78	144	240	96	175	260	79	144	240
Rupture of full drum	247	443	754	247	446	754	247	443	754	247	446	754
3 mm hole in manifold equipment	-	-	-	-	-	-	-	-	-	48	89	130
6 mm hole in manifold equipment	-	-	-	-	-	-	96	175	260	79	144	240
>6 mm hole in manifold equipment	-	-	-	-	-	-	96	175	260	79	144	240

Note there are no hazardous scenarios associated with plug dislodgement (20mm) in the building, as the drums are static. This is a failure mechanism only associated with drum transfer.

The results presented above indicate that consequence distances for scenarios involving extraction system failure are greater than those when the extraction system operates, particularly the near field consequences. If we consider the 3 mm full drum scenario the 50% fatality distance more than doubles, where as there is a relatively small increase in the 1% fatality distance. This trend diminishes as the hole size increases. This is as expected as the extraction system dilutes and ejects chlorine vapours from a 6 m height, however when the extraction system fails the chlorine leaves the building through the building inlet vents which are at ground level. Unlike a release from 6 m, a ground level chlorine release is not required to fall to a height where it will start to have a toxic effect. Consequently the near field effects of a low level release are greater than that of a release from height.

E. Appendix E

Event Frequency Analysis

Frequency Analysis

Leak frequency data is an essential requirement of Quantitative Risk Assessments (QRAs). A wide variety of data sets exist and the findings of a risk analysis are highly dependent upon the data that is employed. This Appendix details the derivation of the event frequencies used by GHD in this risk assessment.

Leak Size Groups

In this Appendix, the leak frequencies are given representative hole sizes based on physical understanding of equipment. Standard leak types used in this assessment are 3 mm, 6 mm, 12.5 mm, 20 mm, 25 mm and 200 mm (rupture). The hole size is essential in the discharge and consequence modelling. These hole sizes are specified by Orica based on the equipment service, duty, material and their locations.

Time in Use

The failure frequencies derived from the parts count procedure are expressed as leak frequency per year. This assessment assumes that the equipment in question is in operation all year round. This study was undertaken assuming the facility is in use 100% of the time.

Chlorine Vessel Failure Frequencies

Orica have supplied GHD with chlorine vessel failure frequency rate data for use in this risk study. With installations storing and handling chlorine containers, such as the Coffs Harbour WTP, there are two basic scenarios for failures resulting in a loss of containment to be considered in risk assessments;

- Generic (spontaneous) failures of stationary containers; and
- Damage during handling, typically dropping a container.

The data presented pertaining to failure frequency rates is sourced from a study completed by ICI in the late 80s in order to identify appropriate failure rate data to be used. This arose because generic pressure vessel data was being applied to drums, which was inappropriate to the drums design. A large range of published and confidential studies where reviewed and internal ICIA and ICI PLC documentation.

Pressure vessel data is inappropriate as they are designed for significantly higher pressures than static pressure vessels, Drums can handle overfill by flexing as the concave ends invert without loss of containment. Non-catastrophic failure develops slowly and signs are visible as they are handled constantly and inspected visually every time they are filled.

The Orica failure frequencies for use internally by Orica and in other chlorine risk studies throughout Australia are outlined in Table E1. These frequencies have been accepted as appropriate for operations in Queensland, Victoria and New South Wales in risk assessments ranging from Major Hazard Facilities to small chlorine stores for water treatment facilities.

Table E1 Failure Frequency Data for Loss of Containment Failures of Chlorine Vessels

Vessel Type	Vessel Dropped or Impacted	Type of Failure	Frequency of Failure	Probability of Failure Given Drop
920 kg Drum	Dropped or Impacted	Dropping	1x10^{-6} per transfer	
		Chimb Failure	-	0
		Catastrophic Failures	-	0
		Valve Damage (6mm Hole)	-	0.001
		Plug Dislodgment (20mm Hole)	-	0.002
	Static	Small 3mm Hole due to corrosion	5x10^{-6} per drum year	-
		Valve Failure through overfilling (3mm Hole)	1x10^{-7} per drum year	-
		Catastrophic Failure	1x10^{-7} per drum year	-
68 kg Cylinder	Dropped or Impacted	All Failures	-	0
	Static	Small 3mm Hole due to corrosion	5x10^{-6} per cylinder year	-
		Valve Failure through overfilling (3mm Hole)	1x10^{-7} per cylinder year	-
		Catastrophic Failure	1x10^{-7} per cylinder year	-

Processing Equipment Failure Frequencies

Carbon Steel Piping

Orica has also supplied GHD with the raw leak frequency data pertaining to chlorine processing equipment and piping with the exception of manual and automatic valves. The failure frequencies supplied by Orica for loss of containment scenarios from chlorine processing equipment and piping again are used in house by Orica and in chlorine risk studies throughout Australia. The failure frequency information is based on extensive data sets compiled by ICI and the frequencies are shown below;

Table E2 Carbon Steel Piping

Hole Size	Leak Frequency (/ metre annum)
3 mm	1 x 10^{-5}
6 mm	5 x 10^{-6}
12.5 mm	3 x 10^{-6}
FBR (25 mm)	6 x 10^{-7}
Joint failure (6 mm)	5 x 10^{-6} per joint per annum
Connection (6 mm)	5 x 10^{-6} per connection per annum

Manual and Automatic valves

The estimate of external leak frequencies from valves is taken from HSE 2005 data. Use of the HSE 2005 data that was collected from UK off shore facilities is considered appropriate although conservative for chlorine operations.

HSE 2005 data is contained within a large database of process equipment failures that have been recorded and collected in a consistent manner over many years. This data is therefore considered statistically valid. The offshore environment frequently has more sand or other impurities in the process streams than onshore plants, which can lead to corrosion / erosion leaks. Moreover, the salt-water environment means the atmosphere is also more corrosive. Hence, given the nature of the environment in which off-shore facilities operate the hazards and the operating conditions are considered to be harsher than those of a small land based hypochlorite facility, therefore the use of the HSE data for determining the rate of valve failures is considered conservative.

A statistically significant difference is reported between manual and actuated valves and these are treated separately. The values of failure frequencies for valves are summarised in the table below. Leak frequencies are quoted as per valve year of operation.

The HSE 2005 data is provided in small and medium hole size distributions nominated at 5 mm and 25 mm in size. Small leaks are typically from corrosion and flange leaks, whereas medium leaks tend to be from valve stem leaks or an energy impacts from some source (dropped object / struck by).

The small and medium hole size frequencies are reapportioned and split in a 50:50 ratio into appropriate hole sizes used for the chlorination plant.

Table E3 Valve Leak Frequencies

HSE 2005 Valve Leak Frequencies / annum		
Hole Diameter (mm)	**Valves, manual, block D=25mm**	**Valves, automatic D=25mm**
3	4.1×10^{-5}	3.4×10^{-4}
6	4.1×10^{-5}	3.4×10^{-4}
12.5	8.9×10^{-6}	3.0×10^{-5}
25	8.9×10^{-6}	3.0×10^{-5}

Emergency System Reliability Data

The Coffs Harbour WTP Chlorination facility has several controls that are intended to reduce the impact of a chlorine release within the chlorine dosing building, this consists of two key elements;

- The ‘Chlorguard’ automatic valve shut-off system, which isolates the chlorine flow from the drums in the event of chlorine gas detection; and
- The building extraction system, which automatically starts upon chlorine gas detection.

The severity of consequence of any given chlorine release within the chlorination building is heavily dependent on the operational integrity of each of the control systems. Hence, for this risk assessment to produce meaningful risk results the reliability of each of these systems must be considered, as must the consequences of a failure in any or all of these systems.

The automatic shut off valves are part of the Chlorguard system provided as a stand alone air actuated system. There is a separate detector for the Chlorguard system (not part of chlorine detection, alarm and extraction system). Oxygen supply is from a separate cylinder. The failure rate of the components of the shut off system is considered in Table E4.

Table E4 Failure Rate for Shut off Valves and Associated Equipment

Equipment	Failure Likelihood	Source	Adjusted Failure Rate	Comments
Shut off actuator	0.007 - per actuator	D J Smith 1985 data, quoted by Lees	0.025	One drum, i.e. 187 kg, more than one actuator failing is ignored as very low probability
Oxygen supply line 20 mm x 8 m	0.0018 - all actuators fail to close	HSE data for line failures	-	Oxygen line is alarmed for low vacuum and alerts staff. Leak at same time is very unlikely.
Detector fails	0.000008 - all actuators fail to close	as gas detectors, Lees data	-	Ignored as very low probability

The raw data in Table E4 gives a low overall failure rate of 0.7 %, and has been conservatively rounded up to give an overall failure rate of 2.5 % or 1/40 to be more consistent with industry operating experience.

Failure of the Building Extraction System

The reliability of the extraction fan system is estimated as follows;

$$R = \exp(-\lambda t)$$

Where R = Reliability

λ = mean time between failures / in hours

t =- test frequency time / in hours

It has been assumed that the mean time between failure is 0.2 time / year (λ) and that the average test time is every 8 weeks.

This estimates a reliability of 97% for the exhaust system or a probability of failure on demand of 3%. This is consistent with other water treatment facility studies and is considered conservative for this type of service.

Initiating Event Frequency

Additional data supplied by Coffs Infrastructure Alliance to develop drum scenario frequencies include;

- There will be a maximum of 4 full drums of chlorine stored onsite at any one time;
  - The maximum drum interchange at the facility is a maximum of 20 drums every year i.e. a throughput of 20 full drums and 20 empty drums per year.

The following failure frequencies are calculated for the Coffs Harbour WTP Chlorination facility.

Drum Event Frequency

Using the data supplied by Orica, GHD has calculated the frequency of each loss of chlorine containment initiating event. These frequencies are detailed in the tables E5 and E6 below.

Table E5 Initiating Event Frequencies - Drum Transfer (scenario tag T)

During Transfer					
Drum Status	**Hole size**	**Drop Frequency (per transfer)**	**Drop Frequency (per year)**	**Failure Probability (per drop)**	**Event Frequency (per year)**
Full	6 mm	1.00E-6	4.00E-5	1.00E-3	4.00E-8
Empty			4.00E-5		4.00E-8
Full	20 mm		4.00E-5	2.00E-3	8.00E-8
Empty			4.00E-5		8.00E-8

Note – 80 drum transfers per year, i.e. 40 full drums brought in and 40 empty drums taken out

Table E6 Initiating Event Frequencies - Drum Storage During Chlorination (scenario tag D)

Static			
Drum Status	**Hole size**	**Failure Frequency (per drum/yr)**	**Event Frequency (per yr)**
Full	3 mm	5.10E-6	2.04E-5
Empty			0.00E+00
Full	Rupture	1.00E-7	4.00E-7
Empty			0.00E+00

Note – Average of 4 full drums stored on site at any one time

Equipment Event Frequencies

There were two scenarios identified in the chlorination building, release from the drum and a release from the chlorine feed manifold. The parts count for the scenarios can be seen below.

Table E7 Scenario Parts counts for Chlorination Facility

Section Tag	Section	Chlorine Drums	Carbon Steel Piping (m)	Carbon steel flanges	Connections	Manual Valves	Automatic Valves
D	Chlorine drum	-	-	-	-	4	-
M	Chlorine vapour in the manifold	-	12	10	4	4	2

The leak frequency associated with each scenario is determined by the combination of a parts count and the nominated failure frequency for each equipment item.

Table E8 Scenario Leak Frequencies for Chlorination Facility

Section Tag	Hole Size (mm)	Frequency / pa
T	6F	4.00E-08
	6E	4.00E-08
	20F	8.00E-08
	20E	8.00E-08
M	3	9.62E-04
	6	9.72E-04
	12.5	1.31E-04
	25	1.02E-04
D	3	2.04E-05
	6	3.30E-04
	200	4.00E-07

Figure E1 Leak Frequency Distribution Given Control Reliability Assumptions

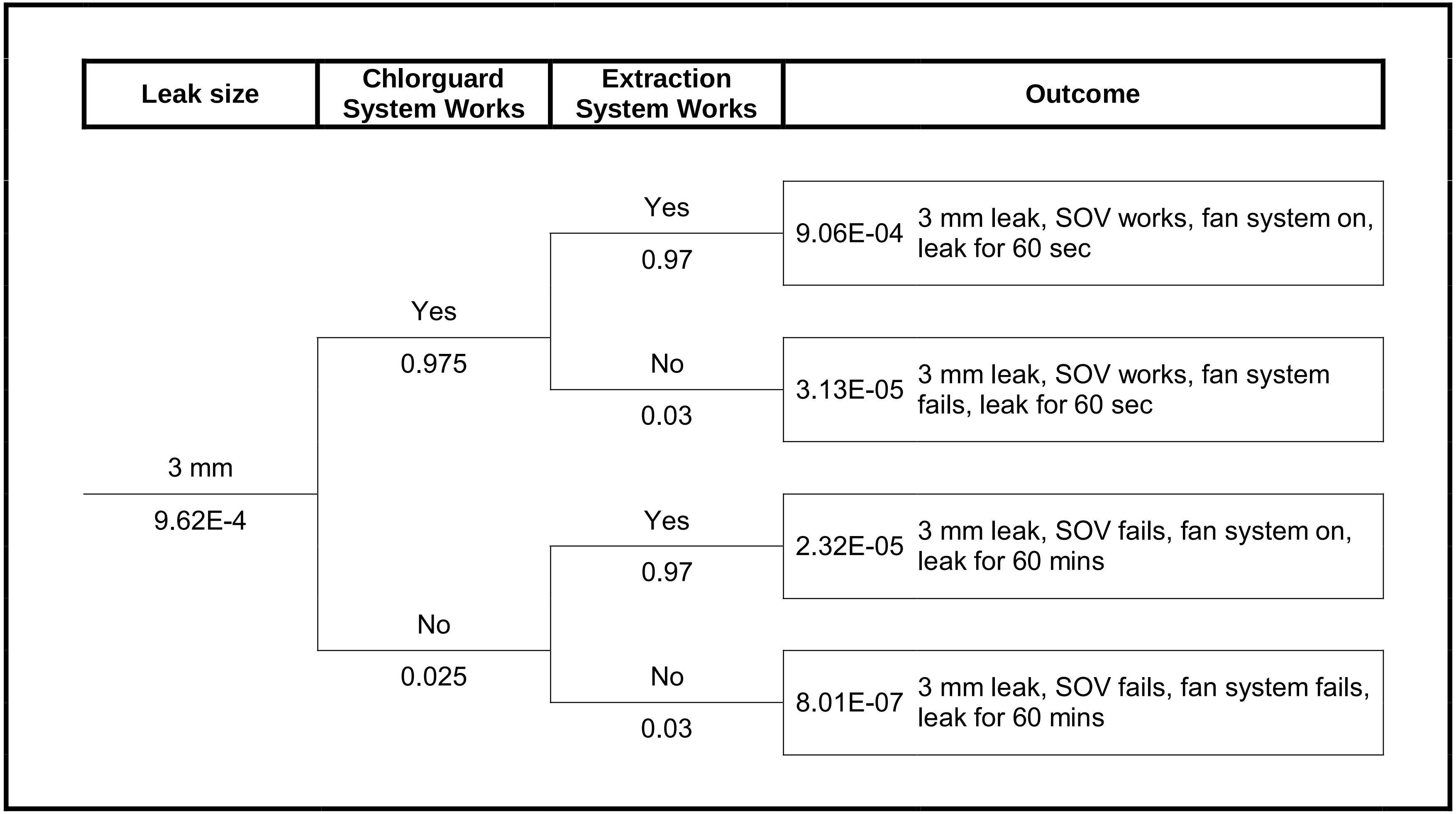


Table E9 Scenario Leak Frequencies for Chlorination Facility

Scenario ID	ET Description	Frequency
D_3mm_1	3 mm leak in drum, SOV fails, fan system on, leak for 60 mins	1.92E-05
D_3mm_2	3 mm leak in drum, SOV fails, fan system fails, leak for 60 mins	6.63E-07
D_6mm_1	6 mm leak in drum, SOV fails, fan system on, leak for 60 mins	3.11E-04
D_6mm_2	6 mm leak in drum, SOV fails, fan system fails, leak for 60 mins	1.07E-05
D_200mm_1	200 mm rupture of drum, SOV fails, fan system on, leak for 60 mins	9.90E-09
D_200mm_2	200 mm rupture of drum, SOV fails, fan system fails, leak for 60 mins	1.00E-10
M_3mm_1	3 mm leak in manifold, SOV works, fan system on, leak for 60 sec	9.06E-04
M_3mm_2	3 mm leak in manifold, SOV works, fan system fails, leak for 60 sec	3.13E-05
M_3mm_3	3 mm leak in manifold, SOV fails, fan system on, leak for 60 mins	2.32E-05
M_3mm_4	3 mm leak in manifold, SOV fails, fan system fails, leak for 60 mins	8.01E-07
M_6mm_1	6 mm leak in manifold, SOV works, fan system on, leak for 60 sec	9.16E-04
M_6mm_2	6 mm leak in manifold, SOV works, fan system fails, leak for 60 sec	3.16E-05
M_6mm_3	6 mm leak in manifold, SOV fails, fan system on, leak for 60 mins	2.35E-05
M_6mm_4	6 mm leak in manifold, SOV fails, fan system fails, leak for 60 mins	8.10E-07
M_12.5mm_1	12.5 mm leak in manifold, SOV works, fan system on, leak for 60 sec	1.24E-04
M_12.5mm_2	12.5 mm leak in manifold, SOV works, fan system fails, leak for 60 sec	4.26E-06
M_12.5mm_3	12.5 mm leak in manifold, SOV fails, fan system on, leak for 60 mins	3.17E-06
M_12.5mm_4	12.5 mm leak in manifold, SOV fails, fan system fails, leak for 60 mins	1.09E-07
M_25mm_1	25 mm leak in manifold, SOV works, fan system on, leak for 60 sec	9.65E-05
M_25mm_2	25 mm leak in manifold, SOV works, fan system fails, leak for 60 sec	3.33E-06

Scenario ID	ET Description	Frequency
M_25mm_3	25 mm leak in manifold, SOV fails, fan system on, leak for 60 mins	2.47E-06
M_25mm_4	25 mm leak in manifold, SOV fails, fan system fails, leak for 60 mins	8.53E-08
T_6mm_1	6mm hole in full drum occurs outside the treatment building, ie no containment. Release continues for 30min	4.00E-08
T_6mm_2	6mm hole in empty drum occurs outside the treatment building, ie no containment. Release continues for 30min	4.00E-08
T_20mm_1	20mm hole in full drum occurs outside the treatment building, ie no containment. Release continues for 30min	8.00E-08
T_20mm_2	20mm hole in empty drum occurs outside the treatment building, ie no containment. Release continues for 30min	8.00E-08

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